December 11, 2013

Richard Corey, Executive Officer
Air Resources Board
1001 I St.
Sacramento, CA 95814

Dear Mr. Corey,

New Phase 1 Greenhouse Gas (GHG) Emission Standards

The California Trucking Association (CTA) supports a nationwide standard for the reasons illustrated by staff in the Initial Statement of Reasons (ISOR). Due to the interstate nature of the trucking industry, California-only standards typically disadvantage California-based motor carriers thereby decreasing the State's economic competitiveness. Therefore, we applaud CARB's choice to harmonize with the EPA/NHTSA standards and would encourage CARB to work cooperatively with EPA/NHTSA to ensure 50-State Phase 2 standards are promulgated.

Amendments to CARB's Existing GHG Tractor-Trailer Regulation

CTA supports the recommendation to sunset the requirements applicable to new 2014 sleeper cab and day cab tractors, however, we must reiterate our opposition to this regulation as the underlying analysis to justify its initial passage was flawed.

Please see our attached October 15th, 2013 letter to the Federal EPA for more details.

New Optional Low Oxides of Nitrogen (NOx) Emission Standards for Heavy-Duty Engines

CTA supports staff's proposed three-tier approach for setting the optional lox NOx standard. As noted in staff's projections in Table 9, a very small subset of engines will likely be certified to a .05 or .02g/bhp-hr standard.

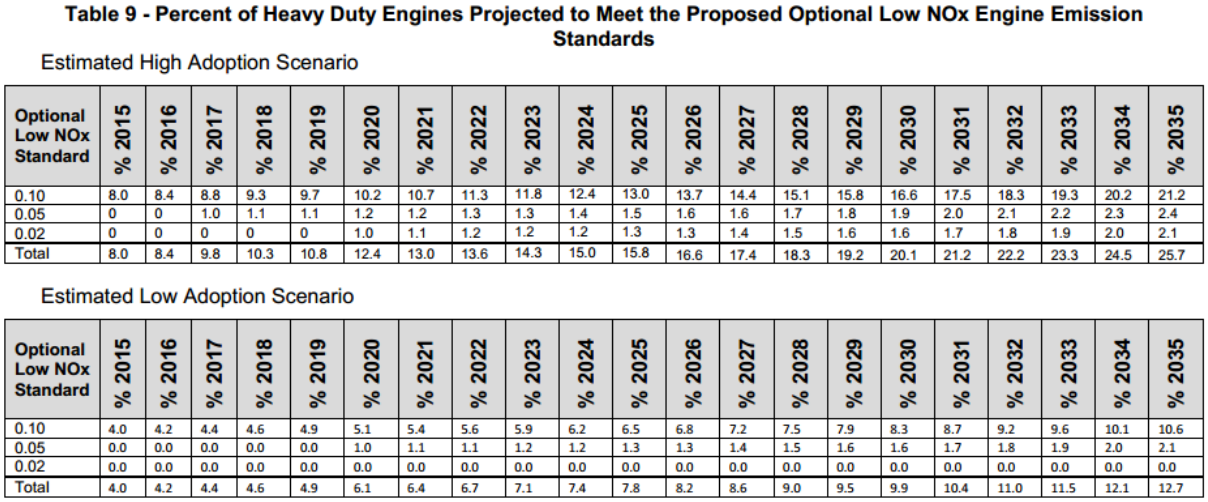


Table 9 - Percent of Heavy Duty Engines Projected to Meet the Proposed Optional Low NOx Engine Emission Standards

Estimated High Adoption Scenario

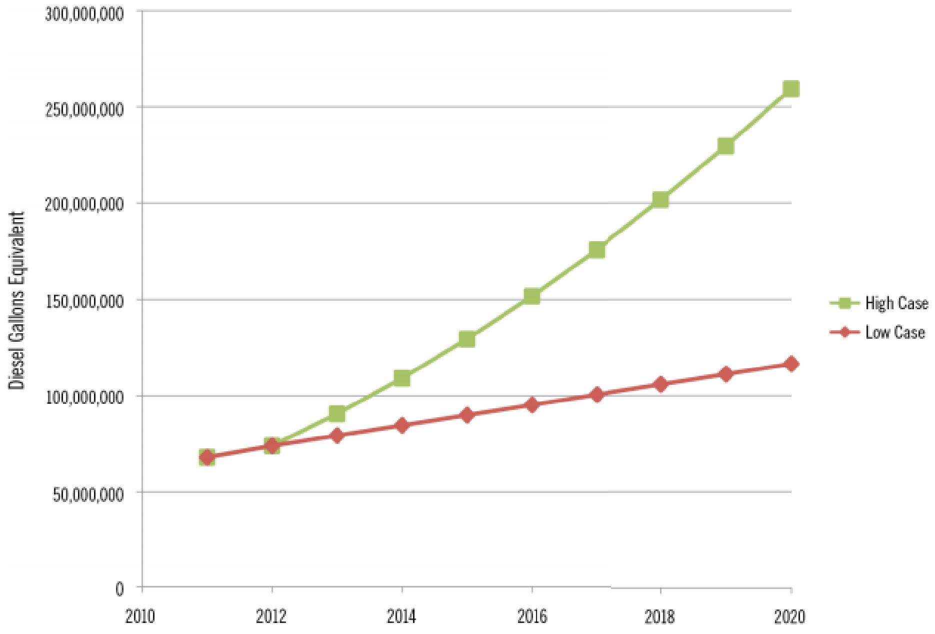
Optional Low NOx Standard	% 2015	% 2016	% 2017	% 2018	% 2019	% 2020	% 2021	% 2022	% 2023	% 2024	% 2025	% 2026	% 2027	% 2028	% 2029	% 2030	% 2031	% 2032	% 2033	% 2034	% 2035
0.10	8.0	8.4	8.8	9.3	9.7	10.2	10.7	11.3	11.8	12.4	13.0	13.7	14.4	15.1	15.8	16.6	17.5	18.3	19.3	20.2	21.2
0.05	0	0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4
0.02	0	0	0	0	0	1.0	1.1	1.2	1.2	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	2.0	2.1
Total	8.0	8.4	9.8	10.3	10.8	12.4	13.0	13.6	14.3	15.0	15.8	16.6	17.4	18.3	19.2	20.1	21.2	22.2	23.3	24.5	25.7

Estimated Low Adoption Scenario

Optional Low NOx Standard	% 2015	% 2016	% 2017	% 2018	% 2019	% 2020	% 2021	% 2022	% 2023	% 2024	% 2025	% 2026	% 2027	% 2028	% 2029	% 2030	% 2031	% 2032	% 2033	% 2034	% 2035
0.10	4.0	4.2	4.4	4.6	4.9	5.1	5.4	5.6	5.9	6.2	6.5	6.8	7.2	7.5	7.9	8.3	8.7	9.2	9.6	10.1	10.6
0.05	0.0	0.0	0.0	0.0	0.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	2.0	2.1
0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	4.0	4.2	4.4	4.6	4.9	6.1	6.4	6.7	7.1	7.4	7.8	8.2	8.6	9.0	9.5	9.9	10.4	11.0	11.5	12.1	12.7

The California Energy Commission estimates that natural gas trucking could displace roughly 4-10% of the diesel fuel consumed in California a year. Therefore, we agree with staff's conservative adoption estimates for the two lower NOx optional standards. To the extent that, at least in the initial years, these engines will require natural gas as a fuel, there are still significant infrastructure, cost and operational hurdles towards widespread adoption on a statewide basis. Widely available lower NOx diesel engines will accrue greater overall emission reduction benefits even if certified at .1g/bhp-hr.

Figure 15: Annual Petroleum Displacement From Natural Gas Trucks (Gallons)



Source: California Energy Commission

However, we would suggest that staff provide more detail regarding its vision of how lower NOx engines will be incentivized. Manufacturers will be reluctant to utilize an optional certification if they do not believe market demand will materialize for these engines. Staff provided some initial concepts for incentivization:

1. Carl Moyer Attainment Program Funding

- We support staff's suggestion to raise the fleet size limit to more than 10 for the purchase of optional low NOx-certified engines. It stands to reason that larger fleets will be more likely to act as early adopters.
- Staff notes that maximum funding for new vehicle purchase projects is 25 percent of the incremental cost, however, the statute governing the Carl Moyer Program is more permissive. Health and Safety Code Section 44283(e) reads (e) "A grant shall not be made that, net of taxes, provides the applicant with funds in excess of the incremental cost of the project. Incremental lease costs may be capitalized according to guidelines adopted by the state board so that these incremental costs may be offset by a one-time grant award." We would suggest that ARB revisit its policy

which restricts funding to 25 percent for new vehicle purchase projects as, due to Truck and Bus Rule compliance timelines, the supply of vehicle replacement projects may be limited after the 2015 timeframe.

- We also support the concept of a weighting factor to recognize the technology advancement benefits of these projects.

2. **Proposition 1B**

- CTA supports the inclusion of a technology neutral optional low NOx-certified engine truck replacement and repower option in the next Prop 1B guideline update, but would push CARB staff to prioritize Cleaire substrate replacement projects prior to taking on new commitments

3. Truck and Bus Regulation

- The existing provision in the Truck and Bus Rule (which provides credit to allow a fleet to treat another vehicle as PM BACT compliant until 1/1/2017) is unlikely to incentivize purchase of optional low NOx-certified engines since they will not be available until the post-2015 timeframe.
- Staff does not elaborate on further future amendments to the rule, but CTA would suggest performing outreach to the trucking industry to discuss how, if at all, the rule's backend requirements could be amended. CTA is still concerned with the enforceability and fairness of the rule as written today. Further amendments to the rule need to be carefully considered by CARB staff. Such amendments could include more compliance time for 2007-2009 model year engines.

Also, delaying introducing a longer engine warranty will hurt introduction of low NOx-certified engines. The warranty issue serves as a surrogate for the underlying issue regarding the importance of engine reliability for the trucking industry. This issue was covered at some length in 2012 by the American Truck Dealers[1]:

> *However, data suggests that DPF and trap maintenance intervals have occurred much more often than projected, at $300-500 per service. This is particularly true for units in vocational use. Moreover, the lost earnings associated with trucks out of service, due to reliability issues, far exceed any service and parts costs associated with these mandates*
>
> *…*
>
> *For example, it has been reported that for the eighth largest carrier in the U.S., "maintenance costs for Schneider's 2007 model trucks were about 28.2% higher than vehicles manufactured before October 2002.*
>
> *Reliability is critical for commercial fleets and owner-operators both because of the costs of keeping trucks in operation and the even greater potential costs associated with out-of-service*

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[1] A LOOK BACK AT EPA'S COST AND OTHER IMPACT PROJECTIONS FOR MY 2004-2010 HEAVY-DUTY TRUCK EMISSIONS STANDARDS

> *equipment. In addition to higher truck prices and operating costs, anticipated reliability issues are often cited as contributing to the marketplace disruptions discussed herein.*

Low NOx-certified engine technology will need to prove reliable to find wide acceptance among fleet operators as upfront incentives may not adequately mitigate motor carrier costs (real or perceived) associated with maintenance and downtime.

Anti-Idling Amendments

CTA would like to echo the American Trucking Associations' comments on the proposed anti-idling amendments. While CTA supports compliance with CARB rules, we are concerned that ARB's proposed amendments may add unnecessary levels of complexity to the idling enforcement process. We are happy to see that initial concepts which would have held facilities responsible for idling on their property have been removed, but would suggest that some additional amendments may need to be considered to accomplish CARB staff goals without causing more unnecessary confusion and wasting of extremely limited CARB enforcement resources.

CTA staff is happy to work with CARB staff on further amendments to the rule to ensure that idling laws are fairly applied.

If you have any questions about the above comments, please feel free to contact Chris Shimoda, Manager of Environmental Policy at cshimoda@caltrux.org.

Thank You,

Chris Shimoda, Manager of Environmental Policy
(916)373-3504

October 15, 2013

Environmental Protection Agency
attn: David Dickinson
1200 Pennsylvania Ave. NW Room B108
Washington, DC 20460

Attn Docket ID No. EPA-HQ-OAR-2013-0491

California State Motor Vehicle Pollution Control Standards; Tractor-Trailer Greenhouse Gas Regulation; Request for Waiver of Preemption

We would like to thank the Environmental Protection Agency (EPA) for allowing us the opportunity to submit the following comments. The California Trucking Association (CTA) is the largest statewide organization in the country representing the trucking industry, including 2000+ trucking companies operating both in-and-outside of California. Many of our members are regulated parties under the California Air Resources Board's (CARB) Tractor-Trailer Greenhouse Gas Regulation (the rule) and, because the rule was first adopted in 2009 and became effective in 2010, have already made significant investments to comply.

The Clean Air Act (CAA) allows California to seek a waiver of the preemption which prohibits states from enacting emission standards for new motor vehicles. EPA must grant a waiver before California's rules may be enforced. According to the CAA, EPA shall grant a waiver unless the Administrator finds that California:

- *was arbitrary and capricious in its finding that its standards are, in the aggregate, at least as protective of public health and welfare as applicable federal standards;*
- *does not need such standards to meet compelling and extraordinary conditions; or*
- *such standards and accompanying enforcement procedures are not consistent with Section 202(a) of the Clean Air Act.*

The CTA supports environmental responsibility in the goods movement industry. The Technology and Maintenance Council of our national affiliate, the American Trucking Associations (ATA), was involved in the development of the interim test method for verifying fuel saving components under the SmartWay Technology Program[1]. The ATA also supported the first national heavy-duty commercial vehicle fuel efficiency standards[2].

However, CTA must express its concerns with several items related to CARB's waiver request.

Timing of Waiver Request

As noted above, the rule was adopted by CARB in 2009 and became effective on 1/1/2010. The specific performance standards subject to CARB's waiver request have also been in effect since

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[1] http://www.epa.gov/smartway/documents/technology/verified/420f12022.pdf

[2] http://www.truckline.com/article.aspx?uid=a84aeb0d-b2f6-449c-b0ce-b2824f2e99e9

1/1/2010. This means that the regulated public has been conforming to the rule with no meaningful enforcement effort for close to four years.

We are not familiar with any precedent for the excessively delayed timing of this waiver request for an in-use requirement and CARB has not officially advised the regulated public that they lack the authority to enforce large portions of the rule. These delays and subsequent lack of clarity have undoubtedly resulted in additional compliance and administrative costs to businesses.

Need of standards to meet compelling and extraordinary conditions

In reviewing the EPA's 2009 decision to grant a waiver of CAA preemption for California's 2009 Greenhouse Gas (GHG) Emission Standards for New Motor Vehicles the agency found that the impacts of climate change on existing ozone conditions in California along with the cumulative impacts identified by proponents of the waiver (e.g., impacts on snow melt and water resources and agricultural water supply, wildfires, coastal habitats, ecosystems, etc.) were sufficient to establish the existence of compelling and extraordinary conditions.

However, we must note that in its support documentation CARB, when addressing whether the rule meets the compelling and extraordinary circumstances criteria, does not make a single reference to greenhouse gases, climate change, carbon dioxide or the cumulative impacts of global warming, but instead references the California Clean Air Act of 1988 and "attainment of the state standards".

Indeed, California continues to grapple with National Ambient Air Quality Standard non-attainment issues for both ozone and fine particles. In it's most recent Statement Implementation Plan (SIP), California further linked its GHG and criteria pollutant programs, stating "California's climate and criteria pollutant programs are complementary, and the AB 32 regulations ARB is adopting will provide emission reductions that will be incorporated into future air quality plans for ozone and fine particles."[3]

Still, California has yet to quantify how its GHG policies contribute to attainment of ozone or fine particle standards in any meaningful way or include these reductions in their SIP, despite stating that the rule would reduce 4.3 and 1.4 tons per day of NOx in 2014 and 2020, respectively[4].

Likewise, if the projected 1.0 million metric tons (MMT) of CO2-equivalent (CO2e) statewide and national 6.2 MMT CO2e emission benefits of the proposed regulation by 2020 are expected to positively impact ozone conditions in non-attainment areas, quantifying this impact would have important regional implications. We would urge EPA to consider how these co-benefits could be better quantified to both measure the overall impact of GHG policies on regional air quality and compare the relative cost-effectiveness of these policies versus traditional criteria pollutant reduction programs, especially if regional non-attainment is a continued justification for the establishment of compelling and extraordinary conditions.

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[3] http://www.arb.ca.gov/planning/sip/2007sip/2011_ozone_sip_staff_report_with_appendices.pdf

[4] http://www.arb.ca.gov/regact/2008/ghghdv08/ghgisor.pdf

Protectiveness of Trailer Standard

Because EPA has not yet regulated trailers hauled by combination tractors, CARB has argued that its standards for 2011 and subsequent model year dry-van and refrigerated-van trailers are at least as protective of the public health and welfare as non-existent applicable federal standards. This is an argument CARB has made in the past, which EPA has agreed with.

However, EPA did have the opportunity to create federal standards for trailers in its joint 2011 Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles rulemaking with the National Highway Transportation Safety Administration (NHTSA), but elected at that time not to. Clearly the mere absence of federal standards does not mean the EPA must simply defer to the assumed determination of protectiveness of any CARB standard, especially if that determination is not built on rational analysis or assumptions.

EPA/NHTSA explained its rationale for not regulating trailers in 2011 in its Regulatory Impact Analysis[5]:

> *Unlike trucks and engines, EPA and NHTSA have very limited experience related to regulating trailers for fuel efficiency or emissions. Likewise, the trailer manufacturing industry has only the most limited experience complying with regulations related to emissions and none with regard to EPA or NHTSA certification and compliance procedures.*
>
> ...
>
> *None of the commenters that supported trailer regulation in this action addressed the complexities of the trailer industry, nor a method to measure trailer aerodynamic improvements.*
>
> *In the NPRM, the agencies discussed relatively conceptual approaches to how a future trailer regulation could be developed; however, we did not provide a proposed test procedure or proposed standard. The agencies proposed to delay the regulation of trailers, as the inclusion would not be feasible at this time due to the diversity and complexity of the trailer industry, as well as a lack of critical information from the SmartWay program, industry and other key stakeholders.*

In its rulemaking, EPA and NHTSA likely had at its disposal at least the similar, if not superior data to CARB on which to craft a rulemaking. In previous waiver requests, EPA has stated that waiver opponents "must show that California's analysis, or the assumptions California relied on to support its protectiveness determination were arbitrary and capricious. Competing analyses, each based on rational assumptions, are not sufficient to deny a waiver."[6]

We believe that an examination of the public record associated with CARB's adoption of the rule (Attachment A), taken together with EPA's own 2011 analysis of measurements for trailer fuel

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[5] http://www.epa.gov/otaq/climate/documents/420r11901.pdf

[6] http://www.gpo.gov/fdsys/pkg/FR-2009-07-08/pdf/E9-15943.pdf

efficiency and emissions, demonstrates that CARB did not rely on rational assumptions to support its protectiveness determination.

Despite multiple attempts to do so (Attachment B), CTA has never been able to verify that the industry average estimated vehicle speeds relied upon by CARB to construct their cost-effectiveness and emissions reduction scenarios were built upon any discernible empirical evidence. On 11/3/2011, CTA submitted a Public Records Act request for each technical, theoretical, and empirical study, report or similar document, on which ARB relied upon to construct its cost-effectiveness scenarios. As the attached response demonstrates, we do not believe any such evidence, studies, reports or similar documents ever existed and that some key assumptions in the analysis were the products of conjecture. CTA did offer to assist CARB to collect California-specific speed and vehicle miles traveled data and submitted a 35 truck sample to CARB staff and then subsequently built a larger 136 truck survey (Attachment C), but never received a response.

CTA does not dispute that aerodynamic retrofits, especially when taken with the entire suite of operational strategies offered to SmartWay partners, offer some fuel efficiency and emission reduction benefits to fleets. However, we agree with EPA and NHTSA's 2011 assessment that there is a great deal of complexity in establishing a statutory requirement for trailer fuel efficiency and emissions. We cannot agree with CARB's protectiveness determination for the simple fact that they have never been able to demonstrate that the assumptions relied upon to quantify the rule's benefits were rational, rather than entirely arbitrary.

If you have any questions please contact Chris Shimoda, Manager of Environmental Policy at (916)373-3504 or cshimoda@caltrux.org.

Thank You

Eric Sauer, Vice President of Policy and Regulatory Affairs
California Trucking Association
(916)373-3562
esauer@caltrux.org

ATTACHMENT A

November 3, 2011

California Trucking Association
We drive for a living. Safety is our priority.

James Goldstene, Executive Officer
California Air Resources Board
1001 I St.
P.O. Box 2815
Sacramento, CA 95812

Mr. Goldstene,

The following is from the Initial Statement of Reasons for the Heavy Duty Tractor Trailer Greenhouse Gas Reduction Measure (Page ES6):

> *Assuming this range, the fuel savings would be approximately $4,000 to $5,700 per year for a tractor-trailer combination...The assumptions for this calculation are as follows: a baseline fuel economy of 5.8 miles per gallon, an average long-haul mileage accrual rate of 125,000 miles per year,* ***84 percent of the vehicle miles traveled at highway speed benefit fully from the aerodynamic devices****, and a projected diesel fuel cost of $3.14 per gallon. If the cost per gallon in diesel fuel is higher than $3.14, the fuel savings due to the proposed regulation would be proportionately greater.*

The California Trucking Association, pursuant to the California Public Records Act of 2004 (PRA), respectfully requests that the Air Resources Board make available each technical, theoretical, and empirical study, report, or similar document, if any, on which the agency relied upon to conclude that **84 percent** of commercial vehicle miles traveled (VMT) are done at highway speeds in the state of California. Thank you in advance for your cooperation.

