Discussion of joint-agency *Technical Assessment Report* in context of LEV III GHG standards

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California Air Resources Board
Technical workshop on LEV III standards
El Monte, CA
November 16th, 2010

Outline

- Introduction
  - Motivation: Vehicles, energy, carbon dioxide (CO_2)
  - Timeline for California and U.S. regulatory process
- Technical Assessment Report (TAR)
  - Context, objectives
  - Technologies, costs, scenarios for 2025
  - Summary of findings
- Ongoing work, next steps

Motivation for Vehicle Standards

- U.S. Presidential Memorandum (May 21, 2010)

> “ America has the opportunity to lead the world in the development of a new generation of clean cars and trucks through innovative technologies and manufacturing that will spur economic growth and create high-quality domestic jobs, enhance our energy security, and improve our environment. ”

  - US agencies to work with State of California to guide 2017-2025 standards
  - Goals: Improve energy security, industry competitiveness and job creation, and environmental protection through transformation of our nation's fleet of cars and trucks

- California statement (May 21, 2010)
  - California Air Resources Board to work in partnership with US EPA and NHTSA
  - Develop combined criteria pollutant and greenhouse gas standards for 2017-2025

> “ California is deeply committed to continuing in its efforts to achieve the steep reductions in greenhouse gases needed to stabilize the planet’s temperature. ”

See:
US: http://www.whitehouse.gov/the-press-office/presidential-memorandum-regarding-fuel-efficiency-standards
CARB statement: http://www.arb.ca.gov/newsrel/2010/VehState.pdf

Motivation: Climate Change Mitigation

- Long-term CO_2 mitigation programs are driven by climate stabilization goals
  - California 2005 Executive Order S-03-05: 80% CO_2 reduction by 2050
  - What would this mean for the transportation sector? Automobile technologies?
  - What level of GHG standards might help put vehicles on such a path?

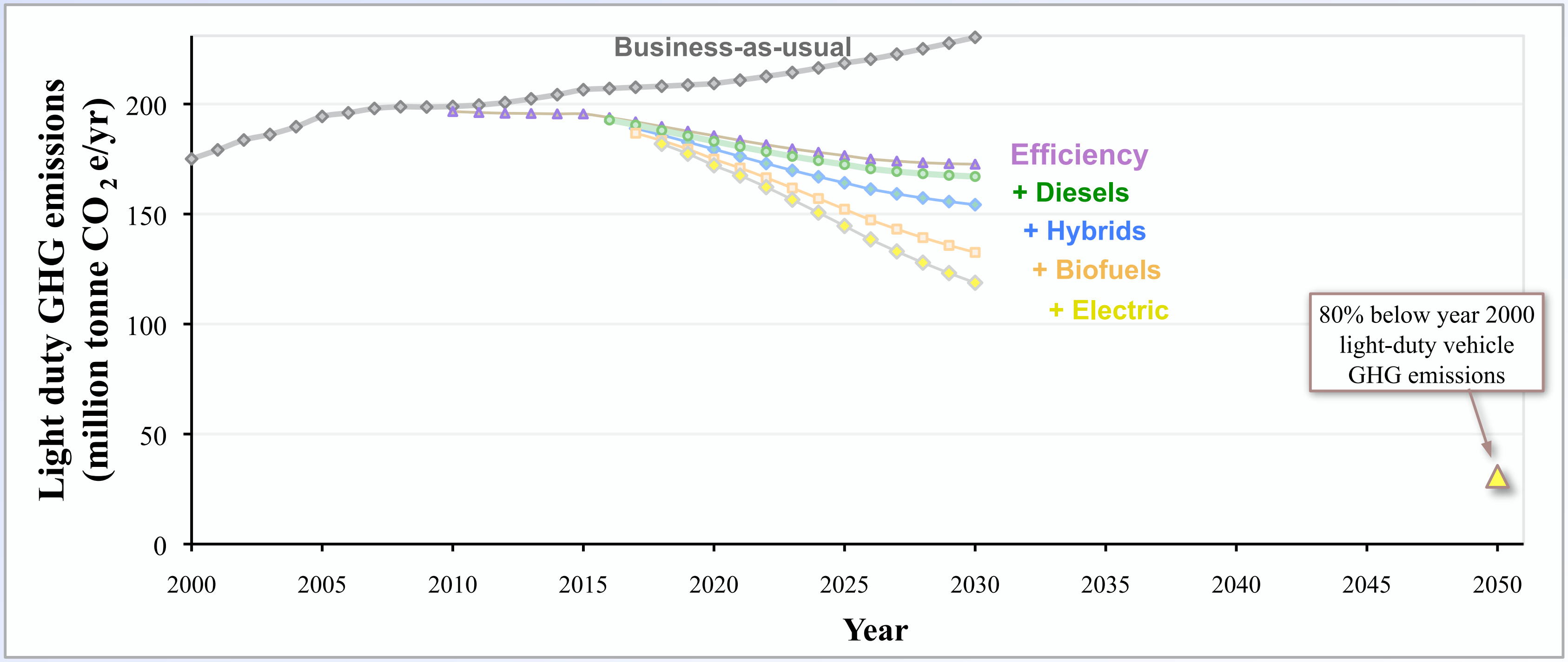


Diagram for illustration purposes; Includes efficiency (engine, transmission, vehicle road-load improvements), advanced diesels and hybrids, biofuel (ethanol and biodiesel) usage and GHG intensities consistent with Low Carbon Fuel Standard (LCFS); Electric-drive vehicles, per ZEV program, include hydrogen fuel cell vehicles; Electricity GHG consistent with Renewable Electricity Standard and hydrogen GHG consistent with LCFS

Efficiency, Low-CO_2 Technologies

- There are many different technologies available to reduce vehicles' CO_2 emissions
- Technical efficiency, low-CO_2 options
  - Petroleum efficiency
    - Gasoline
    - Diesel
    - Hybrid
  - Alternative fuels
    - Compressed natural gas
    - Biofuels
  - Electric-drive
    - Plug-in hybrid electric
    - Electric
    - Fuel cell electric

Regulatory Timeline: 2025 Standards

US 2017-25 standards:
- EPA, NHTSA process
- Sept. 2011: propose
- July 2012: finalize

CA works on new standards:
- CARB public workshops on CO_2, NOx, PM, etc.
- Standards through 2025

CARB hearing:
- April: LEVIII, ZEV

Work continues:
- CARB workshops
- Agencies collaborate
- Industry meetings

US 2017-25 announcement:
Oct. 1: "Notice of Intent" for federal EPA/NHTSA rulemaking

Joint US/CA work for 2017-2025:
- EPA/NHTSA/CARB co-author
- Joint technical report: "**TAR**"
- Analyze 143-190 gCO_2/mi by 2025*

Obama Administration:
May 21: Announce work on 2025 CO_2/FE standards; CARB collaborates

2010 | **2011**

** initial scenarios evaluated for the TAR; no decisions have been made on level of future proposed standard*

Technical Assessment Report ("TAR")

Interim Joint Technical Assessment Report:

Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025

Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Office of International Policy, Fuel Economy, and Consumer Programs
National Highway Traffic Safety Administration
U.S. Department of Transportation

California Air Resources Board
California Environmental Protection Agency

EPA

NHTSA
www.nhtsa.gov

California Environmental Protection Agency
Air Resources Board

- Report available at –
  - *http://www.arb.ca.gov/msprog/clean_cars/ldv-ghg-tar.pdf*

