Technical Assessment in US Greenhouse Gas (GHG) Regulations:

Methodology and Key Results

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Outline

- Background
- Technical assessment
  - Data sources, resources, steps
- Regulatory findings for proposed 2017-2025 standards
  - Vehicle technology modeling
  - Technology cost assessment

Background: Timeline for 2017-2025 Standards

Finalize regulations

Public stakeholder comment period

Proposal of Federal and California Regulations:
- Target: ~54 miles per gallon
- Target: ~164 grams CO_2/mile

Further technical assessment:
- Deliberation with auto industry
- Vehicle modeling; contract work

Joint technical report:
- Agencies collaborate on *TAR*
- Assess range of stringency

Initiation of work:
- US EPA, NHTSA, and CARB initiate work on CO_2/CAFE standards for 2017-2025

2010 | 2011 | 2012

Today

Technology Assessment: Data Sources

- Many automotive technologies will be applied for compliance with existing 2012-2016 and proposed 2017-2025 regulations
- The technology assessment is based on many data sources
  - Available public technical literature
    - E.g., SAE journal articles
  - New and contracted technical work
    - Vehicle simulation work of technology packages from Ricardo
    - Teardown engineering cost assessment from FEV (e.g., on turbocharging, gasoline direct injection, dual clutch transmission, stop-start, hybrid system components, lithium ion batteries)
    - Mass-reduction assessment (e.g., Lotus Engineering)
    - Battery modeling for electric vehicles (from US energy laboratory)
  - Confidential business information
    - From individual automobile manufacturers
    - From individual suppliers (e.g., of turbochargers, tires, advanced materials)

Publicly available, peer-reviewed technical reports

Technology Assessment: Resources

- Federal rulemaking:
  - By US Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA)
  - Website: *http://www.epa.gov/otaq/climate/regulations.htm*
  - Major documents:
    - Proposal: "Notice of Proposed Rulemaking" (NPRM)
    - Technical: "Joint Technical Support Document" (TSD)
    - Other reports: *http://www.epa.gov/otaq/climate/publications.htm#vehicletechnologies*
    - Public docket: *http://www.regulations.gov/#!searchResults;s=EPA-HQ-OAR-2010-0799*
- California rulemaking
  - By California Air Resources Board (CARB)
  - Website: *http://www.arb.ca.gov/regact/2012/leviiighg2012/leviiighg2012.htm*
    - Also: *http://www.arb.ca.gov/msprog/clean_cars/clean_cars.htm*
  - Major document: "Initial Statement of Reasons" (ISOR)
  - Includes GHG; criteria pollutants, and ZEV regulations as package