Sincerely,

Eric Sauer, Vice President of Policy and Regulatory Development
California Trucking Association
(916)373-3562

Affected Number of Vehicles

MY	CY	T6 CAIRP	T6 instate	T6 OOS	T7 CAIRP	T7 NNOOS	T7 NOOS	T7 tractor	Total	Percent of out-of-state trucks	Percent of in-state trucks
All MYS	2010	31	1209	131	27462	380152	18525	9547	**437058**	91%	9%
2011	new	1	20	5	865	34020	584	205	35700	97%	
Pre 2011	used	30	1189	126	26597	346132	17941	9343	401358	91%	
2011	2011	31	1229	133	28273	386521	19071	9785	**445043**	91%	9%
2011	new	3	82	11	1,199	68,622	809	397	71123	98%	
2011	used	29	1147	122	27074	317899	18263	9387	373920	90%	
	2012	32	1257	137	29524	403865	19916	10178	**464910**	91%	9%
	new	3	78	12	1422	73372	959	431	76277	97%	
	used	29	1179	125	28103	330493	18957	9747	388632	90%	
all	2013	32.64786	1277.136	138.719	30598	416208	20640	10565	**479460**	91%	9%
2013-14	new	3	96	14	1,635	83,648	1,103	512	87010	97%	
2013&older	used	29	1,181	125	28,963	332,560	19,537	10,054	392450	90%	
	2014	33.17981	1298.367	140.979	31680	429553	21370	10971	**495046**	91%	9%
	new	3	99	14	1,743	85,084	1,176	539	88658	97%	
	used	30	1,199	127	29,937	344,469	20,194	10,432	406389	90%	
	2015	33.54916	1315.217	142.548	32618	440382	22003	11352	**507846**	91%	9%
	new	3	98	13	1,639	82,530	1,106	527	85916	97%	
	used	30	1,218	129	30,979	357,851	20,897	10,825	421930	90%	
	2016	33.8786	1328.165	143.948	33452	454166	22565	11671	**523359**	91%	9%
	new	3	87	12	1,555	79,212	1,049	497	82414	97%	
	used	31	1,241	132	31,897	374,954	21,516	11,174	440945	90%	
	2017	34.29829	1344.544	145.731	34284	468486	23126	11974	**539394**	91%	9%
	new	3	87	12	1,559	81,871	1,052	507	85091	97%	
	used	31	1,258	133	32,724	386,615	22,074	11,467	454303	90%	
	2018	34.80478	1364.642	147.884	35139	481603	23703	12273	**554266**	91%	9%
	new	3	88	12	1,559	83,659	1,052	511	86883	98%	
	used	32	1,277	136	33,580	397,945	22,651	11,763	467383	90%	
	2019	35.45122	1389.694	150.63	36121	496606	24366	12612	**571281**	91%	9%
	new	3	90	13	1,678	89,235	1,132	535	92687	98%	
	used	32	1,300	138	34,443	407,371	23,234	12,077	478594	90%	
	2020	36.04615	1412.359	153.158	37005	507751	24962	12910	**584229**	91%	9%
	new	3	98	14	1,766	93,832	1,191	566	97471	98%	
	used	33	1,315	139	35,239	413,919	23,770	12,344	486759	90%	
										93%	**9%**

Cost Scen_Tires

(in-use sleeper/daycab tractor pulling compliant trailer)

INPUT Baseline Fuel Economy (mpg)	INPUT Vehicle Miles Traveled (miles/year)	INPUT Fuel Economy Improvement
6	62,378	0.0769

75% VMT for in state tractors	9% weight
85% VMT for out-of state tractors	91% weight

0.841 % VMT for in-state & out-of state tractors

Fuel economy benefit adjusted to account for reefer trailer benefit (less than dry van, but dry van dominates market);
Reefers 31% aero for reefer= 4 %, dry van 69%--aero for dry van= 5%

Assumed Ave. of **74,171** miles traveled per year; estimated from Institute of transportation Studies, University of Davis (CARB Contract #04-328)

Cost Scen_New Sleeper Cab

(new sleeper tractor pulling compliant trailer)

INPUT Baseline Fuel Economy (mpg)	INPUT Vehicle Miles Traveled (miles/year)	INPUT Fuel Economy Improvement
5.8	105,125	0.10

New Class 8 tractor-trailer combinations travel between 100,000 to 150,000 miles/y, used the ave. of **125,000** miles/y.
Source: Report entitled, "Tranformational Trucks: Determining the Energy Efficiency Limits of a Class 8 Tractor-Trailer" Rocky Mountain Institute, July 2008.

Cost Scen_Trailers

(for trailer only check)

INPUT Baseline Fuel Economy (mpg)	INPUT Vehicle Miles Traveled (miles/year)	INPUT Fuel Economy Improvement	
5.7	62,378	0.065	
5.8	105,125	0.065	assumed new trailers put into full long haul service

Rocky Mountain Institute

Truck Efficiency and GHG Reduction Opportunities in the Canadian Truck Fleet

by
Michael J. Ogburn
Laurie A. Ramroth

Executive Summary

Fuel-efficiency devices such as retrofittable aerodynamic technologies, fuel-efficient tires, and auxiliary power units can effectively offset engine-efficiency losses resulting from the 2002 and 2007 Environment Canada and U.S. EPA emissions regulations, while reducing greenhouse-gas (GHG) emissions significantly. To identify which fuel-saving devices are most effective, consistent, clear involvement from government is critical. If the industry is to quickly and effectively improve its GHG emissions, government must play a leadership role, a technical role, and a financial role.

This report discusses how truck operators can reduce the fuel use and GHG emissions of their vehicles. Beginning with an explanation of end-use efficiency, we outline the major end-use opportunities on highway trucks and then discuss the financial and environmental benefits of the efficiencies. Estimates show that if the entire Canadian fleet of 294,000 Class-8 trucks were to adopt a full package of energy-efficiency technologies, Canadian truck owners and operators would save 4.1 billion litres of fuel and reduce emissions by 11,500,000 tonnes of GHG each year. This is equivalent to taking 64,000 Class-8 trucks off the road or taking 2.6 million cars off the road.

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Industry Obstacles and Government Leadership

For years, tractor-trailer operators have been the target of energy-saving initiatives that pushed ideas ranging from more aerodynamic vehicle shapes to a myriad of fuel and oil treatments, all of which claim significant savings. The industry's challenge is to determine which of the advertised savings are real and applicable to a given fleet's operation. While some large fleets have shown initiative and have undertaken significant testing efforts to validate fuel-savings claims, the majority of fleets and most owner-operators do not have the time or expertise to carry out rigorous engineering tests. In an industry with small margins, it's common for truck operators to continue with "business as usual" and avoid the risk of losing time and money on trial-and-error testing.

The concepts underlying the efficiency devices discussed in this report are not new. NASA studies from the 1970s[1] show notable savings from certain technologies, proof that the technologies we present here are no surprise to the scientific community. As can be seen by the age of these projects, studies that differentiate winning technologies from "snake oil" are important but not enough on their own to spark industry adoption.

Consistent, clear involvement from government in identifying proven fuel-saving devices is critical. If the industry is to quickly and effectively improve its GHG emissions, government must play a leadership role, a technical role, and a financial role. To address a lack of clear guidance in the U.S. truck market, the U.S. Environmental Protection Agency (EPA) created a program called EPA SmartWay. This program applies engineering methods to test prototypes, publishes peer-reviewed Society of Automotive Engineering scientific papers, funds early market introduction of certain fuel-saving devices, and also manages a "certification program," in which manufactures can have their new models EPA SmartWay Certified if they have a certain number of fuel-savings options installed.

The basic specifications for a U.S. EPA Certified SmartWay tractor are: model year 2007 or later engine, integrated cab-high roof fairing, tractor-mounted side-fairing gap reducers, tractor fuel tank side fairings, aerodynamic bumper and mirrors, optional equipment that reduces the amount of engine idling (auxiliary power units, generator sets, direct-fired heaters, battery-powered HVAC systems, and automatic engine start/stop systems) and optional low-rolling resistance tires (single wide or dual).

Achieving U.S. EPA Certified SmartWay trailer certification can be done several ways. New long-haul van trailers can be ordered, and existing trailers can be upgraded to qualify provided that they are equipped with: side skirts, weight-saving technologies, gap reducers on the front or trailer tails (either extenders or boat tails), and options for low-rolling resistance tires (single wide or dual).

It is important to note that the industry will not change quickly on its own. EPA SmartWay is a significant government–industry partnership that is informing the truck industry about proven energy efficiency and GHG-reducing technologies. Canada, which has no similar coordinated effort, has taken an initial step in providing incentives for APUs. From 2004 to 2006, Natural Resources Canada ran the "Commercial Transportation Energy Efficiency Rebate" program, which encouraged the purchase of idling-reduction technologies. APUs and modified RV generators have been installed on the trucks of fuel-conscious drivers for years. Recently fuel prices have caused a renewed interest in such devices,

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[1] Montoya, Lawrence C. and Louis L. Steers, *Aerodynamic Drag Reduction Tests on a Full-Scale Tractor-Trailer Combination With Several Add-On Devices*, NASA TM-X-56028, 1974.

[1] Steers, Louis L. and Edwin J. Saltzman, "Reduced Truck Fuel Consumption through Aerodynamic Design," *Journal of Energy*, vol. 1, no. 5, Sept.–Oct. 1977, pp. 312–318.

[1] Muirhead, V. U. and E. J. Saltzman, "Reduction of Aerodynamic Drag and Fuel Consumption for Tractor-Trailer Vehicles," *Journal of Energy*, vol. 3, no. 5, Sept.–Oct. 1979, pp. 279–284.

but not until NRC's rebate did the industry begin to significantly adopt this economically and environmentally beneficial technology en-masse. Canada's rebate of up to 19% of retail cost led to the purchase of 13,280 idling-reduction devices and resulted in an estimated annual savings of 186,000 tonnes of GHG. Showing the importance of government involvement, sales of APU units in Canada jumped in Aug 2003 when the program started. Compared to 2002 annual sales when no rebate was available, sales in 2004 were significantly higher. In the case of one APU manufacturer, sales during 2004 were 810% higher. During this program, C$6.2 million of government funds were spent on the rebate which spurred truck industry investment totaling over C$31 million, a 5-1 leveraging of taxpayer dollars to deliver GHG savings.[2]

Truck-Efficiency Introduction

New emissions regulations have resulted in changes to engine architecture and after-treatment to control certain pollutants. These changes improve emissions (up to 95% cleaner than previous regulations required) but can cause a 3–8% decrease in fuel economy and similar increases in GHG emissions, depending on operational conditions. A major reason for the decrease in fuel economy is that engines are now equipped with a cooled exhaust gas recirculation system (Cooled EGR), which has a negative impact on engine efficiency. Because these systems require higher pressure in the exhaust system than in the intake system to move gas through the control valve, the engines incur greater gas-pumping losses. The Cooled EGR system also demands more work by engine turbomachinery (higher boost) and more heat dissipation through the radiator. Greater heat rejection requires bigger cooling fans with more on-time and also more truck frontal area, which has a negative effect on aerodynamics. To meet 2010 emissions engine makers are considering various strategies including carrying liquid urea on-board and, separately, "next generation cooled EGR" which may also result in fuel economy reductions.

There are opportunities to increase overall truck efficiency to offset the decreases resulting from emission regulations. In 2005 RMI helped Wal-Mart improve the fuel economy of its truck fleet. Focusing on retrofit solutions for maximum near-term impact, testing showed that fuel savings of 25%[3] were possible on Wal-Mart's long-haul fleet. It is important to note that there is no silver bullet. Rather, these savings are the result of several energy-efficiency technologies combined. It is important to approach long-haul trucks from a "whole-system" perspective, where attention is given not only to the tractor but to the trailer and to overnight driver comfort. In the following pages we will explore the practical fuel-efficiency opportunities that are applicable to truck fleets with a focus on the type of technology best suited for fleets to make immediate reductions in fuel use and greenhouse-gas emissions.

End-Use Efficiency

We will start with a simple engineering example. A typical industrial pumping loop includes numerous energy conversion steps, each of which is not entirely efficient and wastes energy. These inefficient steps add to the total amount of energy lost throughout the process (called "compounding losses"). Figure 1 below is an illustration of these conversion steps showing the flow of energy from beginning to end in a typical industrial pumping application. It takes one hundred units of fossil-based energy at the power plant to produce about ten units of energy (embodied in the flow of water) out of the pipe—a loss factor of about ten. When seeking ways to improve the efficiency and the emissions of such a system, it is tempting to focus on the power plant, where 70% of the energy is lost to inefficiency and where 100% of the emissions are generated. However, turning those ten-to-one

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[2] Source: Natural Resources Canada

[3] www.walmartstores.com/GlobalWMStoresWeb/navigate.do?catg=349.

compounding losses around backward yields compounding savings. Saving one unit of energy farthest down the chain, at the point of use, by reducing pipe friction or water flow, avoids enough of the upstream compounding losses to save ten units of energy and an equal (percentage) emissions reduction at the power plant.

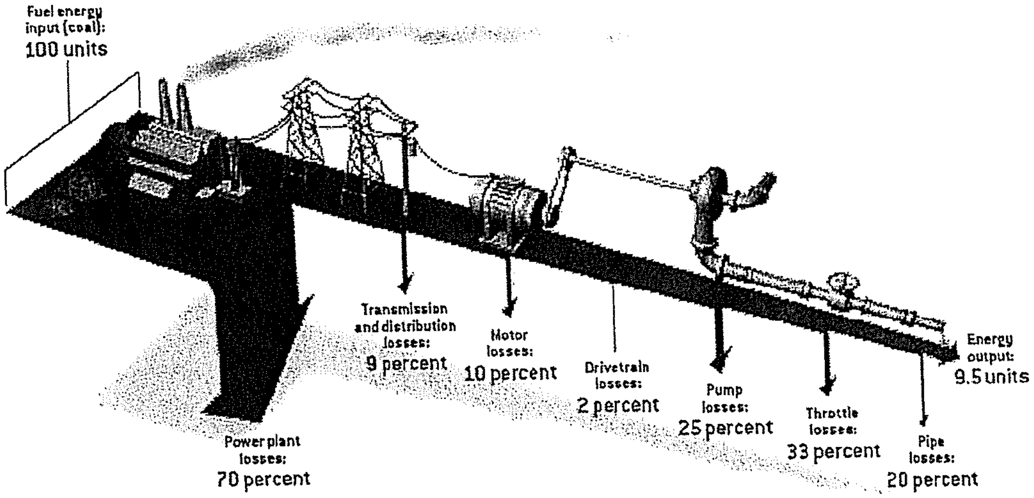

Figure 1: Industrial Pumping Example

Those compounding savings represent significant economic, emissions-reducing, and energy-saving leverage. And, they are the same principles that efficient tractor-trailers use to multiply reduced aerodynamic drag, rolling resistance, and idle-time use into big fuel savings:

> "In a chain of successive improvements, all the savings will multiply, so they appear all to have equal *arithmetic* importance. However, the *economic* importance of an energy-saving measure will depend on its position in the chain. Savings furthest downstream will have the greatest leverage in making the upstream *equipment* smaller, and this saves not just energy but also capital cost. Downstream savings should therefore be done first in order to save the most money. Downstream-to-upstream thinking is thus a special case of a more general rule: Do the right things *in the right order*.[4]

End-Use Opportunity on Tractor-Trailers

When looking for ways to improve the fuel efficiency and GHG emissions of modern tractor-trailers, one can take the same end-use approach that is discussed in the industrial pumping example above. In the average long-haul trucking operation, only about 6.5% of the energy in each litre of diesel fuel is used to move the cargo and only 4.5% is used to move the tractor-trailer. The remaining 89% is lost along the way: 56% to thermodynamic effects in the engine, 12% due to idling, 2% to driveline and transmission drag, 19% to overcome aerodynamic forces, and 11% to tire rolling resistance. Rather than focus on the diesel engine—a tempting target since more than half of the total fuel energy used by a truck is lost in thermodynamics in the engine—we will focus on the end of the chain, where we

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[4] Hawken, Paul, Lovins, Amory and Hunter. *Natural Capitalism: Creating the Next Industrial Revolution.* Little, Brown. 1999.

have the opportunity for compounding savings. These downstream savings let us leverage the principle of end-use efficiency to maximize the benefits of our investments.

Aerodynamics

Basic physics tells us that the majority of energy used to move a typical highway truck down the road is used to counter aerodynamic resistance. At 105 km/h, two thirds of the horsepower created by the engine is used to overcome aerodynamic drag.[5] Of that two thirds, a large portion is caused by aerodynamic drag on the trailer and the tractor-trailer connection. By making changes to the aerodynamics of the trailer it is possible to reduce drag by approximately 20%, resulting in approximately 10% lower fuel consumption for a truck traveling at 105 km/h. It should also be noted that lower speeds result in less aerodynamic drag. By simply reducing a truck's speed from 115 km/h to 105 km/h, it is possible to reduce the fuel consumption of the average truck by approximately 7% with no changes to the truck itself.[6] Assuming trucks spend 75% of their time on highways, this speed reduction equates to a savings of 3100 liters/y and 8.5 tonnes of GHG emissions/y for each truck. If 50% of Canada's Class-8 fleet achieved this result, it would save 460 million liters of fuel and 1.2 million metric tones of GHG emissions each year.

For the purposes of this review we will adopt a "baseline" tractor-trailer design upon which all fuel savings will be based. Our baseline assumption will be a typical "aero cab" tractor pulling a 53-foot trailer (Figure 2). This commonly used configuration is 25–30% more fuel-efficient than the old-style "long-nose" cab with no roof fairings, exposed air cleaners, and exposed exhaust stacks.[7]

Tractor—Bumpers and Tank Fairings

Upon the purchase of a tractor, the dealer offers several different aerodynamic options that improve energy efficiency. Tractors that incorporate aerodynamic mirrors, full aerodynamic bumpers, and aerodynamic fairings on the fuel tanks (Figure 3), typically use 2% less fuel than trucks without these features.[8] Together, we call these devices "Tractor Aerodynamics."

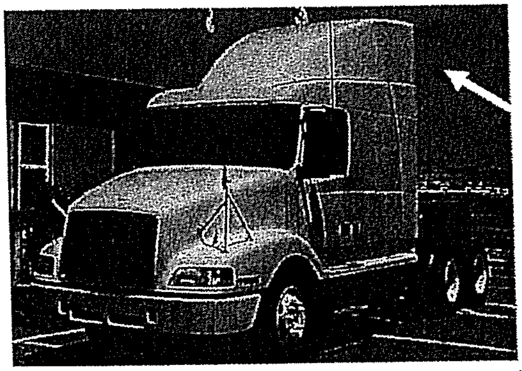

Figure 2: Baseline Assumption: "Aero Cab" Tractor with Roof Fairing

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[5] Technology Roadmap for the 21st Century Truck Program (DOE 2000).

[6] Wood, R. M. et. al, (2003), "Simple and Low-Cost Aerodynamic Drag Reduction Devices for Tractor-Trailer Trucks" SAE 2003-01-3377 (www.sae.org/technical/papers/2003-01-3377).

[7] www.kenworth.com.

[8] Leuschen, Jason and Cooper, Kevin R., (2006) "Full-Scale Wind Tunnel Tests of Production and Prototype, Second-Generation Aerodynamic Drag-Reducing Devices for Tractor-Trailers" SAE 06CV-222 (www.freightwing.com/test/NRC_Wind_Tunnel_Test_SAE_Paper.pdf).

Figure 3: Preferred Tractor: Baseline plus Aero Bumper and Tank Fairings

Trailer—Gap fairing, Base Flaps, and Skirts

RMI's analysis shows that an untapped energy-efficiency opportunity exists through additional attention to trailers as part of the tractor-trailer system. RMI's calculations, based on leading published research, show that approximately half of truck fuel consumption can be attributed to the forces acting on the trailer. In fact, more than 60% of total aerodynamic drag in a tractor-trailer unit is due to the trailer. Using currently available "bolt-on" solutions, the trailer could be reshaped to provide more than a 10% fuel economy improvement to the tractor-trailer system.[9]

Tractor/Trailer Gap

It is important that the air flow as smoothly as possible as it moves from the tractor to the trailer. "Gap fairings" or "nose cones" on the trailer can deliver a 1–2% fuel savings.[10]

Figure 4: Retrofitted Trailer with Base Flaps and Side Skirts. photo: Andrew Smith, ATDynamics

Base Flaps (aka "Boat Tails," "Rear Drag Devices")

Aerodynamic systems attached to the rear of a trailer (known in the automotive community as the trailer's "base") offer the greatest single aerodynamic efficiency opportunity.[11] When the truck moves, the amount of drag created at the trailer base is equal to the drag created when air is forced around the

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[9] Bachman, J.L., Erb, A., and Bynum, C., (2005) "Effect of Single Wide Tires and Trailer Aerodynamics on Fuel Economy and NOx Emissions of Class 8 Line-Haul Tractor-Trailers" SAE 05CV-45

[10] Bachman, J. L. et al, (2006) "Fuel Economy Improvements and NOx Reduction By Reduction of Parasitic Losses: Effect of Engine Design," SAE 2006-01-3474

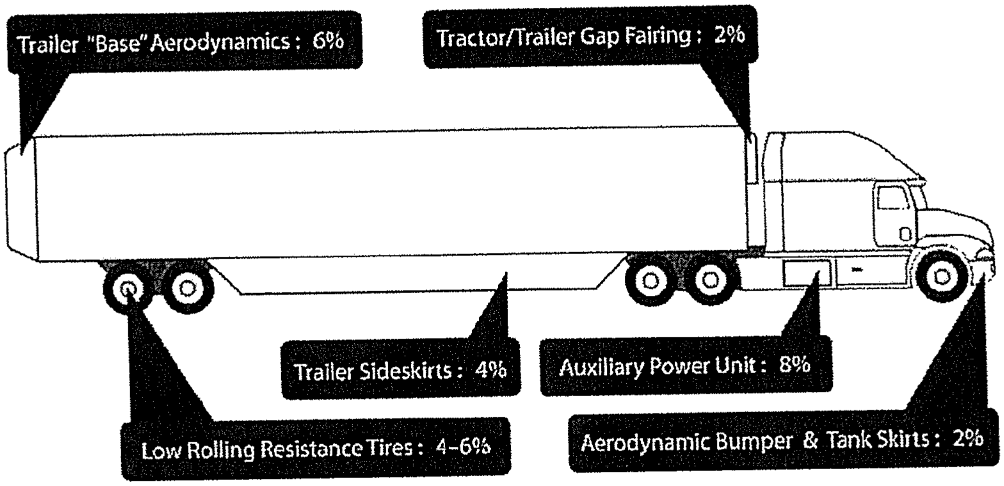
[11] Ortega, J. M. et. al, (2004), "An Experimental Study of Drag Reduction Devices for a Trailer Underbody and Base" AIAA Fluid Dynamics Conference UCRL-CONF-204489

front of the truck. Base flap aerodynamic systems such as "TrailerTail™" (Figure 4) have the potential to reduce the fuel consumption of long-haul fleets by 6%[10] and enhance vehicle safety without interfering with trucking operations.

Side Skirts

Side skirts, now in production by several manufacturers, are available for a variety of trailer styles—including trailers with movable rear axles, spread-axles (see Figure 4), flat-beds, and pin-chassis—for container hauling. These devices offer a 4% fuel savings.[10]

Combined, the aerodynamic improvements from these three trailer solutions, Gap Fairings, Side Skirts, and Rear Drag Devices deliver a potential fuel savings of approximately 12% during highway operation.