Joint-Agency Report

- Technical Assessment Report ("TAR")
  - Conducted May - Sept 2010 by 3 agencies (EPA, NHTSA, CARB)
  - Involved extensive communication with auto manufacturers and major suppliers, environmental NGOs, state and local governments

- Objectives
  - Analyze available and emerging automotive technologies
    - Engine, transmission, aerodynamics, tires, mass reduction, hybrid, electric, etc
  - Assess technical potential and costs for 2017-2025 timeframe
  - Base analysis on best available data, with goal of full transparency from tear-down results, vehicle simulation, literature review; when necessary, rely on confidential business information from OEMs, suppliers

- Interim:
  - Lots of ongoing (2010-2011) research on vehicle simulation modeling, mass reduction and safety, advanced technology cost

Joint-Agency TAR: Scenarios

- A range of scenarios was considered:
  - 2017-2025: target of 3-6%/year improvement in gCO_2/mile
    - Below shows the target CO_2 emission rates of 143-190 gCO_2/mile
    - These are approx. equivalent to 34-43 mpg in consumer (or label) fuel economy in 2025

Case	GHG Emissions		Fuel Economy	
	Rated gCO_2/mile [a]	Annual improvement from 2016	Consumer label (on-road) mpg [b]	Annual improvement from 2016
Baseline (2008)	339	-	21	-
Baseline (2016)	250	-	27	-
New vehicle target in 2025	190	3%	34	2.4%
	173	4%	37	3.3%
	158	5%	40	4.3%
	143	6%	43	5.3%

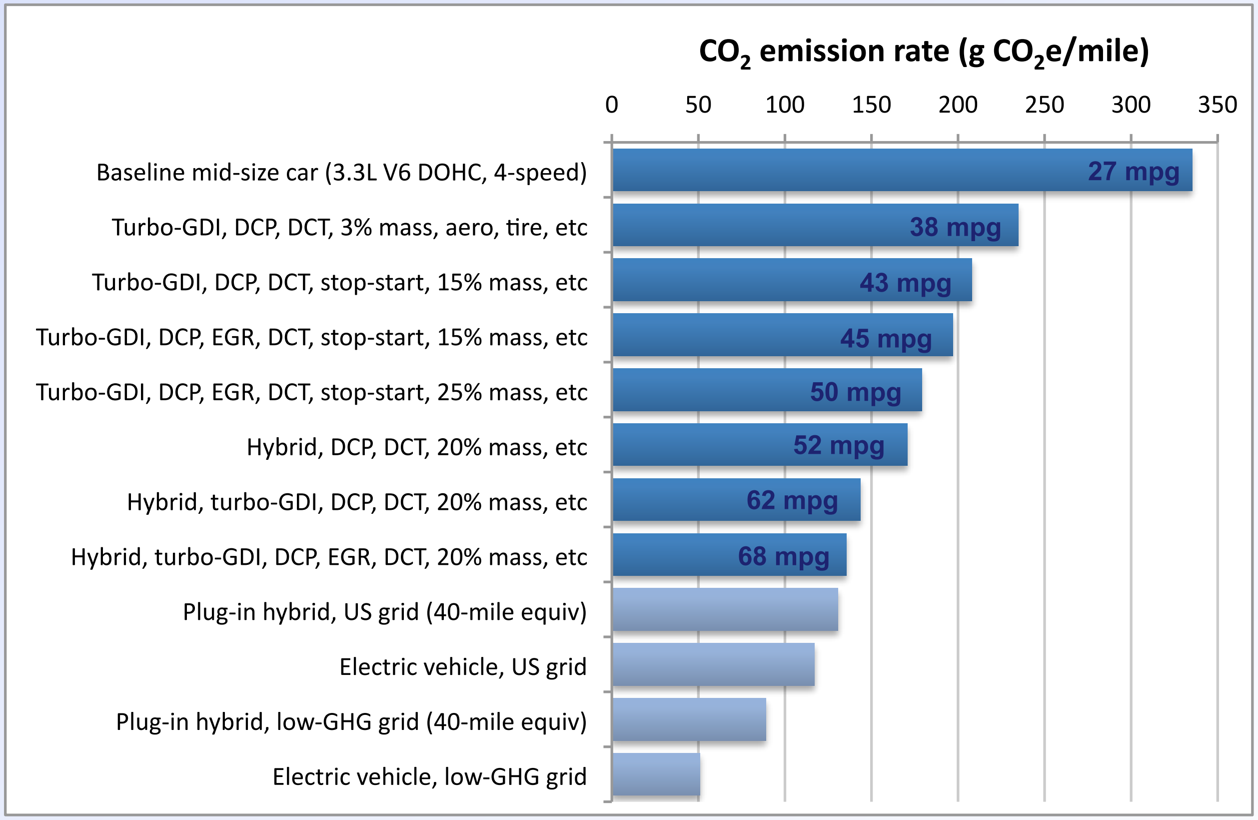
[a] Rated emissions and mpg based on official combined city/hwy test procedure
[b] Based on current label/on-road adjustments, where mpg values are about 20% lower than regulatory test; 8887 gCO_2/gallon gasoline assumed; label fuel economy estimates includes air conditioning credits (10.6 g/mi in 2016; 20.6 g/mi for 2025) and assume no use of other crediting provisions (electric vehicles would make lower average mpg)

Joint-Agency TAR: Technology in 2025

- What changes were made since the recent 2016 rulemaking?
  - Informed by feedback from stakeholder discussions
    - On technology potential, deployment timing, costs, barriers
  - Updating of technology package potential and cost
    - Advanced engines, transmissions, advanced material design, hybrid vehicle components, electric vehicle batteries
    - Development of more hybrid packages across all vehicle types
    - Development of plug-in hybrid, electric vehicles for cars, crossovers
  - Greater penetration of advanced technologies for 2020 to 2025
    - Advanced engines, hybrids, plug-in hybrids, electric vehicles
  - Update analytical and economic assumptions
    - Indirect vehicle cost multipliers; vehicle miles traveled; year 2008 dollars; AEO2010 forecast fuel prices; car-truck mix; future vehicle sales distribution by category; electric grid emissions; company-specific compliance modeling