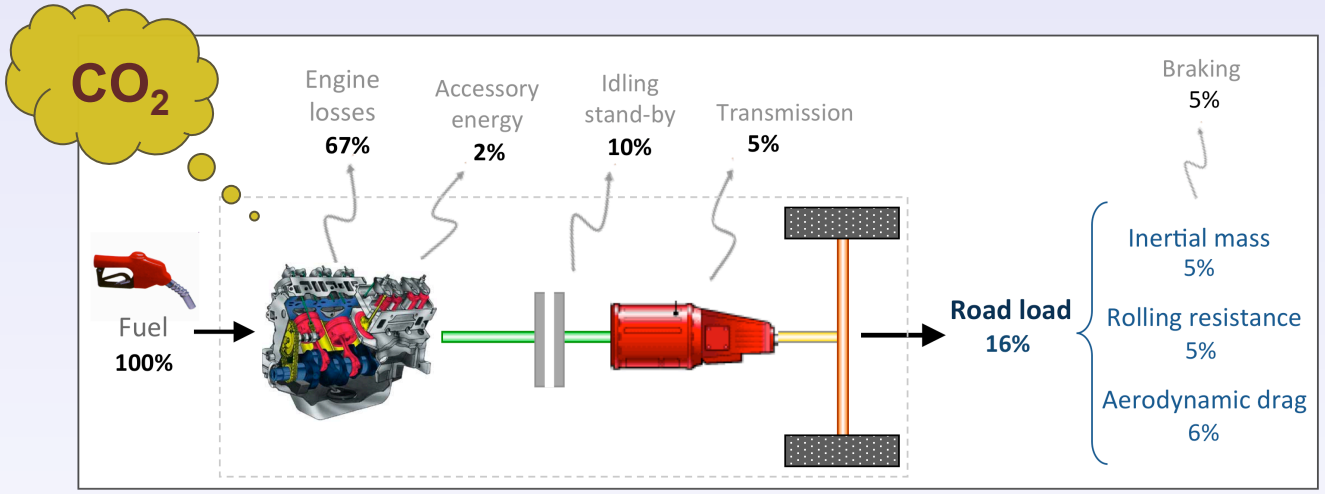
Technology Assessment: Steps

- Baseline fleet modeling
  - Company model-by-model sales/technology today and projected through 2025
- Technology feasibility
  - Differs by vehicle class (E.g., mass reduction, transmission type, hybrid, electric)
- Technology package modeling
  - Model CO_2-reduction with incremental technology
  - Model synergies of multiple technologies (based on Ricardo simulation work)
  - Model 19 vehicle classes (e.g., V6 car, 4-speed transmission)
  - Build up technology costs based on teardown work, OEM, supplier information
  - Develop CO_2 reduction-versus-cost sequence for increasing technology adoption
  - Incorporate crediting (e.g., car air conditioning credits up to 18 gCO_2/mile)
- Automaker compliance cost modeling
  - Assess amount of technology required for each automaker to achieve compliance
  - Incorporate each automakers' baseline for its specific fleet mix by footprint
  - Evaluate projected cost of compliance based adoption of minimum technology

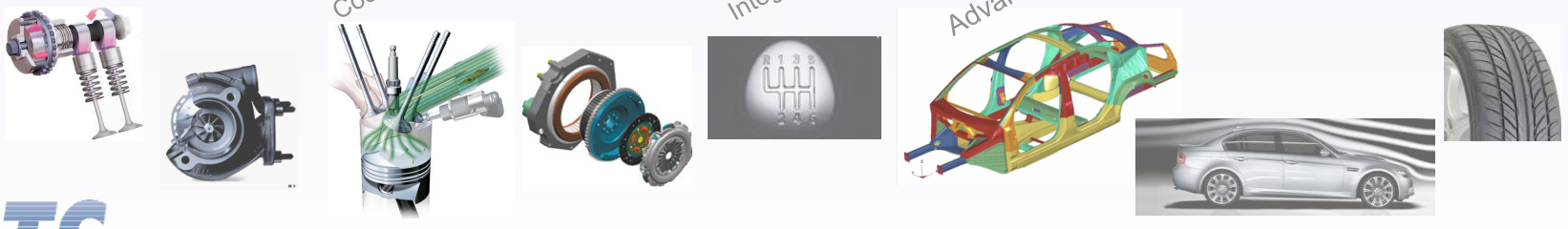
Based on technical contract work and OEM input

Technical Background: Vehicle Efficiency

- The modern internal combustion automobile, at roughly 15-20% efficiency, has many efficiency losses – and many technical solutions



Variable valve lift
Variable valve timing
Low friction lubrication
Cylinder deactivation
Turbocharging
Direct injection
Cooled exhaust gas recirculation
Lean-burn
Compression ignition
Electric power steering
Efficient air conditioning
Efficient alternator
Integrated starter "Stop-start"
6-8 speed transmission
Dual-clutch transmission
Advanced lightweight materials
Optimized vehicle design
Low drag brakes
Improved aerodynamics
Low rolling resistance tires



Sources: Kromer and Heywood, 2007 and U.S. EPA, 2010 http://www.fueleconomy.gov/feg/atv.shtml