Low Rolling-Resistance Tires

To move a truck at 105 km/h along a level highway, the average truck engine produces 220 hp (167 kW). Roughly 70 hp (52 kW) is required to overcome the drag caused by rolling resistance in the tires.[12] By choosing tires with a strong emphasis on fuel economy instead of solely on wear characteristics, significant fuel savings are possible. New versions of common "dual tires" that have been designed for reduced rolling resistance can save up to 4% over standard tires. For greater savings, choosing "wide-base tires," sometimes called "super-singles," can save 4–6% over typical dual tires. Because they need only one rim and have only two sidewalls (compared to the four in a dual-tire configuration), wide-base tires offer the additional benefit of weight savings. When fitted with aluminum rims and wide-base tires, trucks can save 200 lb per axle, or 800 lbs (363 kg) per truck, allowing the truck to carry more.

Engine-Idle Reduction

Technologies that reduce idling time can help achieve significant fuel savings for fleets whose drivers spend their rest periods inside the truck. Traditionally, in trucks without APUs, the primary engine must be running in order to provide electricity and hot or cool air for comfort during resting periods. "Anti-idle" systems now available provide all the comfort a driver expects without having to idle the

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[12] Technology Roadmap for the 21st Century Truck Program (DOE 2000) (http://roadmap.itap.purdue.edu/ctr/documents/21stcenturytruck.pdf).

primary engine. A typical primary engine, usually rated for 350–550 hp, consumes approximately 1 gallon (3.76 litres) of fuel for each hour of idle time. In contrast, an auxiliary power unit (APU) burns 0.2 US gallons per hour (0.76 lph) or less. Battery-electric APU systems can provide electricity and cooling services while using zero fuel and are typically quipped with a diesel fired heater to provide warmth with extremely low fuel consumption rates (0.15 lph). These systems can improve a truck's overall fuel use by 8% or more depending on the amount of idling. APUs also reduce the amount of wear and tear caused by primary engine idling, potentially reducing the amount of maintenance needed over the life of the vehicle. In the US, there is a federal provision to grant vehicles equipped with APUs a 400 lb weight allowance, permitting a maximum vehicle weight of 80,400 lb.

There are three types of APU systems that can provide full comfort to drivers.

1) Diesel APU: Simplest of the three designs, a diesel APU includes a small diesel engine that powers belt-driven automotive-style accessories. Designs vary, but typically an alternator provides 12-V power, an R134a compressor provides air conditioning, and hot coolant from the small diesel warms the cab and the primary engine.

2) Diesel-Electric APU: A diesel-electric APU uses a small diesel engine that runs a 120-V generator mounted outside the cab. Electricity generated by the small engine is then used in-cab to operate accessories and heating systems, and to condition air. This type of APU is often capable of plugging in to 120-V "shore power" (from a nearby building, a gas station, etc.) to provide comfort without running the engine.

3) Battery-Electric APU: This "zero-idle" APU is the cleanest and most energy-efficient type of APU available. Energy is stored in deep-cycle batteries, which provide electricity to operate an electric air conditioner, a diesel-fired heater, and an inverter that provides 120-V accessory power. These systems are recharged by the primary engine during normal operation or can operate using 120-V shore power. For trucks hauling refrigerated freight, there are systems that can recharge via optional connections to reefer units.

California created rules that limit the idling of heavy vehicles and take effect in 2008. Emissions regulations in California, widely recognized as a leader in emissions reduction strategies, often become de-facto standards. Because of growing concern over diesel pollution at local and national levels in the United States, it is likely that other states will adopt similar regulations. This type of regulation may cause the battery-electric APU to become the industry standard, as no diesel APU "retrofit kits," which bring existing APUs up to the new California standard, have been certified by California Air Resources Board (CARB).

Title 13, California Code of Regulations (including Section 2485 - Airborne Toxic Control Measure to Limit Diesel-Fueled Commercial Motor Vehicle Idling) states:

> The new engine requirements require 2008 and newer model year heavy duty diesel engines to be equipped with a non-programmable engine shutdown system that automatically shuts down the engine after five minutes of idling or optionally meet a stringent oxides of nitrogen idling emission standard. The in-use truck requirements require operators of both in-state and out-of-state registered sleeper berth equipped trucks to manually shut down their engine when idling more than five minutes at any location within California beginning in 2008.
>
> Emission producing alternative technologies such as diesel fueled auxiliary power systems (APUs) and fuel fired heaters are also required to meet emission performance

requirements that ensure emissions are not exceeding the emissions of a truck engine operating at idle. Specifically, the regulation requires diesel APUs installed on 2007 and newer truck engines to control particulate matter (PM) emissions by either routing the APU exhaust through the PM trap of the truck engine or by retrofitting the diesel APU with a verified level 3 PM control device that reduces PM emissions by at least 85 percent. Fuel fired heaters installed on 2007 and newer truck engines are also required to meet the Ultra Low Emission Vehicle requirements specified in the Low Emission Vehicle regulations. These requirements are effective beginning in 2008.[13]

Other Improvements

Systems that can improve fuel economy but which are not included in our analysis include a tag axle, which can improve fuel economy roughly 1% and reduce truck weight by 200–500 lbs; automated manual transmissions, which can improve fuel economy and help reduce driver variability; low-viscosity synthetic lubricants, which can improve fuel economy; and diesel-electric refrigeration units, which use less fuel to keep refrigerated loads cool and are equipped to use shore power for "zero-emissions" cooling when the truck is parked at terminal facilities.

Data Analysis

Several assumptions were made in evaluation of fuel and GHG savings. These assumptions included a fuel cost of C$0.97/litre, a fleet size of 294,000 trucks, an average of 1400 hours/year of overnight idle time, and an average driving distance of 160,000 km/year. When discussing the energy efficiency of each device, it is important to note that energy savings are specific to the way trucks are operated. Tires designed to improve fuel efficiency do so while the truck is being driven. An APU, in contrast, improves fuel efficiency when a truck is parked. The technologies described in the following paragraphs are organized according to the mode of operation in which they are used—driving or idling.

While the devices discussed here are additive in their effects, not all of the fuel-saving devices on the market achieve their advertised savings. As shown in NRC full-scale wind-tunnel tests[8],certain aerodynamic devices meant to improve fuel economy actually increase the fuel use of a truck. Fundamentally, these vortex-generating devices can have benefits and can be found on the wings of many aircraft. However, improper application without careful attention can turn these benefits into detriments. In addition, driver and load variability can introduce uncertainty.

Driving

Energy efficiency in driving mode can be improved by changing aerodynamic characteristics and rolling resistance. The specific devices and their corresponding fuel savings are listed in Table 1.

Aerodynamic devices can alone result in a 14% fuel savings and save 17 tonnes of GHG per year if a truck has all of the aero devices discussed in Table 1 installed. These benefits are realized at speeds over 105 km/h. In our calculations we will assume that the average truck spends 75% of its time at speeds near 105 km/h, thus enjoying 75% of the aero fuel savings shown in Table 1. Canadian manufacturer Laydon Composites Ltd. sells several aerodynamic devices for tractors and trailers, including trailer side skirts. Base flaps, which fit to the rear of the trailer and can fold flat to the trailer door for easy cargo access, are being commercialized by Advanced Transit Dynamics. They are being brought to market with select fleets in 2007 and are expected to be commercially available in 2008. Gap fairings and side skirts can be purchased from companies such as Freight Wing.

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[13] www.arb.ca.gov/msprog/truck-idling/truck-idling.htm

Table 1: Driving Add-on Technologies and Associated Savings

		Fuel Savings %	Incremental Cost (C$/truck)	GHG Savings Per Truck (tonnesCO_2eq/y)
Driving	*Aerodynamic Add-ons*			
	Tractor Aero	2%	$ 1,050	2.49
	Side Skirts	4%	$ 1,679	4.98
	Base Flaps	6%	$ 3,150	7.47
	Gap Fairing	2%	$ 891	2.49
	Rolling Resistance (Choose 1)			
	Efficient Dual Tires	4%	$ 55	6.64
	Wide Base Tires	5%	$ 5,913	8.30

Several tire manufacturers offer models with less rolling resistance than standard tires. There are two common configurations: a dual-tire configuration that includes two narrow tires or a single-tire configuration that uses a wide-base tire. Results vary depending on the baselines used, but it is reasonable to expect a 4% increase in fuel efficiency when switching to dual tires and a 5% fuel savings and a 200-lb/axle weight savings when switching to wide-base tires.[14] In calculations of tire costs, we estimated the difference between the fuel-efficient tire configurations and a standard configuration. Wide-base tires have a dramatically longer payback period because of a one-time cost of new aluminum wheels, which adds C$5,880 to the cost. It should be emphasized that this is a one-time initial installation cost that would not be required with subsequent tire replacements. In addition, the use of wide-base tires typically means a weight reduction of approximately 800 lb (363 kg) per truck, which translates to an increase in payload capacity.

Idling

Two types of APU units are considered: diesel-electric and battery-electric. Table 2 lists the fuel-savings and greenhouse-gas-emissions reductions as a result of using these devices on a percentage basis in comparison to the fuel that is required to idle the main engine.[15] Although maintenance cost reductions are not included here, generally less idling of the primary engine means less wear and tear, meaning, in turn, longer maintenance intervals and engine life.

A battery-electric APU runs on energy stored in deep-cycle batteries, which can be recharged during driving via the vehicle's alternator. RMI has accounted for this alternator energy in the form of additional diesel fuel used by the primary engine to recharge the APU's batteries. A standard system with a battery capacity of 220 amp hours that will operate for up to 8 hours is a $3,900 investment. Its fuel savings is greater than the diesel-electric APU at 92%. Battery-electric APUs are available aftermarket as a complete system from several manufacturers including Sun Power Technologies and Bergstrom, Inc., which manufactures the NITE System.

Table 2: Idling Add-on Technologies and Associated Savings

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[14] The specific dual configuration discussed here is based on the Goodyear steer, drive, and trailer model tires G395 LHS, G305LHD Fuel Max, and G316LHT Fuel Max. The wide-base configuration is based on the X One wide-base tires from Michelin. The models used in the steer, drive, and trailer positions are the XZA3, the X One XDA, and the X One XTA.

[15] Fuel savings percentages represent the amount of fuel saved when using APUs over the amount of fuel used when idling the primary engine. The baseline used is 1,400 h/y at 3.79 L/h.

		Fuel Savings %	Incremental Cost (C$/truck)	GHG Savings Per Truck (tonnesCO_2eq/y)
Idling	*Idle Solutions (Choose 1)*			
	APU (diesel-electric)	80%	$ 7,429	11.70
	APU(battery-electric)*	92%	$ 3,932	13.46

(* battery electric APUs are zero emissions—here, "fuel savings" is based on RMI's estimate of the amount of fuel energy used by the primary engine to recharge the battery while driving.)

In the "simple" package discussed below, a diesel-electric APU was chosen because of its availability and acceptance within the trucking community. For a C$7,400, one can save 80% of the fuel that would normally be required for idling (as shown in Table 2). Two Canadian manufacturers of diesel-electric APUs are Mechron Power Systems and Rigmaster.[16]

Fuel, Dollar, and GHG Savings: Two Implementation Scenarios

In this section we have compiled data from those technologies discussed above and evaluated two packages for fuel efficiency and greenhouse-gas-emissions-saving benefits. The first is a "full" package, which assumes implementation of all the technologies discussed above, including all aerodynamic devices, wide-base tires, and a battery-electric APU. The second "simple" package only uses side skirts, and substitutes fuel-efficient dual tires for regular tires and a diesel-electric APU. We picked these two scenarios to demonstrate both the maximum achievable savings and to show the result if only a portion of the Canadian class-8 fleet incorporated these features. This Simple Package, modeled to include installation on only 50% of trucks, is based on the assumption that not all trucks would be suitable for the specific devices discussed here, and that some trucks would utilize only a portion of the full package. For instance, day-cab trucks would not benefit from the installation of an APU due to a lack of overnight idling, and a tanker truck would not be able to utilize the rear drag devices discussed here which are meant for a box-shaped trailer.

Full Package:
- Wide-Base Tires
- Battery-Electric APU
- Tractor Aerodynamics
- Trailer Side Skirts
- Trailer Base Flaps
- Trailer Gap Fairings

Simple Package:
- Side Skirts
- Fuel-Efficient Duals
- Diesel-Electric APU

In calculating potential fuel savings and reductions in greenhouse-gas emissions, RMI considered two scenarios. In the first scenario we assumed that 100% of the Canadian truck fleet installed a "full package" consisting of 100% of the efficiency opportunities discussed above. A second, more conservative, scenario was also considered in which 50% of the Canadian truck fleet adopted a "simple package" of just three fuel-saving technologies. In each scenario, the total amount of fuel consumed in both driving and idling modes offered an overall picture of the potential fuel savings, possible greenhouse-gas emissions reductions, and payback periods. Table 3 summarizes the overall energy savings and emissions reductions under each implementation scenario.

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[16] For more a more complete list of APU systems available on the market today see: www.epa.gov/smartway/idlingtechnologies.htm.

According to Canadian Trucking Alliance data, the average truck fleet owns 3 trailers for every 1 tractor in operation. To achieve full fuel savings both the truck and the trailer must be equipped with fuel saving devices. This means that a fleet must retrofit all 3 trailers to ensure that each truck-trailer combination will be fully equipped for efficiency, To account for this, Table 3 incorporates the larger investment required to purchase additional tires, wheels (in the case of Wide Base Tires), and aero devices to equip all 3 trailers.

Table 3: Summary of Savings for Two Recommended Packages

ASSUMES: 3 trailers per tractor (To represent industry-average trailer-to-tractor ratio)						
Package	Includes	Fuel Economy Improvement (%)	Cost (C$/truck)	GHG Savings (tonnesCO_2eq /truck-y)	10 Year GHG Savings per Truck (tonnesCO_2eq/truck)	10 Year Cost per GHG Tonne Saved (C$/tonne$CO_2$eq)
Simple, on 50% of trucks	Side Skirts, Fuel-Efficient Duals, Diesel-Electric APU	13%	$ 12,546	23.3	233	53.80
Full, on 100% of trucks	Tractor Aero, All Trailer Aero, Wide-Base Tires, Battery-Electric APU	22%	$ 33,589	39.2	392	85.73

The "full package" of fuel-saving devices applied to an "average" Canadian truck driving 160,000 km/y and idling 1400 hours/y delivers an estimated 22% fuel savings and a greenhouse-gas emissions reduction of 39 tonnes per year. Assuming that the improvements to the truck will last ten years and that greenhouse-gas emissions reductions each year are maintained, investment cost per tonne of GHG "saved" is 86 C$/tonne of GHG. If the entire Canadian fleet of 294,000 trucks were to adopt these energy-efficiency technologies, Canadian truck owners and operators would save 4.1 billion litres of fuel and reduce emissions by 11,500,000 tonnes of GHG each year. This is equivalent to taking 64,000 Class-8 trucks or 2.6 million cars off the road.

RMI also analyzed a simple package of modifications—modifications deemed available, affordable, and achievable in the very short term. These modifications have the potential to reduce greenhouse-gas emissions at a cost of C$54/tonne of GHG. Fuel savings produced by this simple efficiency package are estimated to be 13% and each truck would avoid emissions of 23 tonnes of GHG/y. Assuming this simple package of energy-efficiency technologies were adopted by just 50% of the Canadian Fleet (147,000 trucks), Canadian truck owners and operators would save 1.2 billion litres of diesel fuel and reduce greenhouse-gas emissions by 3,400,000 tonnes of GHG per year. This is equivalent to taking 19,000 Class-8 trucks or 800,000 cars off the road.

Conclusions

Fuel efficiency devices such as retrofittable aerodynamic technologies, low rolling resistance tires, and auxiliary power units can effectively offset efficiency losses from the 2002 Environment Canada and U.S. EPA emissions regulations. Furthermore, the fuel savings from these technologies will result in a significant reduction in greenhouse emissions. The devices recommended are easily adoptable as retrofits and have been chosen because they provide the highest percentage fuel savings with the most consistent test results. While the payback periods for the fuel-saving devices range from 1 to 3 years, the investment costs are significant for truck operators. Providing and developing innovative financing options to mitigate the financial burden on truck operators is one role for government, however there are several others that can aid in implementing this technology wide scale.

History shows that when government takes on a technical, financial, and leadership role in implementing these technologies it stimulates the market and helps to change old myths within the trucking industry, as demonstrated by EPA SmartWay and Natural Resources Canada truck efficiency program results. Concrete action by government provides the temporary assistance and consistent direction needed to jumpstart industry action and to create the desired result when industry obstacles are preventing change. Government can and should act as a catalyst to speed adoption of these technologies on a wide scale.

The "full" and "simple" packages which we have described in this paper with 100% and 50% fleetwide implementation scenarios can result in dramatic savings, especially when implemented on a nationwide scale.

If the entire Canadian fleet of 294,000 Class-8 trucks were to adopt the full package, we estimate that Canadian truck owners and operators would save 4.1 billion litres of fuel and reduce emissions by 11,500,000 tonnes of GHG each year, equivalent to taking 64,000 trucks or 2.6 million cars off the road. Adopting the simple package on just 50% of the Canadian Fleet (147,000 Class-8 trucks), Canadian truck owners and operators would save 1.2 billion litres of diesel fuel and reduce greenhouse-gas emissions by 3,400,000 tonnes of GHG per year. This is equivalent to taking 19,000 trucks or 800,000 cars off the road. These packages demonstrate the benefits that can result from wide-scale implementation of energy-efficient technologies on trucks.

Rocky Mountain Institute

Transformational Trucks: Determining the Energy Efficiency Limits of a Class-8 Tractor-Trailer

Michael Ogburn
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July 2008

Abstract

Feasible technological improvements in vehicle efficiency, combined with "long combination vehicles" (which raise productivity by connecting multiple trailers), can potentially raise the ton-mile efficiency of long-haul heavy tractor-trailers by a factor ~2.5 with respect to a baseline of 130 ton-miles/gal. Within existing technological and logistical constraints, these innovations (which don't include such further opportunities as hybrid-electric powertrains or auxiliary power units to displace idling) could thus cut the average fuel used to move each ton of freight by ~64 percent. This would annually save the current U.S. Class 8 fleet about four billion gallons of diesel fuel and 45 million tonnes of carbon dioxide emissions. The authors' next paper will quantify these improve-ments' apparently attractive economics. Further benefits would include lower shipping costs, bigger profits for trucking companies, fewer tractor-trailers on the road, and fewer fatal accidents involving them. Thus transformational, not incremental, redesign of tractors, trailers, and (especially) both as in integrated system can broadly benefit economic prosperity, public health, energy security, and environmental quality.

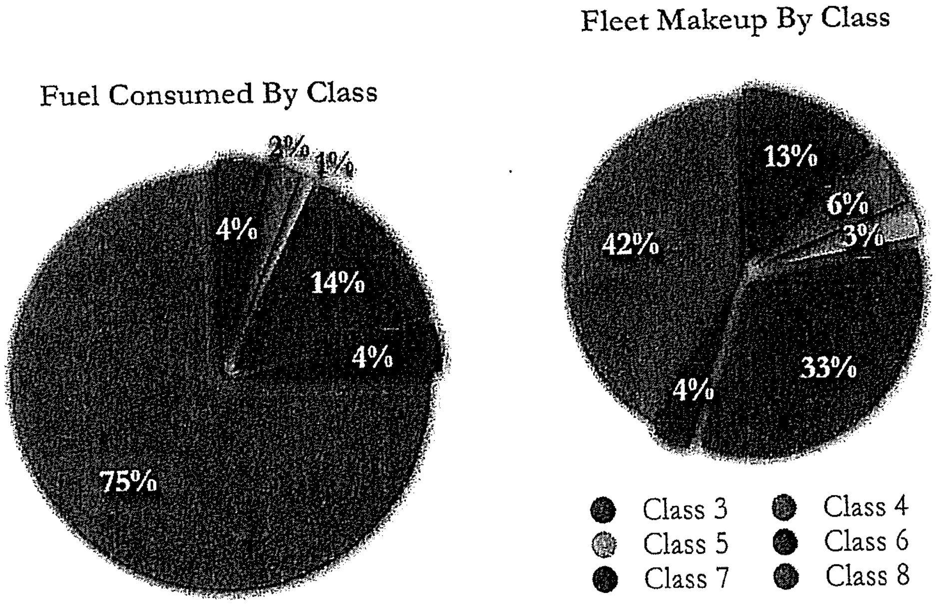
Introduction

High fuel prices are taking a toll on the trucking industry. In 2007, when diesel fuel cost American truckers an average of $2.89/gallon , the U.S. Energy Information Administration predicted it would average $3.21 a gallon in 2008 [1, 2]. In fact, the average price in January 2008 already exceeded this prediction at $3.31/gal and it has only risen since, passing $4.71 in June 2008 [1]. Fuel prices are slashing or reversing fleet owners' profits; many smaller operators are going broke [3]. The ATA estimates that the trucking industry's fuel bill will rise from $103.3 billion in 2006 to over $110 billion in 2007 [4]. Class 8 truck sales are falling [5]. Regulatory pressure is meanwhile mounting to cut fine-particulates, carbon-dioxide, and other emissions. Slower driving, equipment retrofits, and fuel surcharges to customers aren't fully covering operators' increased costs [6].

No matter how higher fuel prices are split between operators and customers, ultimately they decrease national wealth. Moreover, wasted fuel increases oil dependence and depletion, harms energy security, transfers wealth abroad, and destabilizes the economy. Yet correcting fuel inefficiency is typically profitable, both in general and for trucking [7, 8]. Its life-cycle profits offer adopters a competitive advantage, and can cut freight transportation costs for all.

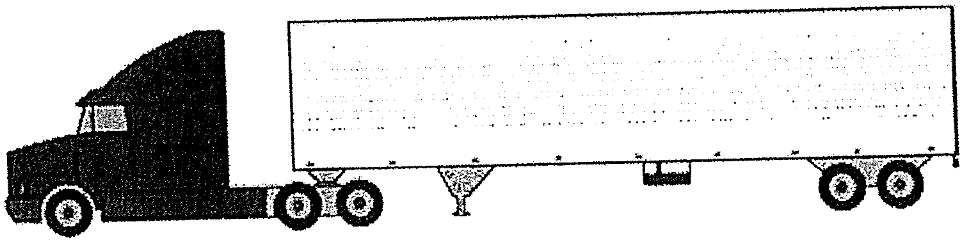
In the United States, transportation uses about two-thirds of all oil. Of total U.S. oil use, Class 7 and 8 trucks used 11.3% in 2000, projected in 2004 to rise to 12.3% by 2025 [9]. This study focuses on Class-8 tractor-trailers, which use 75 percent of the fuel consumed by all U.S. Class 3–8 trucks, as shown in Figure 1 [10].