Joint-Agency TAR: Technology Packages

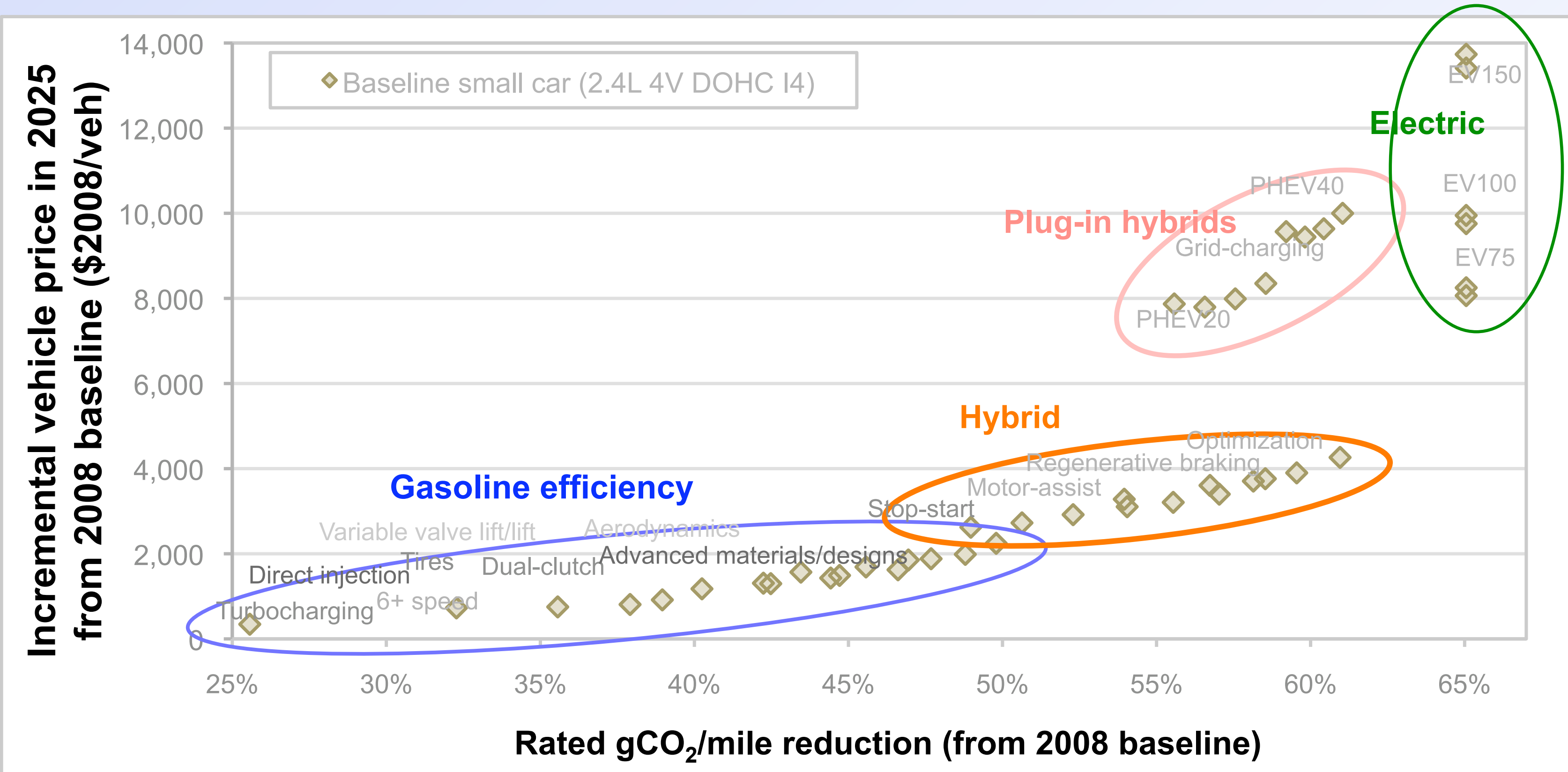
- What did the TAR find regarding levels of CO_2 emission reduction?
  - Many available drivetrain technologies; also hybrids, plug-in hybrids, electric
  - Selected packages from TAR for baseline mid-size sedan (1 of 19 classes)



Technology packages also include other technologies (including aerodynamics, engine friction reduction, improved accessory efficiency, low rolling resistance tires); GDI=gasoline direction injection; DCP= dual cam phasing; DCT= dual clutch transmission; EGR= exhaust gas recirculation; CO_2 and mpg values from rated combined city/highway test cycle (i.e., are not adjusted for consumer on-road labels or A/C credits); assumed average US electric grid emissions are 558 gCO_2/kWh with EPA accounting method; "low-GHG" grid are California 2020 33% RES assumptions

Joint-Agency TAR: Technology Packages

- Major CO_2-reduction potential from emerging technologies by 2025
  - US EPA's OMEGA used many technology packages, 19 vehicle classes to evaluate scenarios
  - Increasing costs from incremental efficiency, to hybrid, and to electric technology



Price in figure refers to the incremental cost to the consumer due to the new technology packages; technology packages include many different technologies; technology labels are approximate for illustration; grid electricity applies US EPA assumptions and accounting method for US electric grid (558 gCO_2e/kWh) for electric and plug-in hybrids

Joint-Agency TAR: Scenarios

- Scenarios used to define boundaries for the 2025 assessment
  - *Target stringency*: 4 targets for stringency (3%, 4%, 5%, 6% per year gCO_2/mile decrease from 2016-2025) set goals for new vehicles
  - *Technology paths*: 4 potential approaches (A, B, C, D), considering uncertainty and constraints about technology development and deployment
    - Defined by factors for *maximum technology penetration rates* by given year:

Technology	Maximum sales share for model year 2025 light duty vehicles			
	Path A	Path B	Path C	Path D
Conventional	100%	100%	100%	100%
Advanced engine	50%	75%	100%	0%
Hybrid vehicles	75%	50%	75%	60%
Electric vehicle	8%	8%	15%	20%
Plug-in hybrid	8%	8%	15%	20%
Mass reduction [a]	15%	20%	30%	15%

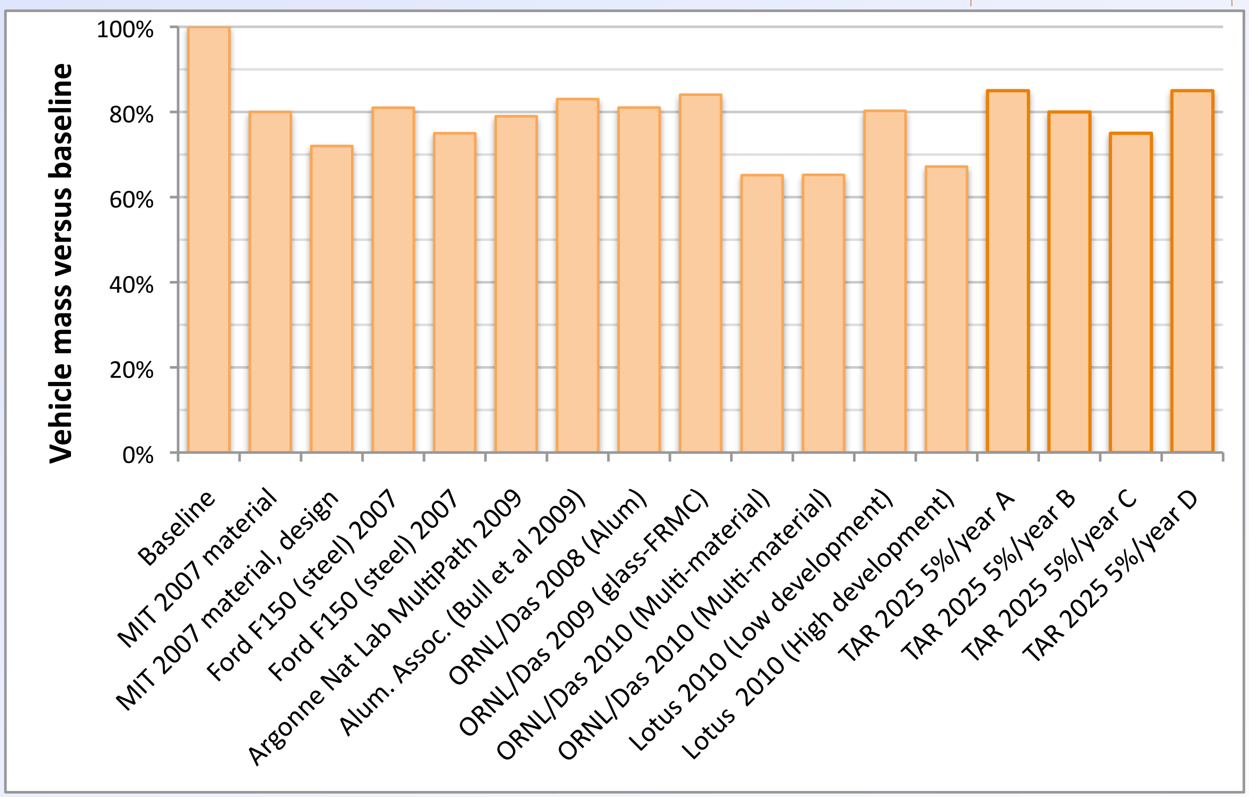
[a] Mass reduction is maximum per-vehicle change from the 2008 baseline allowed on each vehicle, whereas other percents in table are maximum sales share of fleet that can apply each technology