Figure 1: Class-8 Trucks Account for the Majority (75 percent) of Trucking Fuel Consumed [10]



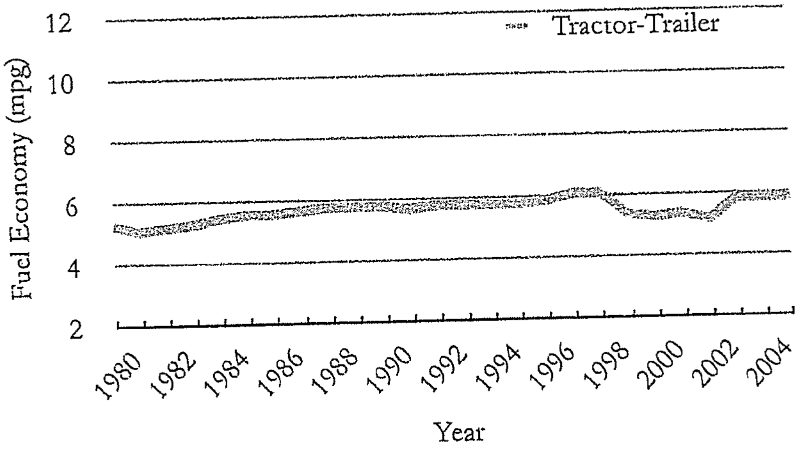
Averaged over its entire lifetime, through many owners and uses, the US Department of Energy finds that a typical U.S. Class-8 tractor-trailer (Figure 2) travels 45,739 miles/y (73,610 km/y) at 5.7 mpg (41.3 l/100 km) [10]. When new, however, it often travels between 100,000 and 150,000 miles/y [11,12]. Our analysis conservatively assumes 100,000 miles/y for efficient new units. The typical tractor-trailer has a 400-hp engine, an aerodynamic drag coefficient C_d of 0.6, dual tires with a rolling resistance coefficient of 0.0073, and an empty weight of 30,000 lb (13,608 kg).

Figure 2: RMI Baseline Tractor-Trailer, $C_d = 0.6$



From 1970 to 2005, U.S. tractor-trailer fuel economy increased by only 0.6 percent per year (Figure 3) [13]. In December 2007, President Bush signed the Energy Independence and Security Act, which sets the first U.S. fuel economy standards for medium- and heavy-duty trucks [14]. This has increased interest in energy efficiency opportunities in heavy-duty vehicles (HDVs). A heavy-duty truck is over 8,500 pounds in the federal jurisdiction and over 14,000 pounds in California [15]. Specifically we will be focusing on Class 8 tractor-trailers.

Figure 3: Fuel Economy, 1980–2005 [13]



We analyze those opportunities in two stages: Step 1 explores available technological efficiency gains, while Step 2 examines the complementary benefits of increasing volume and load capacity, requiring important regulatory changes we explore. Integrating both steps into a whole-system design yields benefits greater than the sum of the parts—if the parts are properly combined through more collaborative design of both tractors and trailers, making conveniently available both new or retrofit efficiency packages that are designed to work optimally together.

Efficiency is measured in Step 1 largely by miles per gallon, but in Step 2, by ton-miles (or, for lighter and bulkier cargoes, "cube"-miles) per gallon. The purpose of a truck is to deliver tons or "cubes" of freight, so raw mpg is an inadequate and sometimes misleading metric: Step 2 can reduce mpg but can haul so much more freight per tractor-trailer that ton- or cube-miles per gallon increase.

Step 1 includes aggressive but achievable improvements in air drag and tire rolling resistance, weight, and engine efficiency, while modestly increasing volume and weight capacity—all known to be technologically and economically feasible. We first reduce the energy needed to move the tractor-trailer, and then shrink the powertrain to match the reduced load and adopt more advanced powertrain technologies.

Step 2 investigates hauling two 48-foot (14.6 m) trailers instead of one and increasing maximum gross vehicle weight rating (GWVR) from 80,000 pounds to 120,000 pounds, so each tractor becomes far more productive when part of a "long combination vehicle" (LCV) or (as the American Trucking Association calls it) "high productivity vehicle" (HPV).

Certain assumptions in Step 1 require a fresh approach—a redesign with no preconceived notions—to accommodate the aerodynamics and tractor-trailer interfaces, but our approach leaves unchanged the truck's basic geometry. We assume that trailers will stay the same length they've been for many years—48 to 53 feet (14.6–16.2 meters)—and that tractor-trailers will remain articulated much as they are now—to ensure both "backward" and "forward" compatibility, so new equipment can be coupled with old. We don't assume radical changes to the standard height, width, and load-floor height common in today's trailers because these would require excessive changes to existing infrastructure (roads, bridges, loading docks, etc.).

Step 1: Improving Platform Efficiency of a Class 8 Long-Haul Tractor-Trailer

Class-8 highway trucks continuously require more than 180 horsepower (hp) (137 kW) to drive at 60 miles per hour (mph) (97 km/h) along a level, windless highway. [20] (Our analysis adopts this speed as typical because such trucks typically spend three-fourths of their operating time at highway speeds.) This power is not the engine power, but is the power required at the wheels after being created by the engine and passed through the transmission and axle, often called "tractive load." Of this tractive load, approximately 100 hp (75 kW), is needed to move the air out of the way, while the other 80 hp (60 kW), is needed just to roll the tires of a loaded tractor-trailer. Available technologies can dramatically reduce both these needs. Their relative importance shifts at different driving speeds because the power to overcome aerodynamic drag rises as the cube of speed.

Since this analysis deals with highway (over-the-road) fuel economy, it considers energy savings only in highway driving, not in driving cycles that also include low-speed operation and stops. Thus two important energy-saving options not counted in this paper are reducing idling time and hybridizing the powertrain. Auxiliary power units (APUs), which provide services like comfort and communica-tions to drivers while the main engine is off, are taken to be standard in the future truck industry, and typically save 8 percent of the total fuel used by a conventionally designed tractor-trailer in long-haul use where an average truck not only drives 100,000 miles/y but also idles overnight 1400 hours/y.

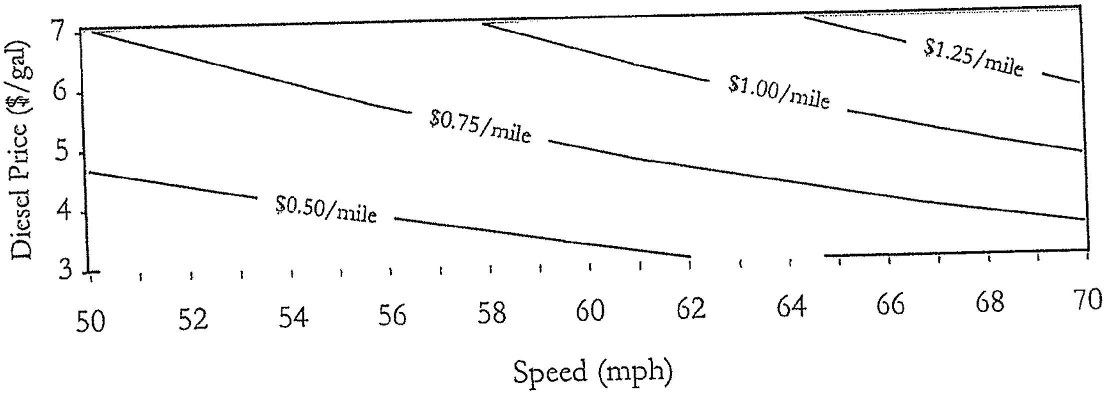
A Brief Look Back

In World War II, General George Patton remarked that "the truck is our most valuable weapon." Since then, the truck industry has seen rapid growth but the truck itself has seen relatively slow technological change. As freight mileage increased rapidly through the second half of the century, the industry was slow to adopt efficiency techniques like the cab roof air deflector. Even today some trucks operate cross-country without this simple device. In 1980 the truck industry was deregulated, leading to an increase in the number of carriers operating border to border, and, after the Surface Transportation Assistance Act of 1983, there was a gradual shift to 53-foot trailers. From 1984 to 2004, the EPA phased in regulations to control oxides of nitrogen (NOx) and particulate matter (PM). These regulations will bring PM and NOx to very low levels through a program that starts in 2007 and ends in 2010 [16]. The benefits to air quality and human health are clearly positive, but the changes represent a large technological challenge for makers of tractor-trailer' diesel engines.

The pressures to adopt APUs are economic and, increasingly, regulatory: in January 2008, the state of California—a leader in heavy-duty tractor emissions regulations—began limiting heavy-duty vehicles from idling for more than five minutes [18]. We also have not considered hybridization because it works best in stop-and-go driving, not in long-haul trucks. On certain urban delivery routes, Eaton and FedEx have achieved a 50 percent fuel efficiency improvement when using hybrid delivery trucks, while Eaton expects just a 3–5 percent fuel efficiency improvement in tractor-trailers in certain highway situations [19].

A final aspect not considered in this analysis is the effect that speed has on fuel economy. Decreasing vehicle speed from 65 mph to 60 mph can improve fuel economy 8%. [54] As diesel prices rise, a fleet operator can keep fuel costs constant by reducing the speed of their trucks. (Figure 4) By incorporating this with changes to logistics costs (delivery schedules, driver wages, etc) a fleet can re-calculate its optimal speed as fuel prices change.

Figure 4: Adjusting Speed to Maintain Fuel Costs[1]



A critical but often overlooked aspect of energy efficiency strategy is the sequence of improvements. Energy efficiency in trucking is traditionally improved by wringing out energy losses from the components with the biggest losses—the engine, idling, and auxiliaries. The DOE's 21st Century Truck Partnership found that the engine's thermodynamic inefficiency wastes 57.9 percent of the energy that the truck uses, auxiliary loads use 3.9 percent, and inefficiencies in the drivetrain are responsible for another 2.4 percent (Figure 5)[20]. If, hypothetically, engine efficiency could be improved 10 percent, you could expect to save about 10 percent in fuel.

This strategy is conventional, straightforward, but suboptimal. A more fruitful approach is to start at the right-hand end of Figure 5, with the energy losses from aerodynamic drag (21 percent) and the tires' rolling resistance (13 percent). Why? Because every unit of energy saved at the wheels, by reducing these two components of "tractive load" (energy required at the wheels to move the vehicle), saves an additional 3 units of energy that needn't be wasted getting it to the wheels. This leverage makes energy-saving efforts most effective at the "downstream" end of Figure 5. Moreover, lower tractive loads don't just save torque and the fuel consumed to produce it, but also make the required propulsion systems smaller, hence cheaper and lighter-weight.

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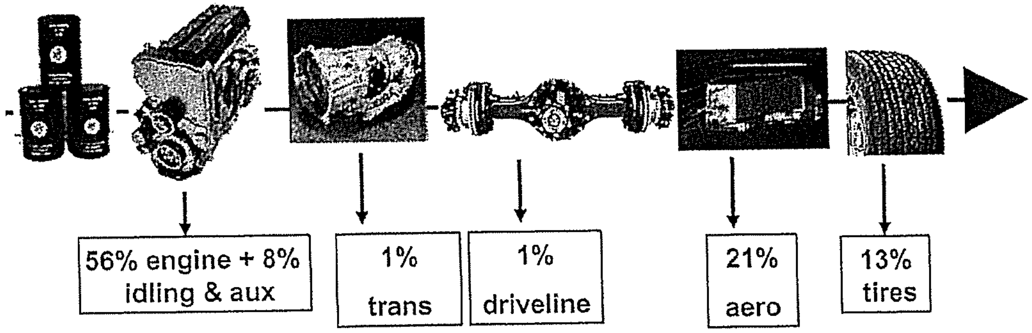
[1] A physics-based road load equation was used to derive the fuel economies for producing this contour plot. Assumptions included in this equation represent an average U.S. highway truck which serves as the baseline for this study: Cd = 0.6, Crr = 0.0073, m = 32,000 kg, pair = 1.2 kg/m3, engine efficiency of 42%, transmission efficiency of 98%, and axle efficiency of 98%.

Figure 5: Energy Use in a Typical Tractor-Trailer [20]



Modestly improving freight-hauling capacity is an even further-downstream improvement than cutting aero and tire drag. We therefore begin with this opportunity, then analyze the main opportunities to reduce tractive load per unit of cargo hauled, then finally examine the upstream opportunities in the powertrain. The much larger capacity increases from Step 2 are considered later.

Design for Reduced Weight and Increased Cubic Capacity

Lighter vehicles save fuel. A typical car weighs roughly 20 times as much as its driver, just 13% of the fuel energy reaches the wheels, and only 6% of the fuel energy accelerates the car (the other 7% is lost to aerodynamic drag and rolling resistance), so only about 1/20th of that 6%, or 0.3%, of the fuel energy end up moving the driver. Fortunately, three-fourths of the tractive load is caused by the car's weight, and energy saved at the wheels leverages sevenfold-greater energy savings at the fuel tank. In contrast, a Class 8 tractor-trailer can haul ~1.5 times its own weight in cargo, and ~34% of the fuel energy reaches the wheels, so about 20% of the fuel energy ends up moving the cargo. Only about two-fifths of the laden gross weight is the empty tractor-trailer itself, vs. ≥95% for the car, but weight saved by lightening the tractor-trailer increases its load-carrying capacity. Thus lightening the truck has less benefit for mpg than in a car, but raises productivity when carrying the ~21% of U.S. cargoes that are limited by weight before volume (i.e., the cargo "weighs out" before it "cubes out").

A tractor's powertrain can be lightened by reducing its required power output (through reduced tractive load or more efficient accessory and auxiliary loads) or by choosing lighter components to deliver a given torque. Combining both methods saves about 3,000 lb (1,361 kg):

- We'll show below that reduced tractive load can provide the same hauling ability up a 2% grade with a smaller and ~1,000 pounds (454 kg) lighter engine
- We'll also show how wide-base tires' lower weight (a benefit additional to their lower rolling resistance) can save approximately 200 pounds (91 kg) per axle, or 800 lb (363 kg) for our baseline truck with four non-steering axles and dual tires.
- Absent extreme conditions, trucks do not require two drive axles. Replacing one drive axle with a non-driven "tag axle" can eliminate two differentials, saving 500 pounds (227 kg).
- Commercially available lighter-weight trailers can save an additional 700 pounds (318 kg).

The slight extra weight of added aerodynamic devices (Table 1) reduces the tractor-trailer's net weight savings from 10 percent to about 7 percent, enabling the tractor-trailer to carry about 7 percent more cargo on the ~21 percent of delivery trips that are done with the vehicle at maximum vehicle weight.

Table 1: Weight change for each modification.

Tractor-Trailer Modification	Weight Change (lbs)
Engine downsize	–1,000 (454 kg)
Rims/tires	–800 (363 kg)
Tag axle	–500 (227 kg)
Lighter trailer	–700 (318 kg)
Subtotal of weight reductions	**–3,000 (1,361 kg)**
Gap seal	+100 (45 kg)
Side skirts	+200 (91 kg)
Rear drag device	+250 (113 kg)
Turbocompounding	+150 (68 kg)
Subtotal of weight additions	**+700 (318 kg)**
Net total	**–2,300 (1,111 kg)**

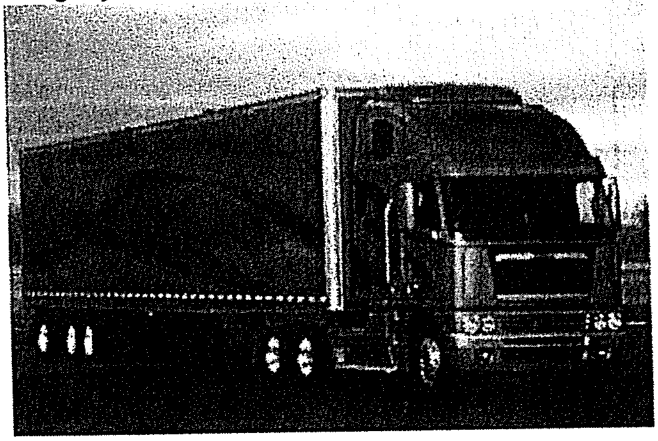
Tractor-trailer combinations are limited to specific heights, widths, and lengths by state and federal Departments of Transportation (DOT) regulations, but their volumetric capacity can still be raised by lowering the floor. Certain trailer floor sections can be thinned by low-profile, high-strength materials and designs. Small-diameter wheels and tires can also slightly lower the vehicle. Finally, a low-profile "fifth wheel" (the industry term for the connecting mechanism) can bring the tractor's connection point with the trailer closer to the tractor's frame. These features can be seen in a demonstration vehicle by Freightliner (Figure 6). All told, experimental evidence from an experienced operator shows that these measures can lower the trailer floor by 6 inches (15 cm), increasing a typical 53-foot trailer's cubic capacity by 5 percent (Table 2)[21]. This allows our Step 1 fleet scenario to haul equivalent freight in the U.S. with 5% fewer vehicles on the road.

Table 2: Six inches of floor lowering can raise a new trailer's volume by 5 percent

	H (in)	W (in)	L (ft)	Volume (ft³)
Current trailer	110 (2.79 m)	101(2.57 m)	53 (16.15 m)	4,012 (113.61 m³)
New trailer	116 (2.95 m)	101(2.57 m)	53 (16.15 m)	4,231 (119.81 m³)

Even more important than these modest initial gains in hauling capacity are the large reductions in tractive load permitted by modern aerodynamic and tire technologies systematically applied.

Figure 6: Freightliner Argosy demonstrates a lowered trailer floor & low profile tires



Aerodynamics

We described earlier how 100hp of the energy needed to move a Class 8 tractor-trailer at 60 mph (96 km/h), more at higher speeds. Thus, in very round numbers, saving a fifth of the aerodynamic drag can save about a tenth of the fuel [23].

Reducing aerodynamic drag is surprisingly easy, yet widely ignored after initial success with cab-roof deflectors (see box: History of Aerodynamic Retrofits). Although tractors' aerodynamics has won more attention, the opportunity is actually about equally shared between tractor and trailer, which respectively cause about 40–50 and 60–50 percent of total aerodynamic drag [23]. Today's market offers two main options:

- sleeker new tractors like the Freightliner Cascadia (Figure 8), whose smoother shape changes the slope of the windshield and recesses lights out of the airstream, and
- retrofittable improvements to trailers.

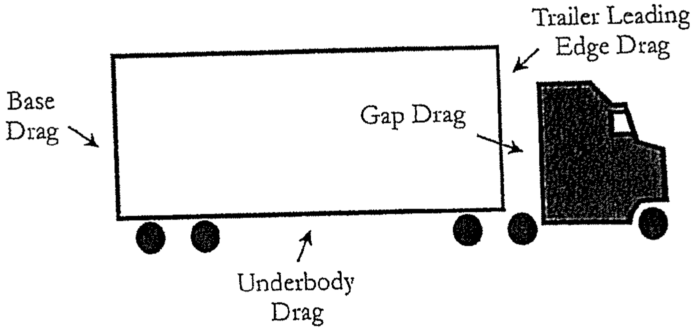
All these opportunities are catalogued by the U.S. Department of Energy's 21st Century Truck Partnership and the Environmental Protection Agency's SmartWay Transport Partnership. Being incremental, they are worthwhile but produce only modest gains, especially since tractor and trailer design are typically dis-integrated, yet the tractor and trailer challenges are closely related (Figure 7): the four most common drag problems for a trailer are the area behind the back of the trailer (the "trailer base"), the area in front of the trailer that is not sheltered by the roof fairing (the "trailer leading edge"), the area beneath the trailer (the "underbody"), and the area between the tractor and the trailer (the "gap"). Thus tractor and trailer aerodynamics cannot be optimized separately.

History of Aerodynamic Retrofits

Origins
The first aerodynamic device was a cab-mounted roof deflector, developed in the 1960s by Airshield [17]. It wasn't until the oil shocks of the 1970s that these technologies were really accepted. They're still not universally used.

Their introduction into the field
In the past, retrofits focused mainly on improving the aerodynamics of the tractor. Modifying the tractor is a comparatively easy first step since an average fleet owns 1 tractor for every 3 trailers. The rising price of diesel fuel is quickly reducing the payback period for trailer add-on aerodynamic devices, making them viable options for saving fuel .

Figure 7: The Four Trailer Aerodynamic Drag Problems



We'll first describe these well-known options, then show how to integrate and extend them by improving trailer aerodynamics at the factory, drastically resculpting the tractor to reduce discontinuities in the airstream, and aerodynamically integrating the tractor and trailer.

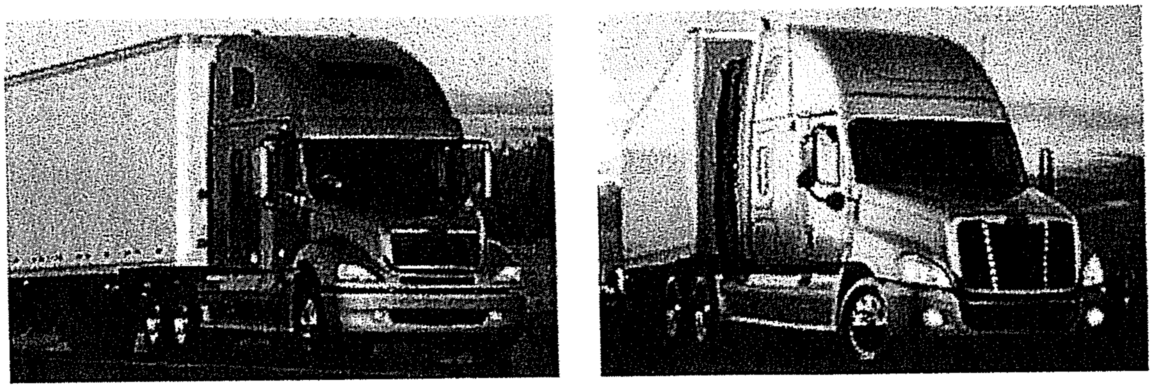
Table 3 shows retrofits proven to improve trailer and gap aerodynamics. Together they reduce the typical tractor-trailer's drag coefficient from a nominal 0.6 only to 0.45.

Table 3: Add-on component drag and fuel increments [22, 23, 24]

		Average ΔC_d (100 kph)
Base drag reduction		
Advanced Transit Dynamics TrailerTails		-0.0612
Trailer leading-edge fairings		
Manac prototype trailer leading-edge frame (includes roof fairing)		-0.0335
Underbody drag reduction		
Aggressive	Freight Wing belly fairing (low rider)	-0.0435
	Laydon Composites main and rear skirts	
Gap sealing		
Fifth wheel forward 254 mm (resulting in what gap width?)		-0.0163
Total Drag Reduction:		**-0.1545**

Further drag can be saved in the tractor (Figure 8), as Freightliner did in its Cascadia vs. Columbia model, saving 3% of total fuel use [25].

Figure 8: Freightliner Cascadia (right) delivers a 3 percent fuel economy gain over its predecessor, Freightliner Columbia (left).



Transformational Tractor-Trailer Path

Much larger drag reductions require a transformational tractor-trailer integrating four key features:

1. a nearly sealed tractor-trailer gap, using deployable four-sided gap sealing (Figure 9);
2. full skirting of the tractor and trailer (equivalent to Figure 10);
3. a rear drag device (boat-tail) approximately 3 feet in length (Figure 11); and
4. a different cab shape with minimal aerodynamic discontinuities.

Sealing the tractor-trailer gap (Figure 9) reduces drag and, like the boat-tail (Figure 11), is especially helpful in crosswinds (See box: Yaw Angle). At low speeds, the four-sided "gap seal" would retract against the cab so the vehicle can articulate around corners. A two-sided prototype version of this kind of device was released by Mack in November 2006. Smooth logistics require that the retractable gap-sealing system allow the tractor and trailer to be detached by normal means, and that new and old tractors and trailers are compatible with one another.

Full skirting of the tractor and trailer has been done in the past, and recently several rear-drag devices (Figure 11) have proven effective in prototype tests. We propose that the tractor be far more aerodynamic and fully integrated with the trailer. It might adopt the "cab-over"[2] designs common in the United States during the 1970s, but other configurations could also meet our drag targets.

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[2] "Cab-over" describes the relative position of the cab and the engine. In a cab-over design the cab is positioned over the engine.

Figure 9: Gap Seal Prototype [26]

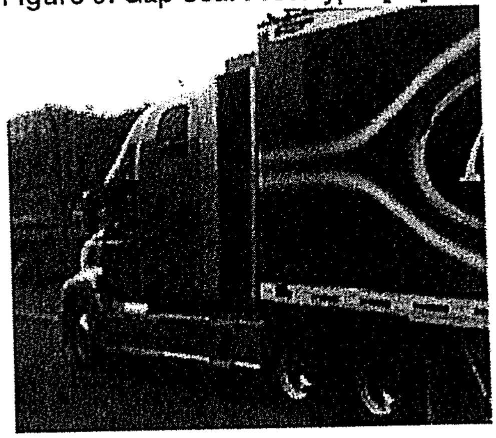
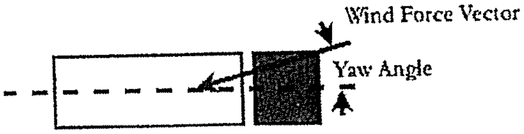


Figure 10: Full Skirting Device [27]

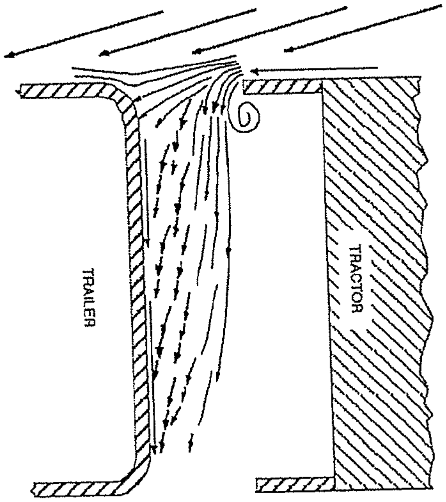
Figure 11: Rear Drag Device [28]

Yaw Angle, Cross-gap flow, and its affect on drag

When a tractor-trailer moves through the air, any cross-wind creates what is known as a "yaw angle" in the oncoming air.



This yaw angle causes air to move from one side of the vehicle to the other through the gap between tractor and trailer, a phenomenon known as cross-gap flow shown below [22]. Depending on the direction and strength of the cross wind, this cross gap flow can significantly increase the aerodynamic drag of a tractor-trailer.



Source: Solus, [22]

Gap sealing systems as shown in Figure 9 can eliminate this type of drag. Rear drag devices shown in Figure 11 also reduce drag in yaw situations by controlling airflow around the base of the trailer.

Figure 12. Likelihood of yaw angle [29].

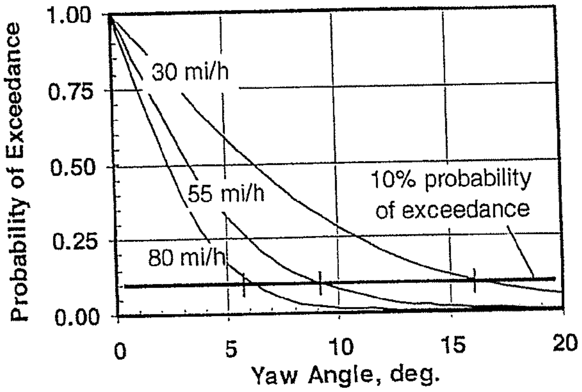
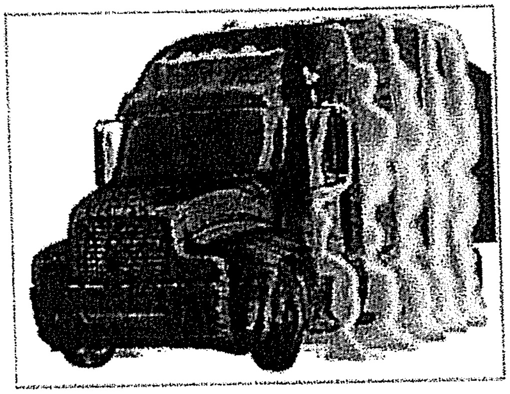


Figure 13: Pressure discontinuities on the tractor's grill, hood, windshield, and roof [30]



The best design will incorporate the features of Figures 9–11 while avoiding the pressure discontinuities of Figure 13, where red areas on the windshield and grill/bumper reveal multiple energy-wasting pressure buildups that should be reduced in both number, size, and severity. Such a design is illustrated by an articulated bus with dimensions similar to those of a heavy truck, as seen in Figure 14. A wind-tunnel test by National Research Council Canada (NRC) on a Prevost articulated bus demonstrated a coefficient of drag of just 0.384. In its stock form, this bus incorporates a gap seal, low sides that emulate tractor and trailer side skirts, and a flat front end that eliminates the multiple aerodynamic discontinuities caused in a tractor by the horizontal separation between hood, windshield, and sleeper roof [17]. When this heavy vehicle was tested with minor aerodynamic modifications, including the addition of a rear drag device and the removal of its mirrors, the modified articulated bus (Figure 14) achieved 0.311 C_d—barely over half that of a typical Class 8 tractor of similar size.

Table 4: Measured average coefficient of drag of a Prevost bus after incremental changes

	Average ΔC_d (60mph)
Single Prevost Bus	0.384
Articulated Prevost H5-60 bus	0.418
Articulated Prevost H5-60 bus, no mirrors	0.344
Advanced articulated bus	0.311

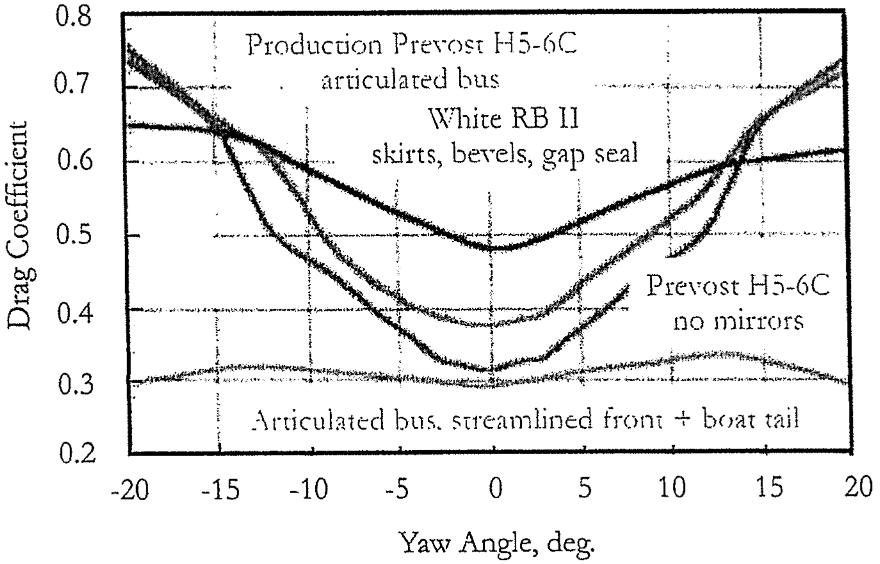
Figure 14: Prevost H5-60 Bus with C_d of 0.384, later reduced to 0.311

This bus's design addresses all four of the aerodynamic trouble areas in a tractor (Figure 7) with integrated solutions that can all apply to a Class 8 tractor-trailer. While we were unable to locate a Class 8 truck test where this exact combination of devices was analyzed, we are confident that a tractor-trailer applying these principles and other aerodynamic innovations would be fully capable of achieving a coefficient of drag of ~0.3, although it might look quite unfamiliar.

To be sure, this bus isn't designed to haul heavy loads up long grades, so it lacks the tractor's big radiator. But the truck's reduced tractive load reduces engine size and cooling needs by one-fourth, as discussed below, from a nominal baseline design; turbocompounding would further reduce the cooling needed per horsepower delivered; and the resulting drag can be made small or negative by aerodynamic ducting of cooling air from positive- to negative-pressure zones. Radiator airflow can also be actively managed with a simple shutter system in the grill to minimize real-time drag by opening to maximize flow on long steep grades where speed is low while closing to minimize flow while cruising at high speed; the vehicle aerodynamics community is considering this option for light- and heavy-duty vehicles.

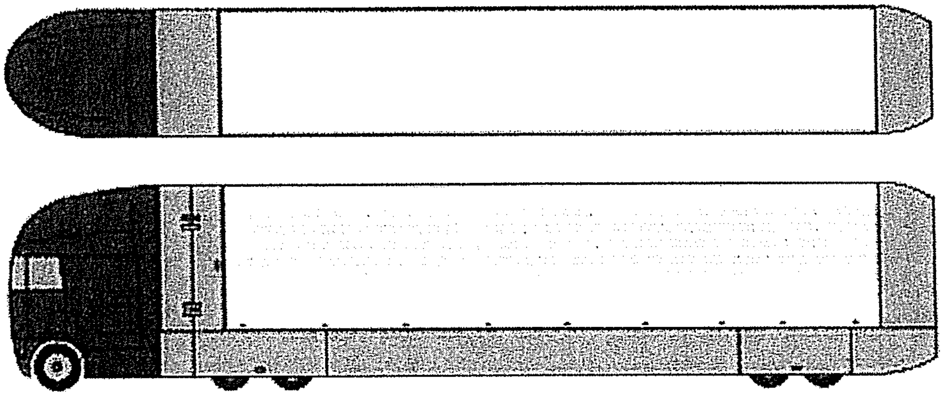
Figure 16's dependence of drag on yaw angle is important. Driving in crosswinds makes air swirl through the tractor-trailer gap, causing more turbulence and drag. Sealing the gap and adding a rear drag device can nearly eliminate this dependence (bottom curve). Figure 12 further demonstrates that a highway truck is <10% likely to experience >10° yaw while operating at 55 mph, so higher yaw angles are a rare U.S. design condition. Note that at high yaw angles, total drag increases due to greater effective frontal area, which must be multiplied by C_d.

Figure 16: Drag Coefficient of the Prevost H5-60 *vs.* a Typical Tractor-Trailer Retrofitted with the Aerodynamic Improvements in Table 4 [17]



A tractor trailer designed with all of the above aerodynamic considerations may look like the artist's rendering shown in Figure 15. This sketch incorporates one possible embodiment of the important aerodynamic features we include in our Step 1 analysis while retaining the basic shape and function of an articulated tractor trailer.

Figure 15: Artist's Impression of a Tractor-Trailer Incorporating Integrated Design Methods



Low-Rolling-Resistance Tires

New technologies can reduce the energy required to overcome the rolling resistance of a tire, caused by friction between and within its many structural layers as the shape constantly shifts between round and flat. The energy lost to heating the tire and road can be reduced by changing the rubber compound, other materials, and construction (layering). Changing the types, quantities, and configurations of all the tire's materials offers considerable latitude in such characteristics as longevity, stiffness, rolling resistance, heat tolerance, traction, and handling. The tire is an exception-ally complex structure and must be optimized in concert with the vehicle design as well as driving conditions, but there is still a well-established potential to reduce rolling resistance without compro-mising other qualities, as illustrated by the gap between the best-in-class and average tires on the market. That is the gap our analysis exploits; potential further gains are possible but not assumed.

Tractor-trailer operators can also replace dual tires with a wider-tread single tire, often called a wide-base tire. Wide-base tires do the work of separate dual tires, with the same performance and safety, but they weigh less because they have fewer sidewalls and have other construction changes. An axle equipped with wide-base tires on aluminum rims is typically 200 pounds (91 kg) lighter than typical dual tires with steel rims. Michelin performed tests where they blew out the steer, drive, and trailer tires and found no significant difference in performance when compared to duals [31].

Combining advanced construction and rubber compounds with wide-base tire designs can save 5 percent of a typical Class 8 fleet's fuel [32]. We assume the following coefficients of rolling resistance (C_{rr} in automotive parlance) for average and best-in-class tractor-trailer tires (Table 5):

Table 5: Portfolio Assumptions for Coefficient of Rolling Resistance [20, 33]

Portfolio	Coefficient of Rolling Resistance
Baseline	0.0073
Step 1	0.0052

Powertrain

These aerodynamic and tire improvements can together save two-fifths of tractive load (Table 6) as calculated from vehicle physics (Appendix 1). This lower load then permits a smaller engine with less weight and cost (Table 6).

Table 6: Efficient tractor-trailers need less pulling power

Portfolio	Operating Conditions
Baseline	185 horsepower road load (138 kW) @ 60 mph (97 km/h) steady state
Step 1	110 horsepower (82 kW) road load @ 60 mph (97 km/h) steady state

The average U.S. Class 8 tractor-trailer is powered by a nominal 400-hp (298 kW) engine. The difference between that peak power output and "steady-state" horsepower is called "reserve torque" and is available for acceleration during passing and hill climbing. Because we have lowered the steady-state horsepower requirement by 73 hp (54 kW), the Transformational Truck characterized in Step 1 will be able to use a 300 hp (224 kW) engine to achieve the same normal performance as a conventional truck using a 400-hp engine (298 kW). We assume no efficiency benefit from the smaller engine, but it does weigh about 1,000 pounds (454 kg) less, and cost about $2,000 less [34, 35].

Matching engine performance to required steady-state horsepower may significantly reduce hill-climbing speed at very steep grades, but need not do so at ordinary grades. RMI's vehicle-physics analysis (Appendix 1) confirms that with Step 1 improvements, a 2 percent grade can be sustained at 60 mph (97 km/h) at full GWVR with a 300-hp engine turbocompounded to 330 effective hp—the same speed on a 2% grade that originally required a 400-hp engine in the baseline tractor-trailer. That is, the decrease from 400 to 300 hp is offset by reduced aerodynamic drag and rolling resistance, plus turbocompounding.

Increasing engine efficiency and reducing engine auxiliary loads, such as fans and pumps, is a key focus of the DOE 21st Century Truck Partnership. Using a baseline of 42 percent engine efficiency, we propose two well-understood improvements to engines to increase their efficiency. Turbo compounding increases nominal thermal efficiency from 42 to 45 percent and peak engine power by 10 percent; it is commercially available in North America, notably in the new Detroit Diesel DD15. (Some turbocompounding innovations are expected to yield further improvements.) An additional increase in thermal efficiency, from 45 to 48 percent, can come from truck engine friction reductions, auxiliary savings, and combustion improvements, all based on 21st Century Truck Partnership predictions. This new peak engine thermal efficiency of 48 percent for Step 1 is below the 2010 target of 50 percent and far below the DOE 2013 stretch target of 55 percent.

Conclusions, Step 1

Our findings align well with those of DOE's 21st Century Truck Partnership. It found that the current 6.8-mpg fleet could be improved to 11.5 mpg. Our analysis shows that an improvement from 6.5 to 12.3 mpg (at 60 mph) is feasible through tractor-trailer integration and whole-system design. Our conclusion is confirmed by recent track tests of a Mercedes-Benz Actros tractor-trailer that demonstrated 12.4 mpg hauling a 25-tonne payload at 50 mph [37]. This saving is worth $30,000 per year per truck,[3] or when spread across a baseline fleet of 500,000 trucks, to $15 billion worth of diesel fuel and 40 million metric tons[4] of CO_2 equivalent saved. Table 7 below summarizes these results. To achieve this savings, RMI considers the aerodynamic goal to be critical, requiring attention from the entire industry. This target is also perhaps the most challenging, though not technically-speaking, of the improvements we recommend as it requires collaboration among the segmented businesses of truck makers and trailer makers, in coordination with the needs of the customer base.

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[3] Assuming implemented on 500,000 trucks that travel an average of 100,000 miles per year at 60 mph. U.S. average price of diesel is $3.94/gal [36].

[4] Using the following CO_2 eq. for CO_2, CH_4, and N_2O respectively, 2.73 kg/L, .00325 kg/L, and .02384 kg/L.

Table 7: Summary of Results of Step 1

	Baseline	Step 1
No. long-haul tractor-trailers	500,000	475,000
Distance traveled (miles/y)	100,000	100,000
Fuel economy (mpg)	6.5	12.3
Freight efficiency (ton-mile/gal)	130	275
Fuel used (gal/y)	7,700,000,000	3,900,000,000
Fuel saved (gal/y)	n/a	3,800,000,000

Step 2: Increased Use of Long Combination Vehicles (LCVs)

Step 1 proposes a vehicle that moves freight more efficiently primarily by reducing the amount of drag it creates. In contrast, Step 2 explores hypothetical changes regulations so that trucks can haul more freight on each trip. To do this we propose that nationwide truck length and weight laws allow trucks to haul two trailers on certain roads. Step 2 includes the productivity benefit from adding a second trailer and increasing the maximum allowable vehicle weight to 120,000 pounds, while including the vehicle efficiency changes described in Step 1.

In fact, the United States has some of the lowest weight limits of western countries. This can create bottlenecks for freight. Canada allows combination vehicles up to 138,000 pounds; Scandinavia[15], up to 130,000 pounds. The U.S. Department of Transportation's 1995 Comprehensive Truck Size and Weight Study found that "Europe specifies a unique GVW limit of 97,000 pounds for a six-axle semitrailer combination handling an international container. Mexican and Canadian general weight limits are high enough to accommodate fully-loaded ISO containers.

Canada's regulations also permit configurations which can handle one-20 foot and one-40 foot fully loaded containers on the same vehicle, or three-20 foot containers nearly fully loaded [sic]."

LCV Use In The U.S.

Adding a second or a third trailer to Class 8 trucks is common in certain states, and is a simple way to deliver more goods per trip. Because many trucks in the United States are loaded to capacity in volume but not in weight, adding a second trailer allows additional goods to be carried. Step 2 of this study proposes double 48-53-foot trailers.

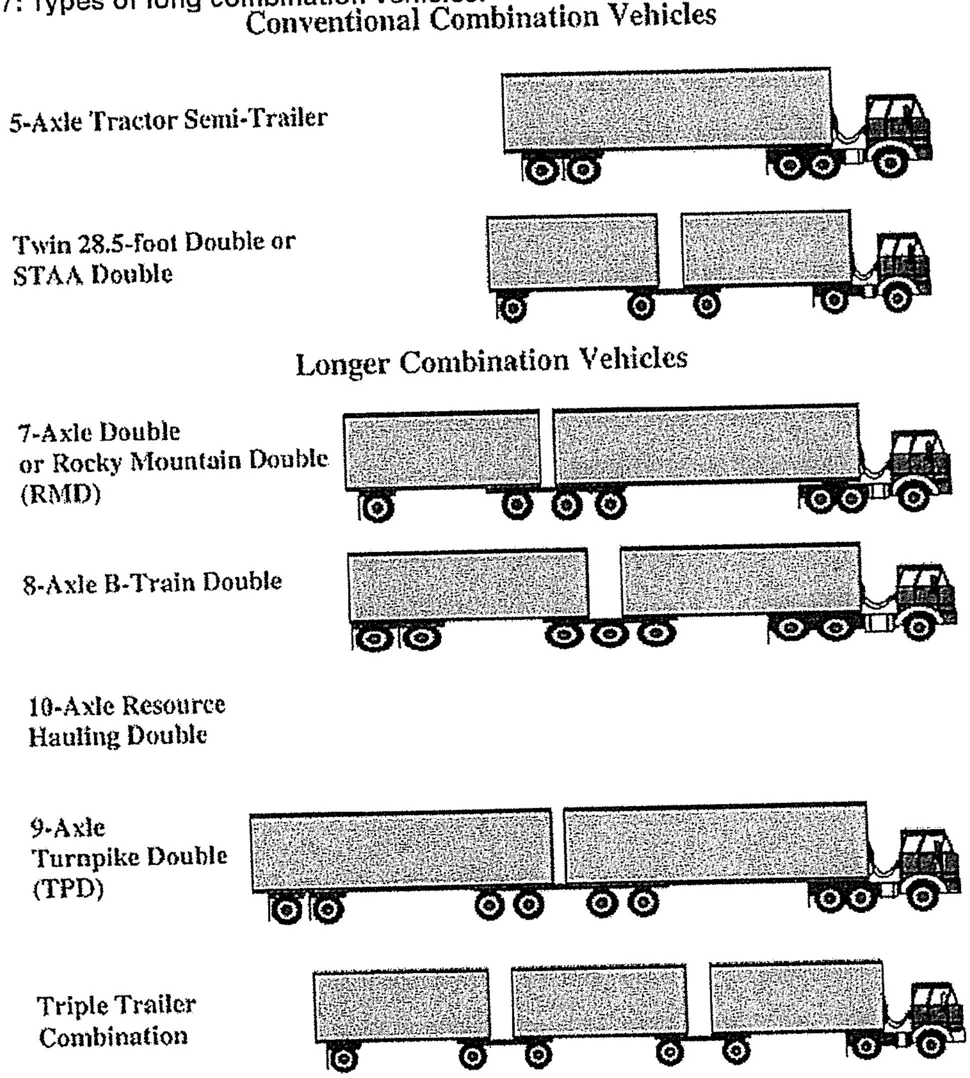
Table 8: Long Combination Vehicles in 13 North American States [38]

States	Truck Tractor and Two Trailing Units		Truck Tractor and Three Trailing Units	
	Length (ft)	Weight (1000 lb)	Length (ft)	Weight (1000 lb)
Colorado	111	110	115.5	110
Idaho	95	105.5	95	105.5
Kansas	109	120	109	120
Montana	93	137.8	100	131.06
Nebraska	95	95	95	n/a
Nevada	95	129	95	129
North Dakota	103	105.5	100	105.5
Oklahoma	110	90	95	90
Oregon	68	105.5	96	105.5
South Dakota	100	129	100	129
Utah	95	129	95	129
Washington	68	105.5	n/a	n/a
Wyoming	81	117	n/a	n/a

Long combination vehicles (LCV) are defined as multi-trailer combination vehicles operating on the U.S. "National Network" and weighing more than 80,000 pounds (36,287 kg) GWVR. Today, all 50 states allow double 28-foot trailers, and 22 states allow trucks to weigh more than 80,000 pounds (36,287 kg) (the U.S. Federal maximum). By harmonizing laws to permit higher weights and longer vehicles, U.S. truck fleets could deliver more freight per trip, using less fuel per ton-mile delivered.