Joint-Agency TAR: Technology Results

- What did the TAR find regarding future technologies?
  - Emerging technologies would be required to achieve 2025 targets
    - Engine, transmission, mass reduction are primary technologies
    - Hybrid electric vehicle technology expected to have much greater penetration
    - Electric vehicles (EVs) and plug-in hybrids (PHEVs) will emerge
  - For example, for 2025 vehicle emission levels below 160 gCO_2/mi (i.e., for the 5-6%/yr target scenarios):
    - Advanced engine: near-universal turbocharging, direct injection
    - Advanced drivetrain: near-universal 6+ speed, dual-clutch, stop-start
    - Advanced material/design: 14-26% average per-vehicle mass reduction
    - Hybrid technology: 25-68% hybrid technology share
    - Electric vehicles: 0-16% electric and plug-in-hybrid share

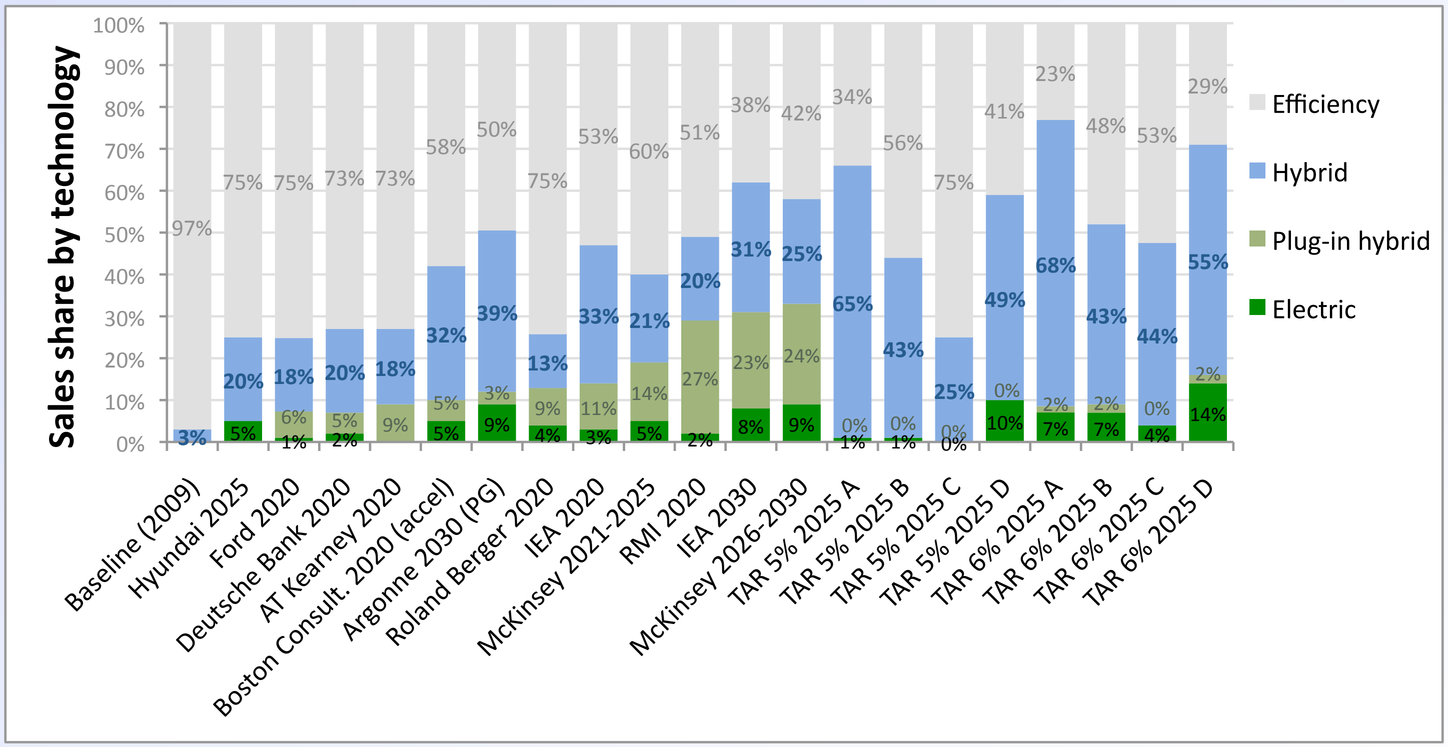
Joint-Agency TAR: Mass Reduction

- In 2020-2025 timeframe, mass-reduction will be a core technology
  - Looked at many studies (e.g., US DOE, Sierra Research, MIT, Lotus)
  - Mass reduction typically deployed before hybrid; with increasing cost
    - Various technical studies suggest feasible levels of mass reduction of 20-35%
    - Every *TAR* scenario for 2025 found average vehicle *mass reduction of 14-26%*



Joint-Agency TAR: Hybrid Vehicles

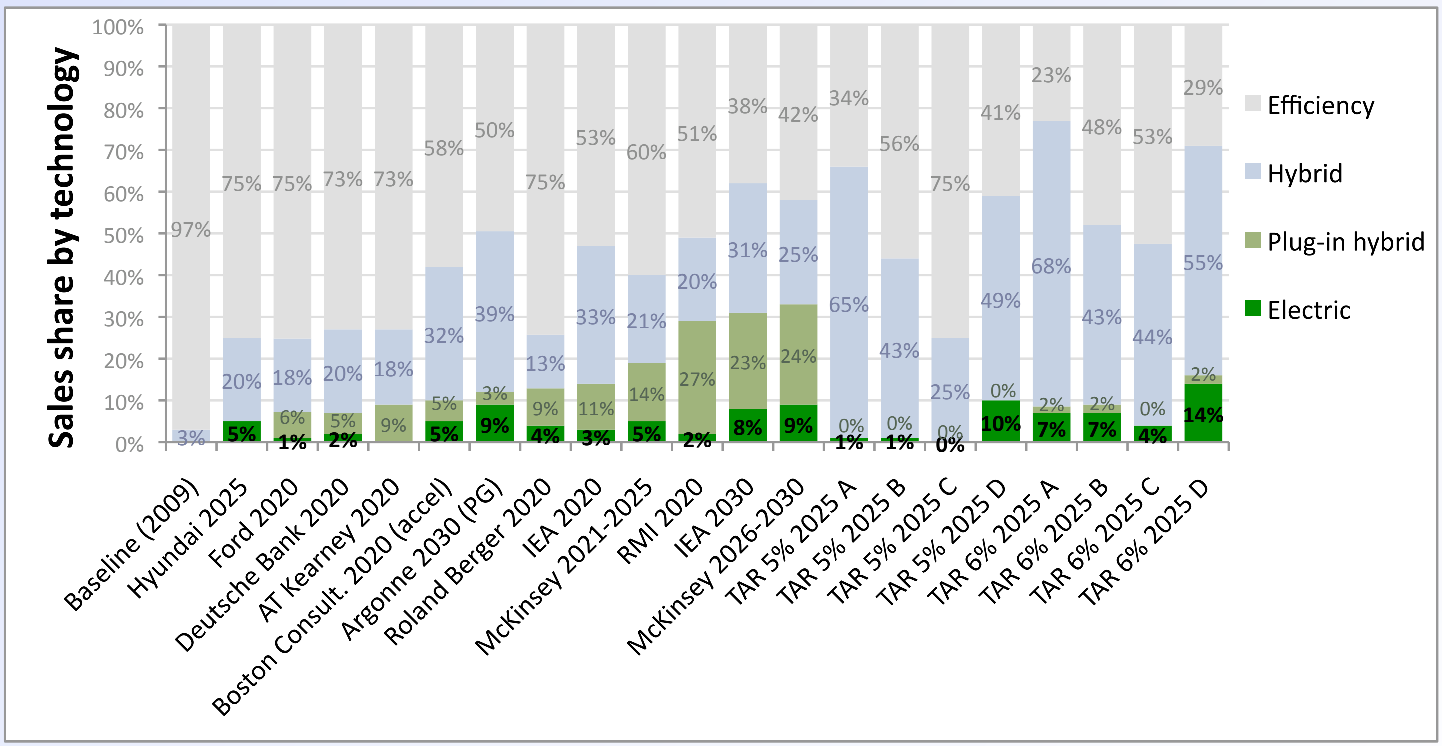
- In 2020-2025 timeframe, hybrid vehicles penetrate the market
  - Hybrids, with lower future costs, are expected to be critical part of future fleet
  - In TAR analysis, hybrids deployed at varying levels to help meet 2025 targets
    - Various research studies: 15-40% hybrid sales in 2020-2025 (without new standards)
    - In *TAR* 5-6%/year scenarios, there are 25-68% hybrid vehicles by 2025