As seen in Figure 17, LCVs in the United States take many forms depending on many circumstances, including regional infrastructure, freight demand, and company logistics. This study, emphasizing long-haul economics, evaluated a combination vehicle whose available data for vehicle productivity, vehicle stability, and vehicle safety overlapped: two 48-ft trailers weighing up to 120,000 pounds, commonly known as a "turnpike double." That's more broadly defined by the Department of Transportation as a tractor pulling two 48-ft trailers or, in Canada, two 48–53-ft trailers. We recommend that broader regulations permit both 48-ft and 53-ft trailers in the U.S. because a large portion of freight in North America is currently hauled on 48–53-ft trailers that could be hooked together with little additional equipment.

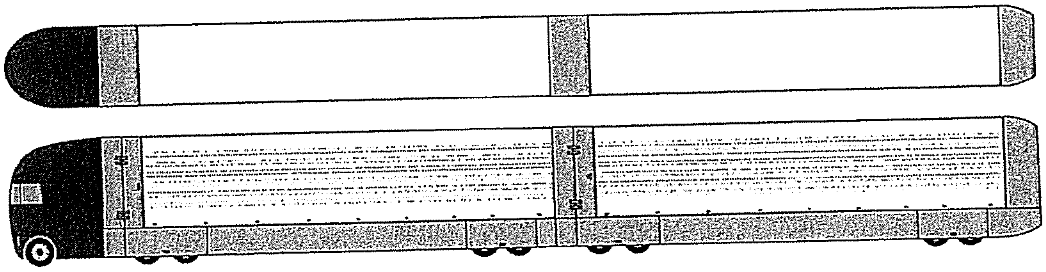
Figure 17: Types of long combination vehicles.



Assumptions, Step 2

Our analysis applies Step 1 efficiencies before Step 2 combinations. A turnpike double has two aerodynamic gaps to seal, not one. To seal the gap between the two trailers, we propose adjusting the aerodynamic surfaces on the first trailer's rear drag device: actively changing the panel angles could continuously optimize the fit while driving around curves. The second trailer's rear drag device will serve as the rear drag device for the entire combination vehicle. Clearly, the tractor's miles per gallon will drop when towing a second trailer whose extra capacity nonetheless delivers more total ton-miles per gallon despite the second trailer's empty weight, cargo weight, aerodynamic drag, and rolling resistance. A recent study by ATRI evaluates this net effect based on the cargo's weight and volume .

Figure 18: Schematic of one possible version of a fuel-efficient turnpike double.



The American Transportation Research Institute (ATRI) recently released an update to its study "Energy and Emissions Impacts of Operating Higher Productivity Vehicles." That study used widely accepted modeling methods—notably Cummins's Vehicle Mission Simulation Tool—to identify the benefits of changing truck size and weight regulations. The study compared today's common five-axle tractor-trailers and a double-trailer configuration with various other combinations of length and weight. Taking into account the drop in miles per gallon (mpg) when towing a second trailer, the study calculated fuel saved per ton-mile of delivered freight. Though the tractor's mpg actually went down, that was offset by the truck's hauling twice as much freight as with a single trailer.

Analysis, Step 2

ATRI found that where 120,000-pound GVWR is permitted, a turnpike double could haul additional freight with 15–39 percent less energy per ton-mile than a standard single (Table 9). In a volume-limited ("cube-out") scenario, adding the weight of a second trailer was assumed to double the amount of cargo delivered without exceeding GVWR. In a weight-limited ("weigh-out") scenario, the cargo was assumed to be dense enough to make the standard single weigh a maximum 80,000 pounds, so little additional cargo of similar density could be added to the second trailer, reducing the fuel saving per ton-mile to only 15 percent. For simplicity, ATRI did not analyze the potential for sophisticated logistics to optimize the capacity increase by mixing high- with low-density cargoes.

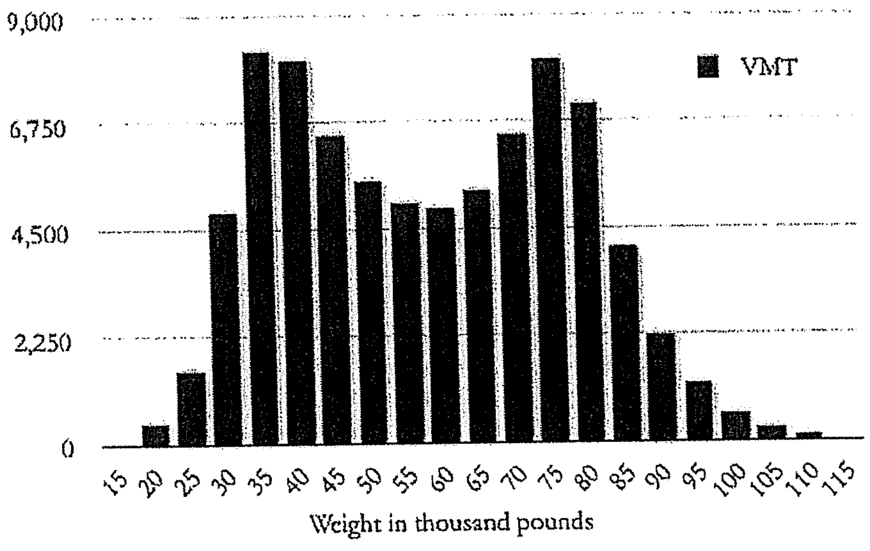
RMI's road load analysis incorporates the increased air drag associated with a longer vehicle [17], its higher weight, and new empty weight to compute the resulting fuel economy. An LCV incorporating our Step 1 design recommendation delivers an estimated 8.7 mpg which is lower, as expected, than a single trailer. However, the increased delivery of goods more than makes up for this, resulting in an increase in freight efficiency of 2.5x over our baseline vehicle.

Table 9: Configurations and fuel savings

Configuration	Description	Percent improvement in ton-mile/gal
Baseline configuration (Traditional tractor-trailer)	Single trailer, 5-axle combination vehicle, 80,000 lbs max. GVWR	N/A
Turnpike double adopted by a volume-limited fleet	Two trailer, 9-axle combination vehicle, 120,000 lbs max. GVWR, operating at approx. 100,000 lb	39%
Turnpike double adopted by a weight-limited fleet	Two trailer, 9-axle combination vehicle, 120,000 lb max. GVWR, operating at 120,000 lb	15%

To estimate the impact of these Step 2 improvements in the fleet, we must assume how many U.S. freight ton-miles could reasonably be shipped in turnpike doubles. About 63 percent of ton-miles are traveled on highways, the rest in urban areas [38]. Since congestion and infrastructure constraints might make turnpike doubles problematic in cities, we conservatively assumed that LCVs could carry 63 percent of all U.S. ton-miles, with the remainder carried by our Step 1 tractor-trailer. We also assumed that 80 percent of ton-miles are volume- and 20 percent weight-limited, consistent with Figure 19, which shows that 21 percent of vehicle-miles traveled by 5-axle tractor-trailers weighing up to 80,000 pounds were in fact laden to 75–80,000 lb [39].

Figure 19: U.S. tractor-trailer VMT, in millions of miles, allocated by total vehicle weight for 5-axle tractor-semitrailer combinations [39]



Operational Considerations

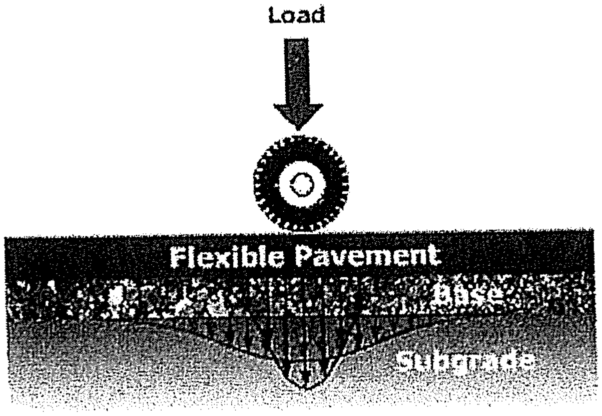
Long combination vehicles require bigger turning radii, wider turning lanes at intersections, a different ratio of trailers to trucks, and probably a different logistical dispersion of drivers and equipment to meet shippers' demands. We also recognize a need to understand the infrastructure needed for parking trailers before entry into cities as a single combination vehicle; to explore the impact on bridges; and to consider changes in wear on road surfaces. Lastly, LCVs will affect road safety, both because they interact differently with traffic and because they will reduce the total number of tractor-trailer trips.

Infrastructure Impacts: Pavement subhead to "LCV considerations"? & same below
Pavement wear depends less on gross vehicle weight than on its distribution: on the configuration of the axles and how they distribute the load on the pavement. The farther these axles are spaced, the more they behave like a separate "loading" for pavement impact analysis or highway design. "Equivalent single-axle loads" (ESALs) are used to describe this distribution.[5] An ESAL expresses the amount of stress on the pavement caused by an 18,000-pound loading on an axle. Table 10 (page 27) shows payload tons per ESAL for three configurations at various nominal weights, indexed to a five-axle semi-trailer weighing 80,000 pounds (shown as 100 weight units).

Pavement Types

Flexible pavements are surfaced with bituminous materials. Their surface and base deflect under load, then a base layer distributes and transmits the load to the subgrade.

Figure 20: Flexible Pavement Load Distribution [40]



Rigid pavements are surfaced with concrete whose stiffness spreads the load over a bigger area.

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[5] It should be noted that although ESAL is the unit most often used, it does not differentiate between fatigue and rutting and cracking like the load equivalency factor (LEF) does.

Figure 21: Rigid Pavement Load Distribution [40]

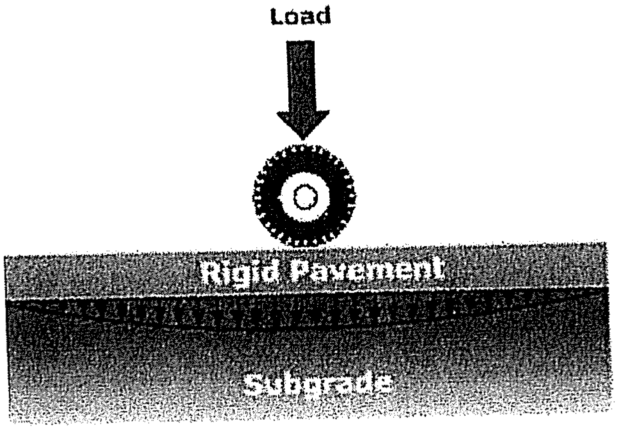

Table 10: Evaluating Axle Configurations Based on Payload Tons Per ESAL[6] [41]

Axle Configuration	GVW	Payload Tons Per ESAL (indexed: 80,000 pound CS-5=100 units)	
		Rigid Pavement (10-inch thickness)	Flexible Pavement (structural number 5, terminal PSI 2.5)
5-axle Tractor Semitrailer	80,000	100	100
	85,000	81	83
6-axle Double-Trailer Combination (STAA Double)	80,000	221	148
	97,000	120	86
9-axle Double-Trailer Combination (Turnpike Double)	95,000	380	333
	129,000	139	139

The nine-axle turnpike double tractor-trailer configuration we propose can carry more payload per unit of pavement damage than can the baseline single-trailer combination: 3.8 times as much on rigid or 3.33 times as much on flexible pavements. Thus at least this LCV configuration should markedly reduce highway wear, because its number and spread of axles increases faster than its load.

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[6] The structural number determines the total number of ESALs that a particular pavement can support. Present Serviceability Index correlates ridability to pavement measures such as slope variance and cracking. Terminal PSI is the end-of-life Present Serviceability Index.

Infrastructure Impacts: Bridges

Adding turnpike doubles to the U.S. fleet will make the fleet smaller but heavier, requiring evaluation. Bridges' load ratings are typically either 55 percent or 75 percent of the "yield stress" at which they start to bend irreversibly. Changing a truck's weight changes the moment, shear, and fatigue stresses it exerts on a bridge, proportionally to its weight, its axle loading, or closer axle spacing that concentrates the load into a shorter span. Classically, only steel bridges are susceptible to fatigue, but some studies suggest that commonly used prestressed concrete spans, if overloaded, are also susceptible. Experimental data and fracture mechanics principles have shown that for steel, fatigue damage is proportional to the cube of the stress range amplitude—the maximum range of stresses created as the vehicle passes [42]. Moment (bending) forces are predominant in bridge design and are often used as a proxy for shear and fatigue stresses. Worst-case moment forces are used to ensure that turnpike doubles can cross safely.

To determine LCV fleets' potential impact on bridges, most studies use states' 55–75-percent-of-yield-stress ratings, or an intermediate value like the 68.8 percent used by the Federal Highway Administration (FHWA). This range of assumptions can drastically change the number of bridges needing repair or reinforcement to accommodate LCVs, so there is a consensus that infrastructure would need improvement but not on how much. In 1991, the Transportation Research Board published a study showing $9.2 billion (2007 $) in bridge improvements to make rural U.S. bridges safe for turnpike doubles[7], but using a higher percent than their 55 percent of yield stress could greatly reduce this [43]. This uncertainty doesn't seem important, since our assumed Step 2 adoption of LCVs, assuming efficient turnpike doubles to be representative, would save the U.S. an additional (beyond Step 1) $2 billion worth of $3.94/gallon diesel fuel per year. However, the issue merits further study, because Appendix A of the DOT Comprehensive Truck Size and Weight Study says that both simple GVWR rating and the Federal Bridge Formula B covering LCVs may be insufficient. That DOT study found that turnpike doubles at 128,000 lb GVWR (more than our assumed 120,000 lb) would cause up to 22% more stress on a bridge than today's common single-trailer tractor-trailers [44]. Since many existing bridges need repair just to carry today's loads reliably, $9.2 billion, the marginal cost of upgrading them for LCVs should be assessed against LCVs' marginal benefits.

Road Geometry

An LCV must fit on the road, through intersections, and around curves. The American Association of State Highway and Transportation Officials (AASHTO), which recommends road geometry standards, notes that these may not always suffice for turnpike doubles [45]. One area of concern is "offtracking." Depending on the wheelbase between the tractor and trailer, and the number of articulation points, offtracking may occur when the swept path width exceeds the lane width, and differs at low speed (Figure 22) and high speed (Figure 23).

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[7] Assuming 129,200 lbs per turnpike double.

Figure 22: Low speed offtracking. [46]

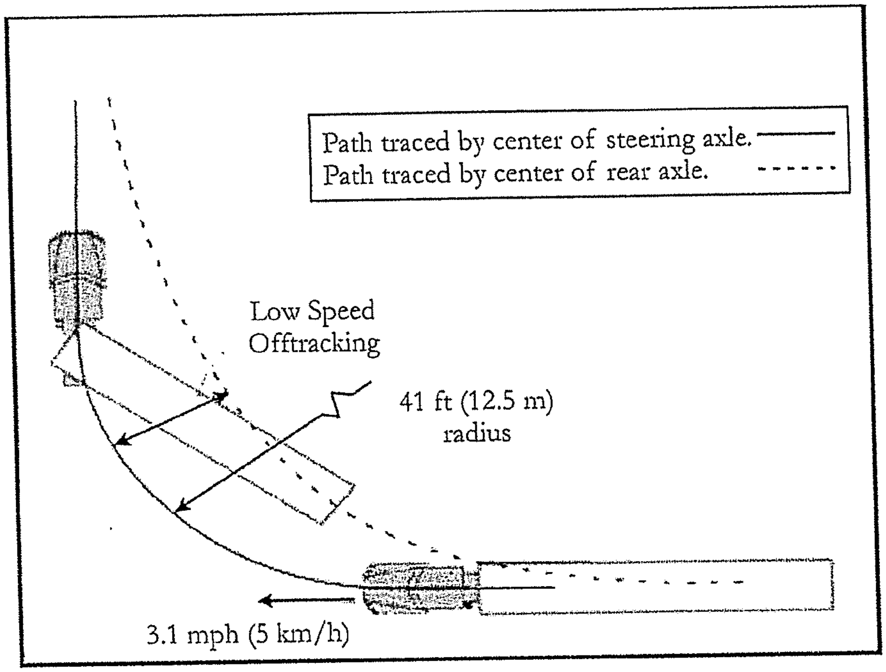

Figure 23: High speed offtracking. [46]

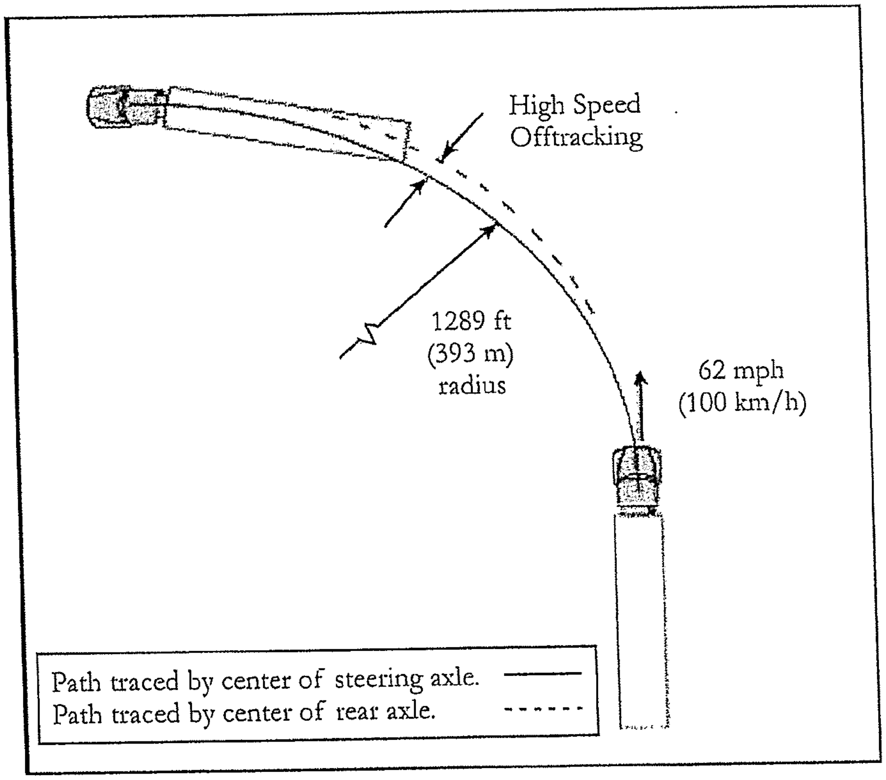

Table 11 shows how the truck making the tightest turn at the lowest speed will experience the most offtracking, and how a turnpike double may require more turning space than a single.

Table 11: Comparison of maximum swept path width of the semi-trailer and turnpike double for three different scenarios and two different speeds.[8,9] [46]

	Maximum Swept Path Width (Feet) at Design and Very Slow Speeds on the Sharpest Horizontal Curve Allowed by AASHTO Design Policy		
Design Speed (mph)	30 mph	40 mph	60 mph
Curve Radius (feet)	273 ft	509 ft	1348 ft
5-Axle Tractor Semitrailer	11.88 ft/13.65 ft	9.43 ft/11.12 ft	8.5 ft/9.3 ft
9-Axle Turnpike Double	14.29 ft/16.69 ft	10.5 ft/12.83 ft	8.5 ft/10.05 ft

In a Department of Transportation study, turnpike doubles at certain interchange ramps offtracked 20 percent more than five-axle 48-foot semi-trailer combinations. AASHTO therefore recommended in 1997 that when LCVs are driven on "moderate to severe curves," pavement widths should be "increased to prevent encroachments." Table 11 shows that for the worst-case scenario, the turnpike double required a lane 2.5 feet wider lane than the current norm to prevent offtracking at design speeds. At low speeds, such as those that would occur in normal urban traffic, the offtracking is worse. On routes used by turnpike doubles lane width needs to be increased to accommodate these offtracking requirements. The marginal cost of this improvement has not been assessed, but again would need to be compared with marginal benefits.

Vehicle Safety and Equipment Performance

A common concern with LCVs is vehicle stability and control. However, certain characteristics of a turnpike double actually make it safer and more stable in certain respects than the commonly used A-train doubles (Figure 24 below).

Stability depends on many attributes, including the load's center of gravity, the vehicle's track width, how the second trailer is connected, and suspension and tire properties. "Static roll stability" (SRS) measures a vehicle's tendency to roll over while turning at constant speed. The harder it is to lift a wheel off the ground, the less susceptible the vehicle is to rollover, so higher SRS values are good. A turnpike double has an SRS comparable to a typical 80,000-pound tractor-trailer's—about 0.3 g (~11 ft s–2) of acceleration, vs. ~0.8 g (~25 ft/s^2) or higher for a typical car, so the common perception that tractor-trailers are prone to rollover is correct, at least relative to cars, much as many SUVs are less stable than sedans.

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[8] The speed that an interchange is designed for is the design speed.

[9] The last two rows indicate maximum swept path at design and very slow speeds. (maximum swept path at design speed/maximum swept path at very slow speeds)

Table 12: Evaluation Criteria for Safety Measures.[10] [47]

	Evaluation Criteria
SRS	SRS<0.3: very poor 0.3–0.35: poor 0.35–0.4: good SRS>0.4: excellent
Rearward Amplification	Values of 2 or less indicate acceptable performance.
Load Transfer Ratio	Should not exceed 0.6

Table 13: Evaluation of LCVs based on SRS, rearward amplification, and load transfer ratio, highlighting safety differences between STAA doubles and turnpike doubles [47].

VEHICLE STABILITY (SHADED BOXES EXCEED RECOMMENDED LIMITS)		Static Roll Stability (higher is better)	Rearward Amplification (dynamic; lower is better)	Load Transfer Ratio (dynamic; lower is better)
Legal Nationwide	Tractor and Single-Trailer, van, 80,000 lbs	0.36	1.244	0.5447
	STAA double: van, 28x28, 80,000 lbs	0.377	2.15	0.919
Legal in Certain States	Turnpike double: van, 45x45, 129,000 lbs	0.376	1.37	0.5599
	Turnpike double: van, 48x48, 129,000 lbs	0.376	1.28	0.524

"Rearward amplification factor" and "load transfer ratio" measure a vehicle's susceptibility to rollover during evasive maneuvers; lower values of both are better.

- The rearward amplification factor is the ratio of the lateral (sideways) acceleration of the rearmost trailer to the lateral acceleration of the tractor when making a sharp turn. Values below 2 are normally considered acceptable. Single-trailer combination vehicles typically

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[10] All evaluation criteria are taken from the "Western Uniformity Scenario Analysis." References are provided below.
Static Roll Stability: Mueller, T.H., De Pont, J.J., Baas, P.H. "Heavy Vehicle Stability versus Crash Rates." Transportation Engineering Research New Zealand Limited. Accessed June 2008 at www.landtransport.govt.nz/publications/docs/stability.pdf. Page 1. 1999.
Rearward Amplification: National Road Transport Commission. "Performance Based Standards for Heavy Vehicles in Australia." Accessed June 2008 at www.ntc.gov.au/DocView.aspx?page=A02302402400380020. 1999.
Load Transfer Ratio: Vehicle Weights and Dimensions Study Implementation Planning Subcommittee. "Recommended Regulatory Principles for Interprovincial Heavy Vehicle Weights and Dimensions." Accessed June 2008 at www.comt.ca/english/programs/trucking/Regulatory%20Principles.pdf. September, 1987.

have a rearward amplification factor of 1.24, turnpike doubles 1.28, and STAA doubles[11] 2.15. By this measure, the turnpike double configuration is safer than the widely accepted STAA double currently in use nationwide.

- The load transfer ratio measures a truck's stability while turning. This ratio is the portion of a vehicle's axle load that is carried on one side of the truck relative to the other during a dynamic event, such as an evasive maneuver. An ideal vehicle would have a load transfer ratio of 0.5 while a vehicle with all the weight on one side would have a load transfer ratio of 1. It is commonly held that the load transfer ratio should not exceed 0.6. A turnpike double using 48-foot trailers has a load transfer ratio of 0.52—mathematically more stable than one with two 45-foot trailers, and a standard single as seen in Table 13.

Table 13 uses the evaluation criteria from Table 12 to compare the stability of a single-trailer combination vehicle, an STAA double, and a turnpike double. The turnpike double has an SRS comparable to a single trailer's, and its rearward amplification factor is better than that of the STAA double now in wide use. The load transfer ratio of the turnpike double is the smallest of all combinations analyzed in this study. These numbers are taken from the Western Uniformity Scenario Analysis and therefore use weight limits of 129,000 pounds; that's also used by the Western Governors' Association, and slightly exceeds our Step 2 assumption of 120,000 pounds.

Electronic Safety Equipment

Anti-lock braking systems (ABS) electronic stability control (ESC) are widely known in passenger car markets and are available for tractor-trailers as well [56]. Electronic safety technology for tractor trailers is now well-proven and available but it is rarely required by law in the U.S. Today, advanced systems that look beyond the vehicle itself are also available, such as radar collision avoidance systems that alert drivers to the presence of traffic on all sides or to obstacles in the road [57]. Furthermore, tractor trailers in Europe can be purchased with lane departure warning systems or a very impressive active brake assist system which integrates disc brakes with radar collision avoidance, capable of stopping the truck automatically to avoid head-on collision [58] [62]. The National Highway Traffic Safety Administration (NHTSA) conducts research in these areas and RMI strongly encourages the increased adoption of these technologies in U.S. freight transportation markets [60]. Creating incentives or requirements to encourage installation of similar devices on new trucks would measurably improve safety [60] [61].

Driver Safety and Performance

Driver performance also affects safety. An easily controlled truck means less work, less fatigue, and safer driving for longer. A driver fatigue study sponsored by the Federal Motor Carrier Safety Administration compared drivers' performances in single- and triple-trailer combination trucks [48]. Under normal conditions, each driver operated one of three combinations: a single 48-foot trailer, a triple-trailer combination with three 28-foot trailers and standard A-dollies, and a triple-trailer combination with three 28-foot trailers and double-drawbar, self-steering C-dollies. C-dollies, as seen in Figure 24, use a two-arm hitch system with fewer pivot points, hence less rearward amplification. Under normal operating conditions, driver workload and fatigue increased in the sequence: single-trailer, C-dolly, A-dolly. C-dollies used on a turnpike double make the vehicles easier to control, and thus are safer than the more common A-dolly.

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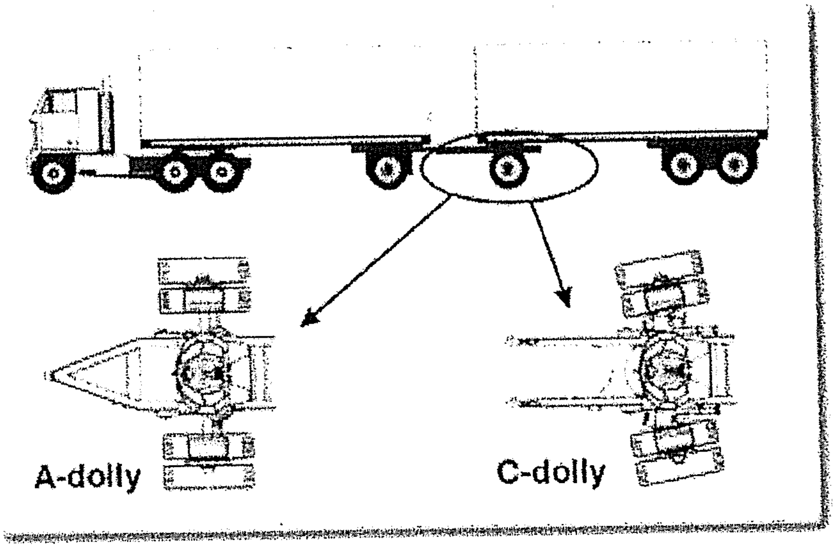
[11] The Surface Transportation Assistance Act (STAA) of 1982 regulates truck size and weight. It required states to allow semitrailers up to 48' long and twin trailer combinations with trailing units up to 28' long (STAA doubles) on federally funded highways designated by the Secretary of Transportation.

Figure 24: Top view of A-Dolly and C-Dolly configurations, respectively. (DOT 2000)



The Engineering Research Division of the University of Michigan Transport Research Institute (UMTRI) recently completed a three-year field study of long combination vehicles using anti-lock brakes (ABS) and double-drawbar dollies [49,50], which explains:

> Two types of converter dollies, which are distinguished by the number of tow bars, are illustrated in Figure 24 [50].
>
> Depending on design style, dollies may have a single- or double-tow-drawbar arrangement for coupling to the towing trailer. In either case, the tow bars terminate in a simple, rugged towing eye. The towing trailer is equipped with one or two pintle hitches consisting of a hook and locking mechanism, which engages and secures the eye(s), thereby supporting and towing the dolly [50].
>
> A-dolly. The defining quality of the A-dolly is its single-point tow bar. The A-dolly is the most common type of converter dolly; over 99 percent of the dollies in use in the U.S. are of this type. The single hitching point allows the dolly to articulate in yaw (steering), pitch (fore/aft rotation), and roll (side-to-side rotation) with respect to the towing trailer [50].
>
> C-dolly. The defining quality of the C-dolly is its double-tow-bar configuration. The C-dolly originated in Canada. Its attractive quality is its ability to improve the stability of multiple-trailer combination vehicles. This is accomplished because the double-tow-bar hitching arrangement eliminates yaw and roll articulation with respect to the lead trailer. Eliminating yaw, in particular, can degrade low-speed maneuverability and produce excessive hitch forces and tire scrubbing during tight turns at low speeds. To mitigate these low-speed problems, the wheels of the C-dolly are allowed to steer by a caster mechanism. However, a centering mechanism provides mechanical resistance to this self-steering action as required for dynamic stability at highway speeds [50].

That study made two key safety findings about dollies: the C-dolly on LCVs reduces rearward amplification in normal use, and it increases an LCV's total maintenance costs by 3–5 percent, due mostly to increased tire wear.

Operating Environment

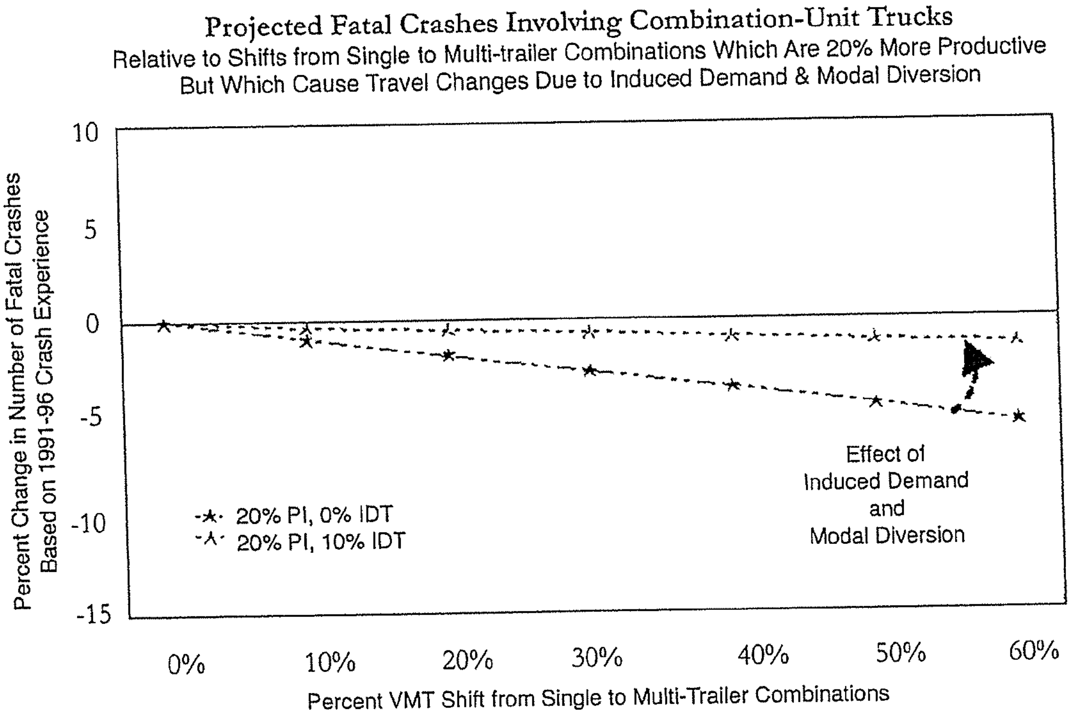
LCVs are longer than singles, so cars take longer to pass them or vice versa. This is especially important to safety on two-lane, two-way roads where passing is in the oncoming-traffic lane. Marked passing and no-passing zones are established based on sight distance criteria only for passenger cars—not trucks (of any length). DOT found that cars on two-lane roads need 8 percent more sight distance to pass LCVs than to pass single trucks (DOT 2000). This is much less than one would expect from LCVs' roughly 50 percent greater length. On the other hand, more LCVs means fewer trucks on the road, hence fewer total passing maneuvers.

Crash Rates

Many studies have compared crash fatality rates associated with tractor-trailers having one vs. more trailers. It's hard to predict the effects of more LCVs, and results are mixed. Deaths per million vehicle-miles travelled for single vs. multiple trailers were estimated at 2.44 vs. 2.08 by a 1993 FHWA study, but at 2.75 vs. 3.02—the opposite relationship—by a 1995–1999 study done for the Western Uniformity Scenario Analysis [47]. Accident reports typically show a tractor-trailer's number of trailers but not its configuration, load, or other vital details. One Canadian study that did classify crash rates by configuration found that traditional single tractor-trailers and turnpike doubles have respective crash rates of 128.1 and 27.06 per 100 million miles—a nearly fivefold safety advantage per tractor (even more per trailer) for turnpike doubles under the conditions of that analysis [51]. Alberta does require enhanced driver qualification requirements and operating restrictions for adverse road and weather conditions.

It's hard to estimate how wider adoption of LCVs would affect overall road safety. Studies of current fleet statistics don't help much because LCVs are far outnumbered by singles,. More LCVs would mean disproportionately fewer singles to haul the same freight—reducing the number of crashes, the amount of congestion, and perhaps the amount of risky passing behavior. On the other hand, each individual vehicle may be at a slightly higher risk for crashing. The net effect, however, probably favors LCVs, because even if LCVs did (as the WUSA study found) have 10 percent higher fatalities than singles per vehicle-mile, they'd still have fewer fatalities per ton-mile, because each LCV hauls more freight. That is, fewer trucks would outweigh the possibility of more danger per truck, as confirmed in Figure 25 [52]. We recommend that future studies count both effects of LCVs—fewer tractor-trailer trips and LCV safety changes at the vehicle level—to assess safety effects on all road users.

Figure 25: LCV's are predicted to result in fewer fatal crashes due to a reduction in overall tractor-trailer VMT, even after including induced demand and modal diversions from rail to truck [52].



Productivity Improvement (PI) is the percent reduction in single trailer VMT attributable to carrying more cargo per truck per trip in muli-trailer.
Induced/diverted travel (IDT) would be attributable to both new commodity movements over greater distances and movements diverted from other modes because of lower trucking costs.

A prior RMI analysis recommended harmonizing to higher GWVR limits, but offsetting any potential risk increase by having uniform and slightly lower speed limits and shorter stopping distances, readily achieved by using disc instead of drum brakes. That study found that safety would improve even as trucks got heavier. We didn't repeat that analysis here because many jurisdictions already permit those or higher weights, and because this study recognizes that four-fifths of loads cube out, and only one-fifth weigh out.

Conclusions, Step 2

In summary, adopting LCVs reduces semi-trailer trips and makes roads safer, partly through greater stability. Such LCVs should be allowed on certain routes but not all. Safe routes would include:

- More than two lanes;
- Climbing lanes, if applicable;
- Roadway geometry designed to prevent LCV off-tracking; and
- Adequate bridge ratings.

Thorough training and safety checks by industry are vital too. More weight means more brake maintenance. In addition, appropriate speed limits should be enforced.

Strict adherence to safe operating procedures will bring multiple benefits. Higher cargo capacity cuts fuel per ton-mile, raises income per trip, and saves trips. This will in turn affect congestion and total travel.

Infrastructure constraints, such as road geometries and bridge ratings, make only some major-highway freight ton-miles—we suggested at least 63 percent—suitable for LCVs. However, over time, infrastructure improvements could advantageously ease these constraints. In our results, 63% of trips are made with Step 2 LCVs, while the remainder are Step 1 vehicles.

It is important to note that increased use of rail to carry goods also offers an opportunity to move goods more efficiently. Intermodal shipping offers the opportunity to transfer truck freight onto rail cars for a portion of the trip. Adding this logistical step can improve overall freight delivery efficiency and also helps remove traffic from US highways. According to CSX, a major U.S. rail company, trains can deliver goods at 432 ton miles per gallon [55].

Table 14: Fuel Results and Assumptions for Step 2

	Baseline	Step 2	
		Step 1 tractor-trailers	Step 2 turnpike doubles
No. long-haul tractor-trailers	500,000	176,000	171,000
Distance traveled (miles/y)	100,000	100,000	100,000
Fuel economy (mpg)	6.50	12.30	8.70
Freight efficiency (ton-mile/gal)	130	275	335
Fuel used (gal/y)	7,700,000,000	1,400,000,000	2,000,000,000
Fuel saved (gal/y)	n/a	4,300,000,000	

Conclusion

Costly oil and changing climate demand efficient trucks. Available techniques can improve fuel economy by more than 90 percent, from 6.5 mpg (36.2 l/100 km) to 12.3 mpg (19.1 l/100 km). Combined with the slight incidental increase in hauling capacity, these Step 1 improvements would raise "fuel productivity" by 110 percent, from 130 to 275 ton-miles per gallon. These benefits can be realized without regulatory change and are comparably easy to achieve by an industry motivated by high fuel costs. Our more challenging Step 2 suggestions require new regulations for longer, heavier, but safer and less road-wearing Long Combination Vehicles that could raise individual-vehicle ton-miles per gallon to 335, while reducing the number of trucks on the road by roughly 30% versus our baseline in a fleet scenario. We strongly recommend rapid industry-wide implementation of Step 1, and a cautious investigation of the benefits of Step 2 by industry and government. The resulting savings in U.S. fuel use, money, and carbon dioxide emissions are summarized in Table 14.

Table 14: Result summary of two-step methodology

	Baseline	Step 1	Step 2	
			Step 1 tractor-trailers	Step 2 turnpike doubles
No. long-haul tractor-trailers	500,000	475,000	176,000	171,000
Distance traveled (miles/y)	100,000	100,000	100,000	100,000
Fuel economy (mpg)	6.50	12.3	12.30	8.70
Freight efficiency (ton-mile/gal)	130	275	275	335
Fuel used (gal/y)	7,700,000,000	3,900,000,000	1,400,000,000	2,000,000,000
Fuel saved (gal/y)	n/a	3,800,000,000	4,300,000,000	
Value of fuel saved ($/y)	n/a	$15 billion	$17 billion	
CO_2 eq reductions		40 million tonnes	45 million tonnes	

Other valuable benefits would include higher trucker profits, lower hauling costs, less congestion, less pollution, and fewer deaths. A systematic, comprehensive approach to efficient trucks and freight-hauling systems—including important options not assessed here, such as hybrid drives, idle-preventing auxiliary power units, more-advanced engines, alternative fuels, fewer empty backhauls, fuller road/rail integration, and smarter logistics—is clearly a key to a richer, cooler, and safer world.

Acknowledgements

We would like to acknowledge the funders of Winning The Oil Endgame without whom this work would not be possible. In addition, much gratitude is given to Cam Burns of RMI for his tireless editing. We would also like to thank the staff of MOVE at RMI for their comments as well as the following reviewers for their time and contributions: Drew Kodjak and Dan Rutherford of the International Council on Clean Transportation (ICCT), Coralie Cooper of Northeast States Center for Clean Air Future (NESCCAF), Cheryl Bynum of EPA SmartWay, Don Anair of the Union of Concerned Scientists, Therese Langer of the American Council for an Energy Efficient Economy (ACEEE), Tom Wieringa of Logistics Management Inc., and Steve Williams of Maverick USA.

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Appendix 1

Analytic Methods
We use the road load equation to calculate the energy required to overcome those forces resisting the motion of a vehicle. We apply only the steady-state portion of the road load equation, which includes three main components—aerodynamic drag, rolling resistance, and grade losses. We also included major energy losses due to the inefficiency of the engine. We did not count driving-cycle effects such as hill-climbing, stop-start operation, idling, or auxiliary loads.

Equation 1: Road load equation and three basic loads (rolling resistance, aerodynamic drag, and grade).

$$F = M_v g C_{rr} + \frac{1}{2}\rho A_f C_d (V + V_w)^2 + M_v g \sin(\alpha)$$

Where:
P = normal load
C_{rr} = rolling-resistance coefficient
ρ = air density
A_f = vehicle frontal area
C_d = coefficient of drag
V = vehicle speed
V_w = component of wind speed on the vehicle's moving direction
M_v = mass of vehicle
g = acceleration due to gravity
α = road angle

We modeled this equation using a spreadsheet to determine the fuel economy at 60 mph given the following assumptions.

Table 15: Assumptions for Baseline and Transformational Truck.

	Baseline	Step 1: Transformational Truck
M_v, kg	32,000	32,000
C_{rr}	0.0073	0.0052
A_f, m^2	11	11
C_d	0.6	0.31
E_{engine}, engine efficiency	42%	48%
E_{trans}, transmission efficiency	98%	98%
E_{axle}, axle efficiency	98%	98%

Table 16: Verification of Excel spreadsheet road load model results using PSAT.

Output (Excel/PSAT)	Baseline	Step 1: Transformational Truck
Fuel Economy (mpg)	6.51/6.26	12.31/11.28

Notes on the model output verification using PSAT: The baseline truck engine operates at 131 rad/s and 1,176 Nm of torque at 60mph. The efficiencies of the axles and transmission within the model matched our road load model. The actual engine efficiency reported by PSAT was 43% instead of the scaled (desired) 42%. The Step 1 engine operates at 131 rad/s and 687 Nm of torque at 60 mph within PSAT. The efficiencies of the Step 1 axle and transmission within the model matched our road load model. The engine efficiency, however, was 45% in PSAT instead of the scaled (desired) 48%. This brought about a slightly lower fuel economy output in PSAT when compared to our road load model.

ATTACHMENT B

California Trucking Association
We drive for a living. Safety is our priority.

June 14, 2011

Honorable Chairwoman Mary Nichols
c/o Charlyn Frazier
P.O. Box 2815
Sacramento, CA 95812

Chairwoman Nichols,

In advance of the release of your staff's Tractor-Trailer Greenhouse Gas Reduction Measure Modified Statement of Reasons, the California Trucking Association (CTA) would like to register the following concerns which have gone unaddressed to date.

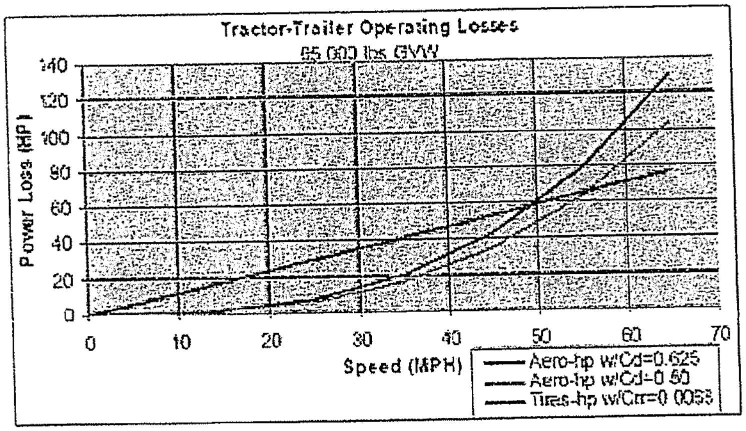
Economic Impact Analysis Still Flawed

The Economic Impact Analysis of the Tractor-Trailer Greenhouse Gas Reduction Measure continues to be based on a flawed model. For instance, on page 64 of the Initial Statement of Reasons, staff writes "fleets that elect to utilize the proposed provision to delay compliance…would not realize the cost savings benefits resulting from the existing regulation."