Note: "Efficiency" includes all gasoline and diesel vehicles that do not have full hybrid or plug-in capability

Joint-Agency TAR: Electric Vehicles

- In 2020-2025 timeframe, <u>electric-drive</u> vehicles emerge
  - All automakers are planning electric vehicle (EV) introductions before 2020
  - In TAR analysis, few EVs deployed except at highest stringency targets
    - Various research studies: 5-33% PHEV and EV sales by 2020-2025
    - In *TAR* 5-6%/year scenarios, there are *0-16% electric vehicles* by 2025



Note: "Efficiency" includes all gasoline and diesel vehicles that do not have full hybrid or plug-in capability

Joint-Agency TAR: Results

- Costs and consumer impacts for scenarios for <175 gCO_2/mile
  - Consumer benefits greatly outweigh the technology costs, by factor of ~2-4
  - $1400-$3500 cost → $5300-$7400 consumer lifetime fuel saving benefit
  - All the different technology scenarios offer 2-4 year payback period:

Scenario[a]	Rated new vehicle gCO_2/mile	New vehicle consumer label fuel economy (MPGe)[b]	Technology Path	Per-Vehicle Cost Increase ($)	Payback Period [c] (years)	Net Lifetime Owner Savings [c] ($)
4%/year	173	37	A	$1,700	2.5	$5,900
			B	$1,500	2.2	$6,000
			C	$1,400	1.9	$6,200
			D	$1,900	2.9	$5,300
5%/year	158	40	A	$2,500	3.1	$6,500
			B	$2,300	2.8	$6,700
			C	$2,100	2.5	$7,000
			D	$2,600	3.6	$5,500
6%/year	143	43	A	$3,500	4.1	$6,200
			B	$3,200	3.7	$6,600
			C	$2,800	3.1	$7,400
			D	$3,400	4.2	$5,700

[a] The TAR also analyzed a 3% per year CO2 emission reduction scenario
[b] Estimated label, or on-road, numbers based on 20% lower mpg (25% higher g/mi CO_2); includes A/C credits; excludes EVs
[c] Consumer payback period based on 3% discount rate, 2008 baseline, AEO2010 reference fuel prices (e.g., $3.49/gal in 2025)

Joint-Agency TAR: Results

- Aside from the consumer fuel saving benefits, there are substantial societal benefits for each stringency level and scenarios analyzed
  - Petroleum consumption: reduced demand for oil and oil imports
  - GHG emissions mitigation: reduced future impacts of climate forcing
  - Associated benefits below are for model year 2025 vehicles (as compared to 2016 baseline vehicles)

Scenario	Rated new vehicle GHG emissions gCO_2/mile	New vehicle consumer label fuel economy (MPGe)[a]	Lifetime CO_2e Reduction[b] (million metric tons)	Lifetime Fuel Reduction (Billion barrels)
3%/year	190	34	340	0.7
4%/year	173	37	410-440	0.9
5%/year	158	40	440-530	1.1
6%/year	143	43	470-590	1.3

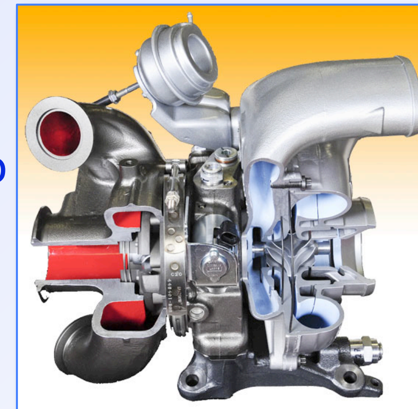
[a] Estimated label, or on-road, numbers based on 20% lower mpg (25% higher g/mi CO_2); includes A/C credits; excludes EVs
[b] Fuel reductions are the same for each of the four technology pathways, but CO_2e reductions vary as a function of the penetration of EVs and PHEVs (due to their increase in upstream emissions).

Post-TAR: Ongoing Work

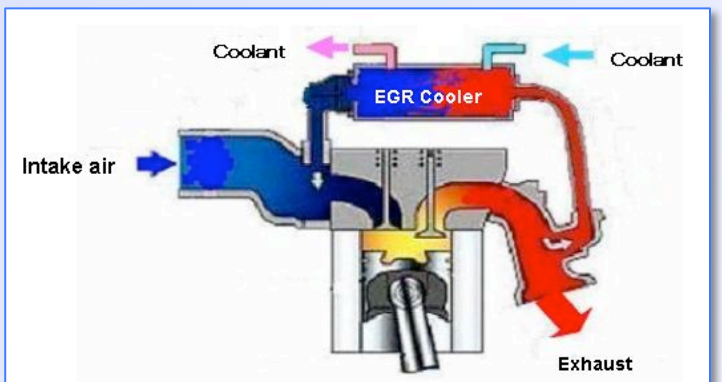
- Agencies' continuing work on future technologies
  - Technical feasibility, costs, impacts
  - Continued one-on-one dialogue with automakers and other stakeholders
- Ongoing work elements include…
  - Technology package potential
    - Simulation modeling of engine, hybrids (e.g., with Ricardo)
  - Technology costs evaluation
    - Costs of engine, drivetrain, battery, technologies (e.g., with FEV, Munro)
  - Mass-reduction feasibility, simulation
    - Follow-up to Lotus study (peer review, cost, crashworthiness)
    - New NHTSA solicitation on mass reduction feasibility
  - Safety: Statistical, compatibility studies on mass, size, safety
  - Continued multi-agency collaboration in all technical, cost areas

Post-TAR: Ongoing Work

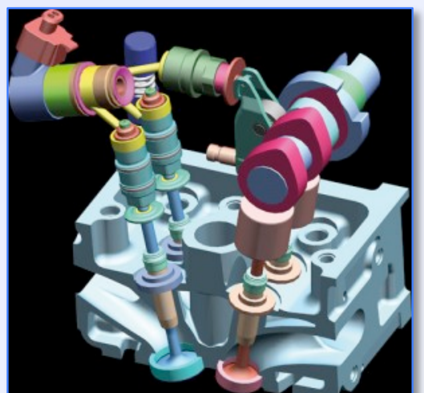
- Engine efficiency technology advances
  - EPA/NHTSA/CARB 2016: turbo direct injection
  - For 2017-2025, ongoing simulation work with Ricardo
  - Next generation engines push efficiency frontier:
    - Dual-stage turbocharging: High BMEP
    - Dual-loop high/low pressure cooled exhaust gas recirculation (EGR) systems
    - Digital valve actuation



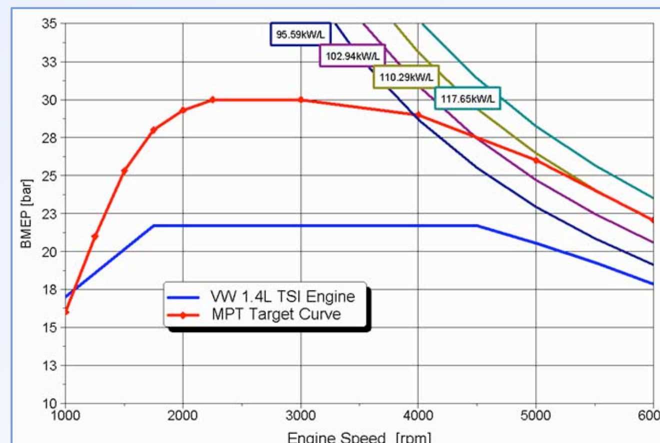
Ford/Honeywell sequential turbo with EGR



Exhaust gas recirculation



Fiat MultiAir

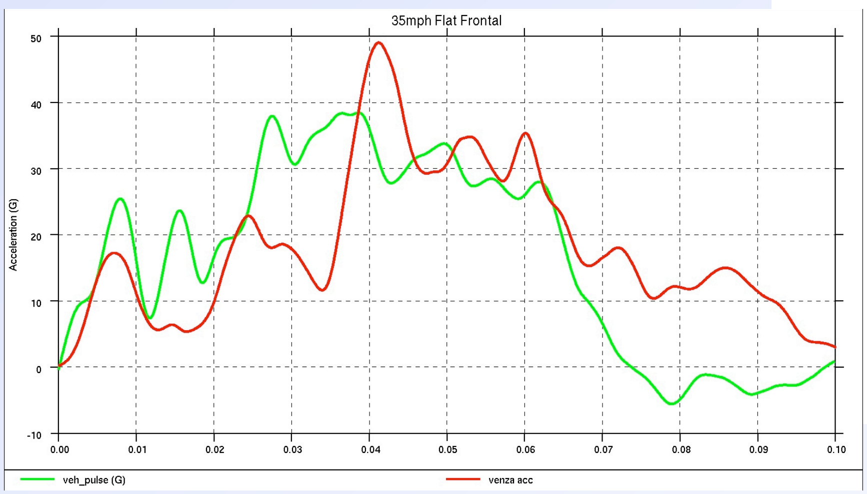


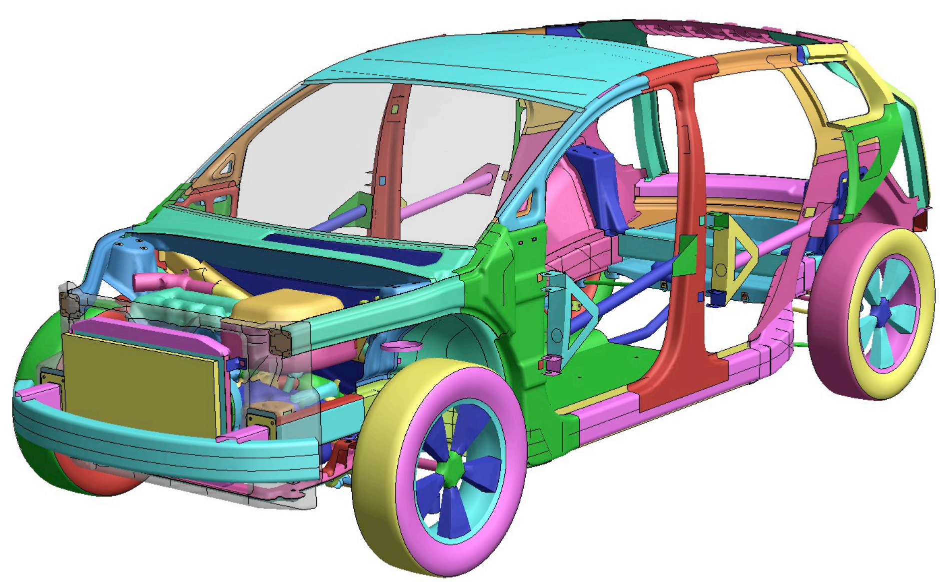
Mahle twin sequential turbo

Sources: *Exhaust gas recirculation: http://images.dailytech.com/nimage/14218_large_egr.png*
Ford/Honeywell: http://www.dieselplace.com/forum/showthread.php?t=327289
Mahle: http://www.ae-plus.com/Key%20topics/kt-Powertrain-news20.htm
Fiat: http://fiat500usa.blogspot.com/2009/05/new-fiat-technology-coming-to-america.html
BorgWarner: http://paultan.org/2007/12/14/borgwarner-r2s-sequential-vgt-turbocharger/

Post-TAR: Ongoing Work

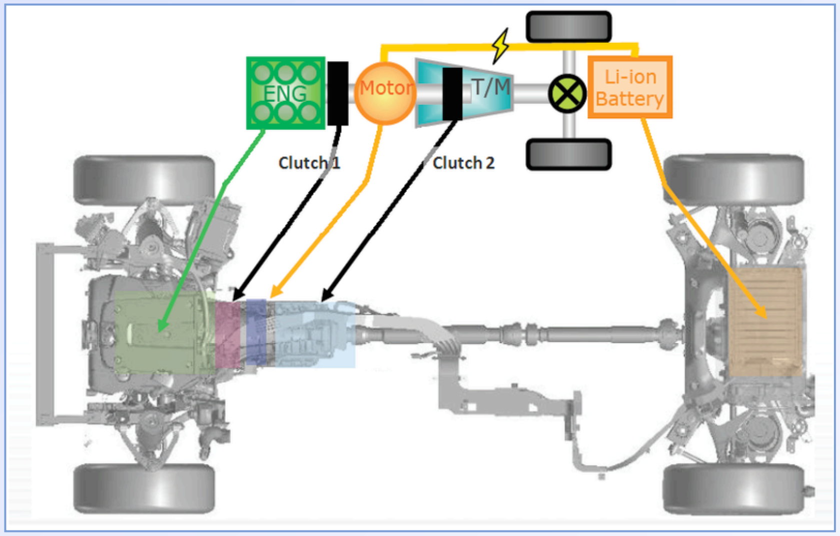
- Lotus mass-reduction crash simulation work
  - CARB/EPA/NHTSA collaboration
  - Computer-Aided Engineering (CAE)
  - Simulate vehicle in front, side, offset crashes
  - Validate crashworthiness of 30%+ mass-reduced vehicle
  - Completion in winter/spring 2011