The assumption is that any fleet which delays compliance with this rule would stand to lose money due to lost fuel efficiencies. This assumption stems from the original staff Economic Impact Analysis which calculated average fuel savings where "**84 percent** of the vehicle miles traveled at highway speed that benefit fully from the aerodynamic devices" and tractors travel 125,000 miles annually. There are some key problems with this supposition:

Overall VMT and VMT traveled at highway speed may be overstated

We have attached a survey of one of our members subject to this rule showing six month average speed data for tractors likely to travel at least 50,000 miles/year. As you can see, **less than 20 percent** of this fleet's vehicle miles traveled (VMT) are done so at highway speeds that benefit fully from Smartway aerodynamic devices.



In analyzing the rule's Economic Analysis, we find no support for 84 percent as accurately representing the VMT done at optimal aerodynamic speeds by the population of tractors regulated by this rule. Nor do we find support for 125,000 annual miles as being reflective of the average VMT of tractors subject to this rule.

Please note that these were both key inputs in your cost-benefit analysis that have *no demonstrated evidentiary support*. http://www.arb.ca.gov/regact/2008/ghghdv08/ghgappc.pdf

Oral Testimony Given to Board Inaccurate, Anecdotal

We would like to clarify and highlight numerous inaccurate and anecdotal statements which were given on record to the Board by ARB staff on December 17, 2010 in connection with this rule.

Inconsistency and arbitrary designation of local haul definition

"For one, we did workshop a lot with the industry on establishing what is a local haul and long haul. And the US DOT has a definition for commercial driver's license that they require that if you operate less than 100 miles, you're not -- you don't need to have the hours of service. It's kind of a mark point for the industry breaking out between what a local haul is and what a long haul begin is about 100-mile radius of operation."

The Tractor-Trailer GHG Rule defines "local haul" as 100 land-miles whereas 49 CFR 395.1(e)(1) specifies that exemption from a driver's record of duty status is limited to those vehicles operating within 100 air-miles of its regular work location. 100 air-miles is the equivalent of 115 land miles.

Moreover, why use a Federal Hours of Service logbook exemption to establish an exemption for an aerodynamic efficiency rule? Using this 100 air/land mile radius is completely arbitrary and the inability to even make the correct air/land mile distinction further belies the incomplete analysis done by Staff.

Aerodynamic Benefits Relative to On-Highway Speeds Overstated, Anecdotal

BOARD MEMBER BERG: Could you just follow up that thought about the mileage and the fact that the smart trucks benefit at 62 miles an hour and the law requires them to go 55 miles an hour? ON-ROAD HEAVY-DUTY DIESEL SECTION MANAGER LEMIEUX: When we did our estimates, we based it on the highway speeds...The only thing I would let the Board know is average speed is not as good a metric because trucks often spend a lot of time at very low speeds and idling, and then they spend most of their time -- a good portion of their time for long hauling at a highway cruise speed. So you can't really use the average speeds in this case.... And also if you've driven on the freeways, even though you do have the 55 mile per hour speed limit, it's not 100 percent the case out there unfortunately. They all have governed speeds, it would be great. But they're oftentimes at 65, 70. I spend quite a lot of time going to Arizona. It's my hobby. And you'll see them out there cruising quite fast.

Again, please see the attached fleet survey. Only 2.8% of this fleet's mileage is done at speeds over 65mph. The economic analysis attached to this rule estimates cost benefits "where 84 percent of the vehicle miles traveled at highway speed that benefit fully from the aerodynamic devices".

In our opinion, it is wholly inappropriate to craft multi-billion dollar environmental policy based on anecdotal statements made to the Board by ARB Staff where there is this large of a divergence in the data.

The California Trucking Association's Request

We respectfully ask that the Board consider the following:

- Formally direct staff to study CTA's proposal to set the local haul exemption to at least 150 air mile radius or work with industry stakeholders to create an exemption which will more closely align the parties regulated by this rule with those reflected in staff's cost-effectiveness studies (i.e. define local haul as a trailer hauled by a tractor which returns to its local haul base in a 24hr period). Direct staff to do so in a manner which studies speed data from real fleets and does not rely on anecdotal observations.

- Also, attached are CTA's 45-day comments from December 2010. Please review our additional concerns regarding staff's economic analysis. In light of these existing concerns and those raised in this letter, please consider whether staff fulfilled its statutory requirement under Government Code sections 11346.3 and 11346.5 and the Health and Safety Code section 57005.

Please direct any questions or concerns to Chris Shimoda, Manager of Environmental Policy at (916)373-3504.

Thank You,

Eric Sauer
Vice President of Policy Development
California Trucking Association

CC: James Goldstene, ARB Executive Officer;
Daniel Sperling, Board Member, ARB
Ken Yeager, Board Member, ARB
Dorene D'Adamo, Board Member, ARB
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Sandra Berg, Board Member, ARB
Ron Roberts, Board Member, ARB
John G. Telles M.D., Board Member, ARB
Ronald O. Loveridge, Board Member, ARB

Vehicle	6 Mo. Mileage Accrual	0-45	46-55	56-60	61-63	64-65	66-75	75-over
401	32675.4	41.61	14.05	39.23	5.08	0.01	0	0
406	255503.9	48.21	18.15	33.59	0.06	0	0	0
408	22751.2	25.63	20.44	52.62	1.3	0.01	0	0
413	28027.8	34.73	15.91	47.83	1.51	0.02	0	0
416	21924.7	51.97	7.2	30.84	9.91	0.08	0.01	0
418	55403.4	26.65	17.6	44.11	7.9	3.66	0.07	0
420	27483.9	45.27	9.18	27.64	17.83	0.08	0	0
424	20354.1	54.83	13.71	27.31	4.1	0.05	0	0
425	40798.8	39.14	7.03	24.47	28.61	0.66	0.1	0
428	45203.2	37.84	9.65	30.89	21.54	0.08	0	0
430	31468.6	38.84	11.96	42.14	6	1.01	0.05	0
438	36952.3	40.34	6.39	19.22	33.85	0.19	0.01	0
445	38156.6	38.58	10.11	29.27	21.95	0.09	0.01	0
446	21203.7	39.81	10.46	46.76	2.97	0	0	0
448	31168.6	44.91	12.94	30.85	8.61	2.49	0.2	0
457	23434.4	53.54	4.08	4.06	4.25	16.2	17.87	0
460	21257.7	49.03	16.29	20.01	14.39	0.25	0.04	0
464	39218.5	41.87	7.65	33.35	17.08	0.05	0	0
467	28918.3	42.16	7.82	38.29	11.69	0.03	0	0
473	29118	45.64	7.48	13.88	32.03	0.6	0.37	0
476	36404.3	37.29	12.19	21.23	29.25	0.04	0	0
477	31523.9	37.26	8.28	40.79	13.66	0.01	0	0
478	36800.6	40.51	11.92	9.8	10.79	20.38	6.6	0
479	45392.3	40.63	6.32	8	8.55	11.01	25.49	0
480	38412.7	41.32	4.01	5.17	8.69	13.18	27.63	0.01
481	34187.4	42.69	4.14	15.19	5.68	15.04	17.25	0
482	32911	38.84	9.49	19.61	31.62	0.4	0.05	0
487	22259	49.67	13.07	24.6	12.57	0.09	0	0
488	26560.7	46.01	11.31	38.59	4.05	0.03	0.01	0
489	26436.6	42.36	7.67	7.5	40.13	1.07	1.24	0.02
495	24186.8	43.49	9.85	12.82	32.34	0.83	0.67	0
496	50096.3	29.7	11.36	49.85	9.09	0.01	0	0
498	46981.5	31.41	7.74	45.97	12.18	2.6	0.11	0
500	40164.9	27.9	7.98	47.38	15.69	0.99	0.05	0
502	20766.1	54.1	14.25	24.27	7.28	0.08	0.02	0
TOTAL	**38974.49**	**41.25**	**10.5**	**28.78**	**14.06**	**2.61**	**2.8**	0

Air Resources Board

Mary D. Nichols, Chairman
1001 I Street • P.O. Box 2815
Sacramento, California 95812 • www.arb.ca.gov

Matthew Rodriquez
Secretary for
Environmental Protection

Edmund G. Brown Jr.
Governor

August 4, 2011

Mr. Eric Sauer
Vice President of Policy Development
California Trucking Association
4148 E. Commerce Way
Sacramento, CA 95834

Dear Mr. Sauer:

Thank you for your letters of June 14, 2011 and July 15, 2011 regarding the Tractor-Trailer Greenhouse Gas regulation (Regulation). In your letters, you raised several issues to which I would like to respond.

As you are aware, the Board approved the Regulation on December 12, 2008, and recently considered and approved amendments to the Regulation on December 17, 2010. The concerns that you raise in your letters regarding the Economic Impact Analysis and the expanded local-haul radius are substantially similar to issues that the Board extensively addressed in the Final Statement of Reasons (FSOR) for the 2008 rulemaking. Please refer to the Agency responses to comments 22-24, 45-50, 75-76, 99, 108, 112, 118, 120-121, 132-133, 155, and 157-159 in the FSOR.

The Board also considered and extensively addressed these concerns during the December 2010 public hearing when it considered the adoption of the proposed amendments to the Regulation. Because of the extensive public process incorporated in the rule adoption and subsequent amendments, I do not believe that consideration of additional changes to the Regulation is warranted.

If you have any further questions concerning this response, please contact Mr. Stephan Lemieux, Manager, at (626) 450-6162, slemieux@arb.ca.gov : Also attached is a more detailed response to several of the issues raised in your letters.

Sincerely,

Mary D Nichols

Mary D. Nichols
Chairman

Attachment

cc: Honorable Board Members

James N. Goldstene
Executive Officer

Stephan Lemieux, Manager
On-Road Heavy-Duty Diesel Section

Attachment

Staff Responses to Several Concerns Raised by California Trucking Association Regarding the Tractor-Trailer Greenhouse Gas Regulation

August, 2011

In recent letters, CTA stated that the Air Resources Board's (ARB or Board) Economic Impact Analysis may overstate the overall vehicle miles traveled (VMT) and VMT traveled at highway speeds of tractor-trailers operating in California. To support this statement, CTA submitted the overall VMT and the VMT-speed distribution from one fleet with 35 tractors. Note that the overall VMT and the percentage of VMT at highway speeds used in ARB's Economic Impact Analysis are industry average estimates from out-of-state and in-state long-haul tractor-trailers. We therefore believe that our estimates more appropriately represent the VMT of the overall fleet than the single fleet example submitted.

The Board understands that different fleets will realize different benefits depending on the aerodynamic technologies used, and how and where the fleet operates (e.g., typical vehicle speed, annual miles per year, road conditions, weather conditions, and area of operation). While aerodynamic technologies provide the greatest fuel consumption savings at highway speeds, data show that fuel savings will also be achieved at lower speeds. Thus, vehicles that accrue less VMT and spend less time at highway speeds will still benefit from aerodynamic improvements but will need a relatively longer time before their initial installation costs of the aerodynamic technologies are recovered. Fleets that operate locally or infrequently will not likely benefit sufficiently from aerodynamic technologies, therefore the Regulation provides exemptions for these applications. Analyzing the data submitted, we found that 9 of the 35 vehicles could qualify for the short-haul tractor exemption where both the tractor and trailer would be exempt from the aerodynamic technology and low rolling resistance tire requirements. In addition, 16 of the remaining 26 vehicles have more than 50 percent of their VMT accrued at speeds greater than 55 miles per hour and 9 of the remaining 10 vehicles have more than 40 percent of their VMT accrued at speeds greater than 55 miles per hour. Consequently, these vehicles will benefit from aerodynamic improvements although the payback period will be longer than average.

CTA also suggested in its letters that fleets with affected 2010 and older model year tractors should be given two additional years to comply with the low rolling resistance tire requirements. ARB has extended the compliance deadline for this requirement by one year, from January 1, 2012 to January 1, 2013. We acknowledged that more time was needed for the development of SmartWay retread tires. The additional year would also allow more time for existing non-SmartWay tires to wear out (thereby avoiding premature replacement). SmartWay retread tire specifications are currently being developed by the United States Environmental Protection Agency in cooperation with retread tire manufacturers, and are expected to be finalized within this calendar year. Thus, ARB believes extending the compliance deadline an additional year to comply with the low rolling resistance tire requirements is not necessary.

September 20, 2011

California Trucking Association
We drive for a living. Safety is our priority.

Honorable Chairwoman Mary Nichols
c/o Charlyn Frazier
P.O. Box 2815
Sacramento, CA 95812

Chairwoman Nichols,

RE: Heavy Duty Tractor Trailer Greenhouse Gas Reduction Measure

Thank you for your response dated August 4th. After reviewing the Final Statement of Reasons (FSOR) for the 2008 rulemaking referenced by your letter to the California Trucking Association (CTA), including Agency responses to comments 22-24, 45-50, 75-76, 99, 108, 112, 118, 120-121, 132-133, 155, and 157-159, we still fail to recognize that the Agency provided support for the accuracy of **84 percent** as the percentage of vehicle miles traveled (VMT) at highway speeds when calculating the cost of this rule.

The closest we found to support for this figure was in the response to question 157:

> *ARB believes that these assumptions are conservative and ensure that the cost-effectiveness analysis in the Staff Report reflects a realistic evaluation of the costs an claimed benefits of the regulation.*

This is reiterated in the attached response by Air Resources Board (ARB) staff in your letter, which states:

> *...overall VMT and the percentage of VMT at highway speeds used in ARB's Economic Impact Analysis are industry average estimates from out-of-state and in-state long-haul tractor-trailers.*

We must respectfully request, once again, a response to the following:

- On what empirical data were these "industry average estimates" based upon?
- Where is the empirical support which led staff to the conclusion that **84 percent** is the percentage of VMT done at highway speeds in this State?

If the Chairwoman or staff deems it necessary, we are ready to make a Public Record Act request for this data. Also, CTA stands ready to assist your staff to perform a survey of fleet overall VMT and VMT-Speed distribution so that this $11.2 billion dollar regulation can be based on the soundest fiscal assumptions available.

Please direct any questions or concerns to Chris Shimoda, Manager of Environmental Policy at (916)373-3504.

Thank You,

Eric Sauer
Vice President of Policy Development
California Trucking Association

CC: James Goldstene, ARB Executive Officer;
Daniel Sperling, Board Member, ARB
Ken Yeager, Board Member, ARB
Dorene D'Adamo, Board Member, ARB
Mrs. Barbara Riordan, Board Member, ARB
John R. Balmes M.D., Board Member, ARB
Lydia H. Kennard, Board Member, ARB
Sandra Berg, Board Member, ARB
Ron Roberts, Board Member, ARB
Ronald O. Loveridge, Board Member, ARB

ATTACHMENT C

	Vehicle	6 Mo. Mileage Accrual	0-45	46-55	56-60	61-63	64-65	66-75	75-over
fleet A	401	32675.4	41.61	14.05	39.23	5.08	0.01	0	0
35 vehicles	406	255503.9	48.21	18.15	33.59	0.06	0	0	0
	408	22751.2	25.63	20.44	52.62	1.3	0.01	0	0
	413	28027.8	34.73	15.91	47.83	1.51	0.02	0	0
	416	21924.7	51.97	7.2	30.84	9.91	0.08	0.01	0
	418	55403.4	26.65	17.6	44.11	7.9	3.66	0.07	0
	420	27483.9	45.27	9.18	27.64	17.83	0.08	0	0
	424	20354.1	54.83	13.71	27.31	4.1	0.05	0	0
	425	40798.8	39.14	7.03	24.47	28.61	0.66	0.1	0
	428	45203.2	37.84	9.65	30.89	21.54	0.08	0	0
	430	31468.6	38.84	11.96	42.14	6	1.01	0.05	0
	438	36952.3	40.34	6.39	19.22	33.85	0.19	0.01	0
	445	38156.6	38.58	10.11	29.27	21.95	0.09	0.01	0
	446	21203.7	39.81	10.46	46.76	2.97	0	0	0
	448	31168.6	44.91	12.94	30.85	8.61	2.49	0.2	0
	457	23434.4	53.54	4.08	4.06	4.25	16.2	17.87	0
	460	21257.7	49.03	16.29	20.01	14.39	0.25	0.04	0
	464	39218.5	41.87	7.65	33.35	17.08	0.05	0	0
	467	28918.3	42.16	7.82	38.29	11.69	0.03	0	0
	473	29118	45.64	7.48	13.88	32.03	0.6	0.37	0
	476	36404.3	37.29	12.19	21.23	29.25	0.04	0	0
	477	31523.9	37.26	8.28	40.79	13.66	0.01	0	0
	478	36800.6	40.51	11.92	9.8	10.79	20.38	6.6	0
	479	45392.3	40.63	6.32	8	8.55	11.01	25.49	0
	480	38412.7	41.32	4.01	5.17	8.69	13.18	27.63	0.01
	481	34187.4	42.69	4.14	15.19	5.68	15.04	17.25	0
	482	32911	38.84	9.49	19.61	31.62	0.4	0.05	0
	487	22259	49.67	13.07	24.6	12.57	0.09	0	0
	488	26560.7	46.01	11.31	38.59	4.05	0.03	0.01	0
	489	26436.6	42.36	7.67	7.5	40.13	1.07	1.24	0.02
	495	24186.8	43.49	9.85	12.82	32.34	0.83	0.67	0
	496	50096.3	29.7	11.36	49.85	9.09	0.01	0	0
	498	46981.5	31.41	7.74	45.97	12.18	2.6	0.11	0
	500	40164.9	27.9	7.98	47.38	15.69	0.99	0.05	0
	502	20766.1	54.1	14.25	24.27	7.28	0.08	0.02	0
Fleet B	491594	25207.6	45.68	32.93	19.47	1.63	0.28	0.02	0
13 trucks	491592	22394.9	54.25	17.4	18.71	5.88	3.55	0.21	0
		19628.1	53.7	16.81	18.31	6.51	4.28	0.4	0
	518220	30630.3	41.11	19.43	29.27	7.79	2.25	0.14	0
		25450.4	44.06	15.89	28.33	9.46	2.14	0.13	0
	950	28298.5	37.22	13.05	49.55	0.18	0	0	0

		25893.7	44.18	12.67	42.71	0.43	0.01	0	0
	913	23370.1	39.26	5.85	7.92	45.87	0.94	0.16	0
		24217.2	39.22	5.44	9.11	45.25	0.85	0.13	0
	911	13090.6	55.21	10.72	15.11	18.81	0.14	0.02	0
		24928	52.8	11.02	25.36	10.69	0.1	0.03	0
	909	39597.8	50.59	11.13	20.49	5.15	4.43	8.21	0
		28523.2	46.84	11.91	20.97	7.22	4.63	8.43	0
	908	31848.8	50.79	26.94	17.45	4.79	0.02	0	0
		26418	57.31	25.01	12.16	5.47	0.04	0.01	0
	903	23277.6	49.58	14.51	24.83	10.65	0.3	0.13	0
		16360.1	47.22	11.57	21.1	19.52	0.48	0.12	0
	901	19452.1	52.42	9.78	17.42	20.21	0.15	0.02	0
		20562.4	49.34	10.14	21.39	18.94	0.17	0.03	0
	123	35592.3	37.92	17.64	33.37	10.57	0.49	0.01	0
		32337.7	41.42	13.56	26.5	17.39	1.1	0.02	0
	87	18136.6	49.59	18.78	24.57	6.16	0.78	0.12	0
		23495.9	40.57	21.82	30.27	5.04	1.72	0.57	0
	914	21289.9	47.06	14.68	24.51	13.52	0.17	0.07	0
		25189.8	44.92	11.13	21.49	22.01	0.29	0.16	0
fleet c	146	22037	59.1	15.98	21.86	2.86	0.19	0.02	0
9 trucks	143	21279.8	60.2	28.87	10.86	0.06	0	0	0
	137	22541	53.16	21.42	24.53	0.83	0.06	0.01	0
	133	37788.4	27.9	26.61	41.63	3.81	0.04	0.01	0
	132	42481	28.28	13.18	48.61	8.84	1.05	0.05	0
	127	21676.3	58.76	27.37	13.33	0.53	0.02	0	0
	117	38976	27.04	12.46	58.59	1.9	0.01	0	0
	150	22543.3	61.64	33.65	4.7	0.01	0	0	0
	149	22899.9	58.82	29.94	10.62	0.6	0.02	0	0
fleet d	20	21617.5	28.06	18.23	39.62	13.38	0.59	0.12	0
5 trucks	110	37978.4	29.33	22.61	43.22	2.78	1.95	0.11	0
	190	29691.3	35.57	14.98	44.06	4.79	0.53	0.07	0
	210	38097.4	31.11	12.92	47.11	5.89	1.69	1.29	0
	240	31833.1	34.31	14.29	37.31	11.84	1.41	0.85	0
fleet e									
2 trucks	2008	28637.9	46.25	52.8	0.93	0.01	0	0	0
	2009	25816	51.6	40.91	7.14	0.25	0.05	0.05	0
fleet f	3589	25067.4	23.74	12.2	44.02	15.42	4.07	0.54	0
10 trucks	5211	52715.8	29.52	20.29	39.97	7.8	1.14	1.15	0.14
	6565	44698.7	29.09	14.26	23.31	20.96	9.45	2.21	0.72
	6566	41970.9	29.53	22.17	33.33	14.3	0.62	0.05	0
	6567	39221.5	23.53	8.72	31.71	13.32	20.21	2.5	0
	6603	40243.7	32.52	13.16	21.45	21	10.75	1.1	0
	6609	52798.9	27.64	10.11	22.58	33.01	4.08	2.58	0

6610	25032.1	29.68	10.59	19.56	28.59	9.49	2.07	0.03
6611	25863	24	7.94	14.18	19	30.14	4.74	0
6614	30612.1	19.6	6.5	9.75	29.06	29.12	5.97	0
	6 Mo. Mileage Accrual	0-45	46-55	56-60	61-63	64-65	66-75	75-over
TOTAL	**32956.71**	**41.58**	**14.65**	**26.76**	**12.47**	**2.88**	**1.66**	**0.01**

	Annual Avg miles per vehicle	1mph-30	31-55	56-57	58-59	60-61	62-63	64-65	66-67	68-69
fleet g 62 vehicle aggregated	111900	4.7	37.4	31	25.2	0.7	0.2	0	0	0