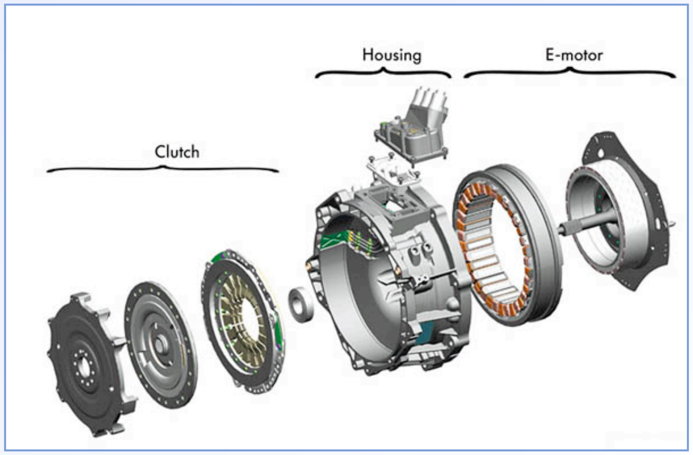


Post-TAR: Ongoing Work

- Hybrid technology advances
  - Synergies with other technologies
    - Engine (Atkinson, Miller, lean-cruise, digital valve); mass-reduction; dual-clutch trans.
  - New hybrid types, improved optimized control strategies
    - Pre-transmission clutch: increased engine decoupling
    - Higher power performance, lighter, and reduced cost Li-ion batteries
    - Smaller motors and batteries
    - Reduced city and highway CO_2 emissions



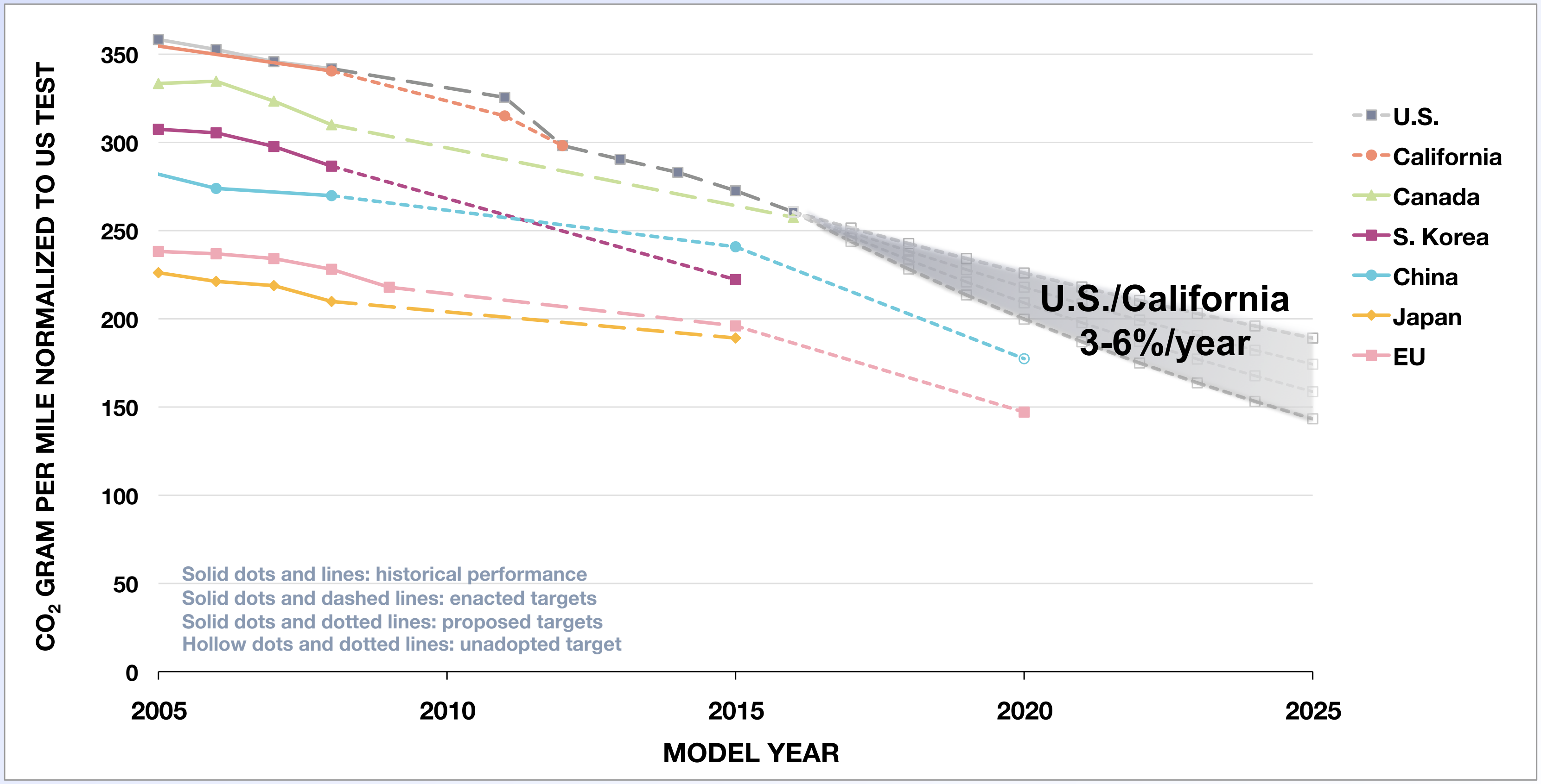
Nissan Fuga/M35 parallel hybrid layout



VW Touareg hybrid module

Vehicle Standards: International Context

- Nearly every major auto market has standards for CO_2, energy goals
  - Different policies (gCO_2/km, km/L, etc), timing, design, stringency, test cycles
  - As US works on 2017-2025 standards, so do other agencies around the world



Source: International Council on Clean Transportation

Conclusions

- Joint-agency *Interim Technical Assessment Report* demonstrates technology potential for year 2025 vehicles
  - Many available and emerging low-CO_2 technologies
  - Increased technology cost with technology complexity
  - Technologies have substantial consumer benefits
    - Every scenario analyzed had consumer payback period of 1.4 to 4.2 years
    - For example: 143 gCO_2e/mile (consumer: ~43 mpg) = 3-4 year payback
  - Technologies have substantial societal benefits
    - Emission reduction: Up to 570 million tonnes CO_2 emissions (MY2025)
    - Energy/fuel security: Up to 1.3 billion barrels fuel saved (MY2025)
- Ongoing work elements include…
  - Multi-agency collaboration on technology potential, cost evaluation, feasibility, safety impacts, upstream impacts, attribute-indexed curves, manufacturer-specific impacts, infrastructure, etc.

- Additional slides follow:
  - References
  - Background

References

- Download EPA/NHTSA/CARB *Interim Technical Assessment Report:*
  - *http://www.arb.ca.gov/msprog/clean_cars/ldv-ghg-tar.pdf*
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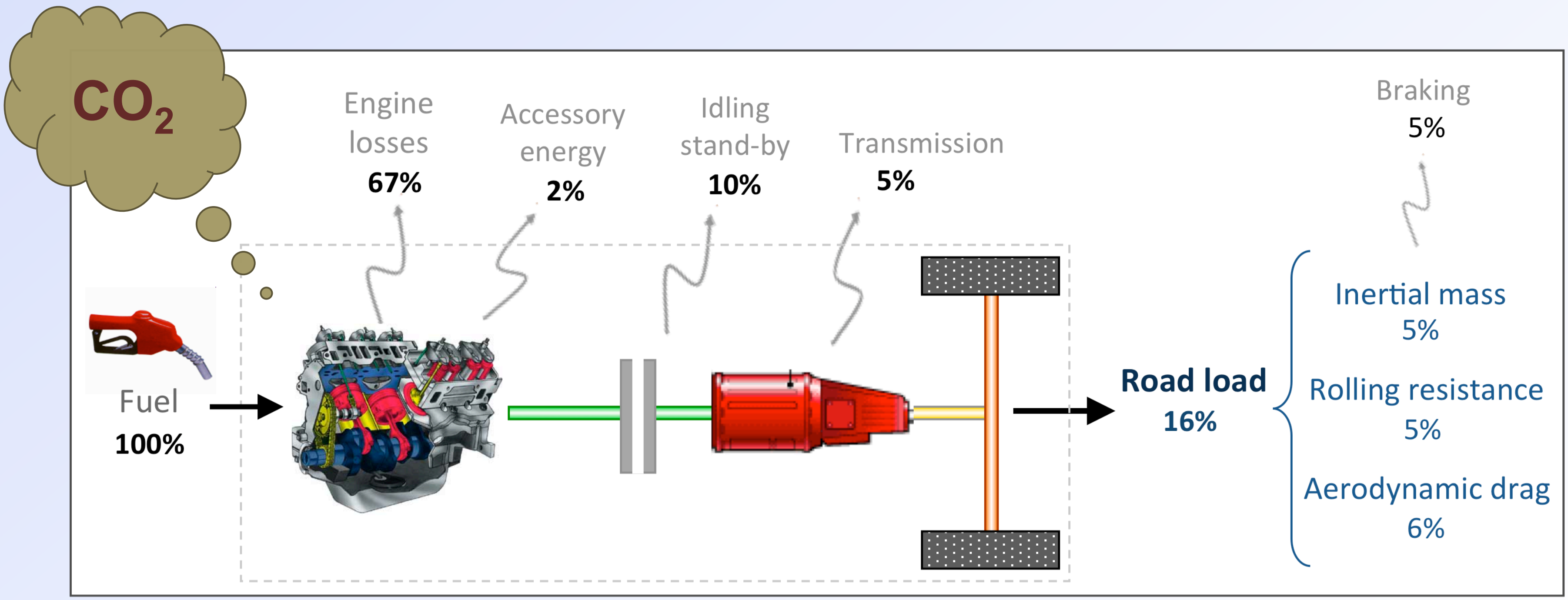
Energy Loss, Efficiency, and CO_2

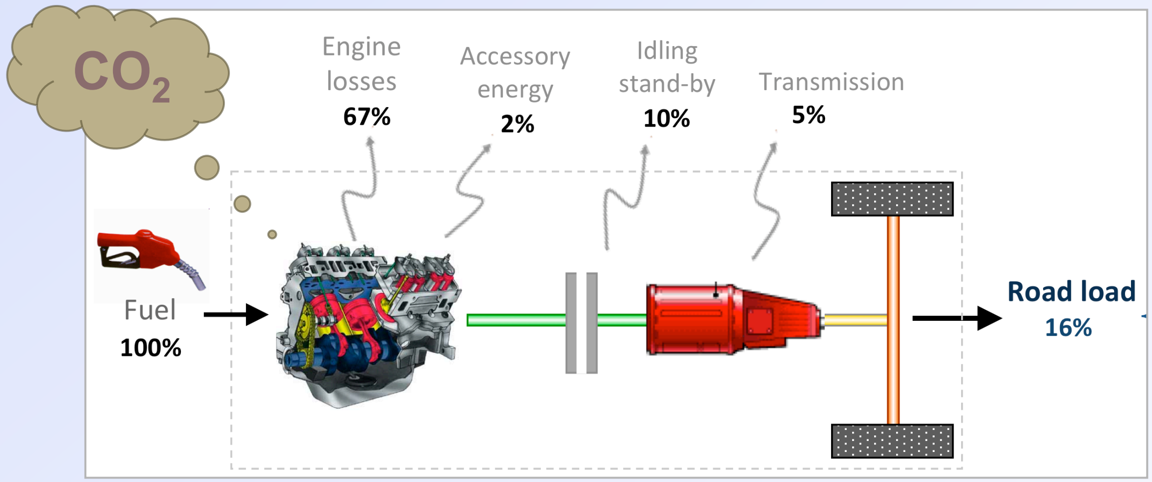
- Why are there so many available efficiency technologies available?
  - Because there are so many energy *losses* in the modern automobile
    - Efficiency is the ability of a powertrain to convert fuel energy into vehicle propulsion
    - Modern vehicles are generally 15-25% efficient
    - More efficient powertrain → less energy needed → less carbon combusted



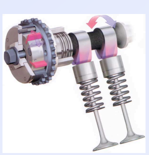
Percents are approximate, based on energy losses for vehicles on the combined U.S. city and highway drive cycles.
Sources: Kromer and Heywood, 2007 and U.S. EPA, 2010 http://www.fueleconomy.gov/feg/atv.shtml

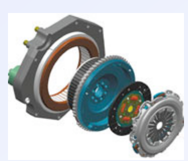
Efficiency and Low-CO_2 Technologies

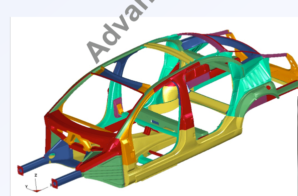
- What emerging efficiency technologies are available for vehicles?
  - These are some of the many being deployed today by automakers around to world

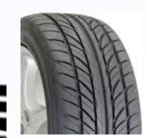


Variable valve lift
Variable valve timing
Low friction lubrication
Cylinder deactivation
Turbocharging
Direct injection
Lean-burn
Compression ignition
Electric power steering
Efficient air conditioning
Integrated starter "Stop-start"
6+ speed transmission
Dual-clutch transmission
Advanced lightweight materials
Optimized vehicle design
Improved aerodynamics
Low rolling resistance tires







GHG-Reduction Technologies

- Many available high-efficiency low-CO_2 technologies for vehicles
  - Many just beginning to be deployed by automakers for 2016 standards
  - More lead-time for 2025+ allows for more technology advancement

Area	Technology or efficiency mechanism for CO_2 reduction		Potential CO_2 reduction[a]	U.S. adoption in new 2008 fleet [b]
Powertrain	Engine	Variable valve timing or lift	2-8%	53%
		Cylinder deactivation	3-6%	6%
		Turbocharging	2-5%	2%
		Gasoline direct injection	8-15%	4%
		Compression ignition diesel	15-40%	0.1%
		Digital valve actuation	5-10%	0%
	Transmission	6+ speed	3-5%	21%
		Continuously variable	4-6%	8%
		Dual-clutch, automated manual	4-8%	1%
Vehicle	Aerodynamics		5-8%	-
	Tire rolling resistance		2-8%	-
	More efficient auxiliaries (steering, air conditioning)		2-10%	-
	Mass-reduction	Advanced materials component	5-10%	-
		Integrated vehicle design	10-20%	-
	Hybrid systems	Stop-start mild hybrid	5-10%	<1%
		Full hybrid electric system	20-50%	2%
	Electric-drive	Plug-in capable electric vehicles	30-75%	0%
		Fuel cell vehicles	30-75%	0%

Critical 2010-2020 efficiency, CO_2 technologies

Increasingly important 2020-2025 technologies

[a] Many technologies can be combined, percents are approximate but not strictly additive; from US EPA, 2010
[b] From US EPA, 2009 "Trends" report