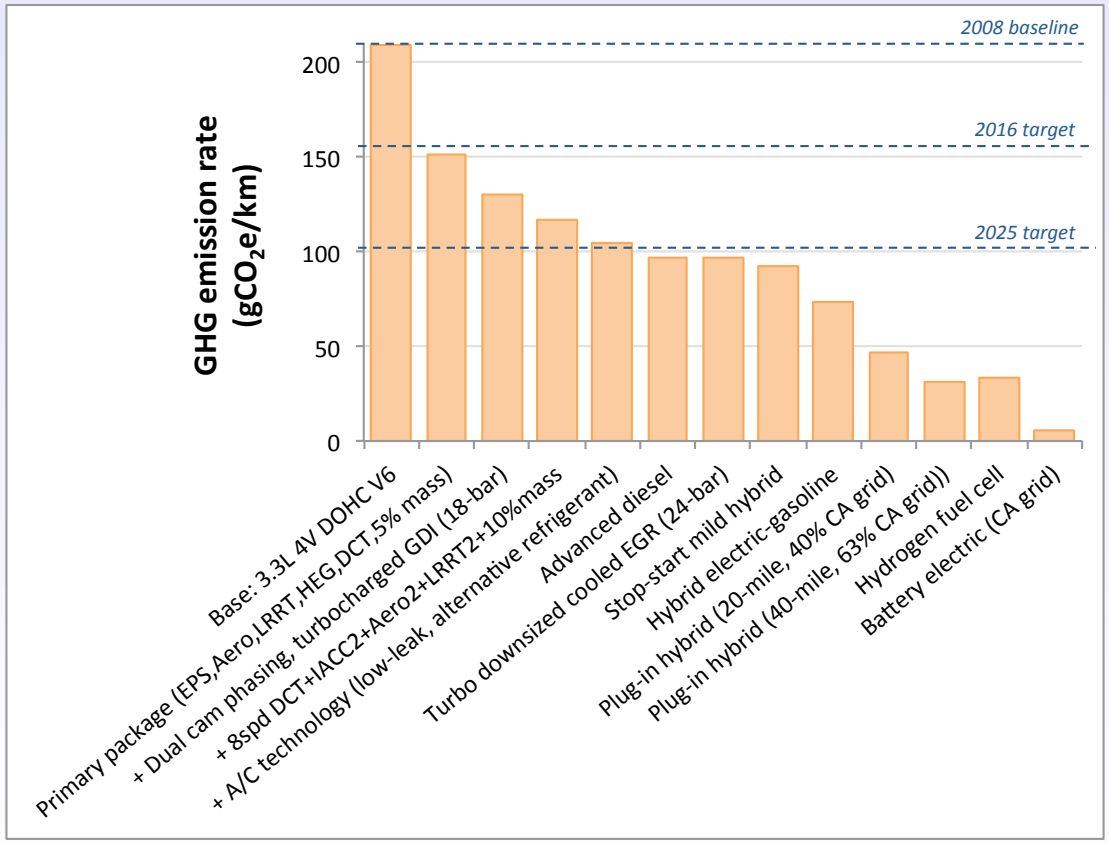
Individual Technologies

Area	Technology for CO_2 reduction		Technology share, MY2010	Potential CO_2 reduction
Powertrain	Engine	Low friction lubrication	-	0.5%
		Engine friction reduction	-	2-4%
		Variable valve timing (and lift)	86%	4-6%
		Cylinder deactivation	7%	5-6%
		Turbocharging	3%	2-5%
		Turbo, gasoline direct injection	9%	8-15%
		Cooled EGR, turbo, GDI	-	20-25%
		Compression ignition diesel	0.5%	15-25%
		Digital valve actuation	-	5-10%
	Transmission	Early torque converter lock-up	-	0.5%
		Optimized shifting	-	2-6%
		6+ speed	40%	2-8%
		Continuously variable	10%	8-11%
		Dual-clutch, automated manual	-	9-13%
Vehicle	Aerodynamics		-	2-5%
	Tire rolling resistance		-	2-4%
	Accessories (steering, air cond., alternator)		-	1-4%
	Lower refrigerant emissions (low-leak, low-GWP)		-	2-10%
	Mass-reduction	Advanced material component	-	1-5%
		Integrated vehicle design	-	5-10%
	Hybrid systems	Stop-start mild hybrid	<1%	6-8%
		Full hybrid electric system	3%	30-35%

Technology CO_2-reduction potential differs by vehicle class, by drive cycle, and when multiple technologies are combined

Example: Combined Technology Packages

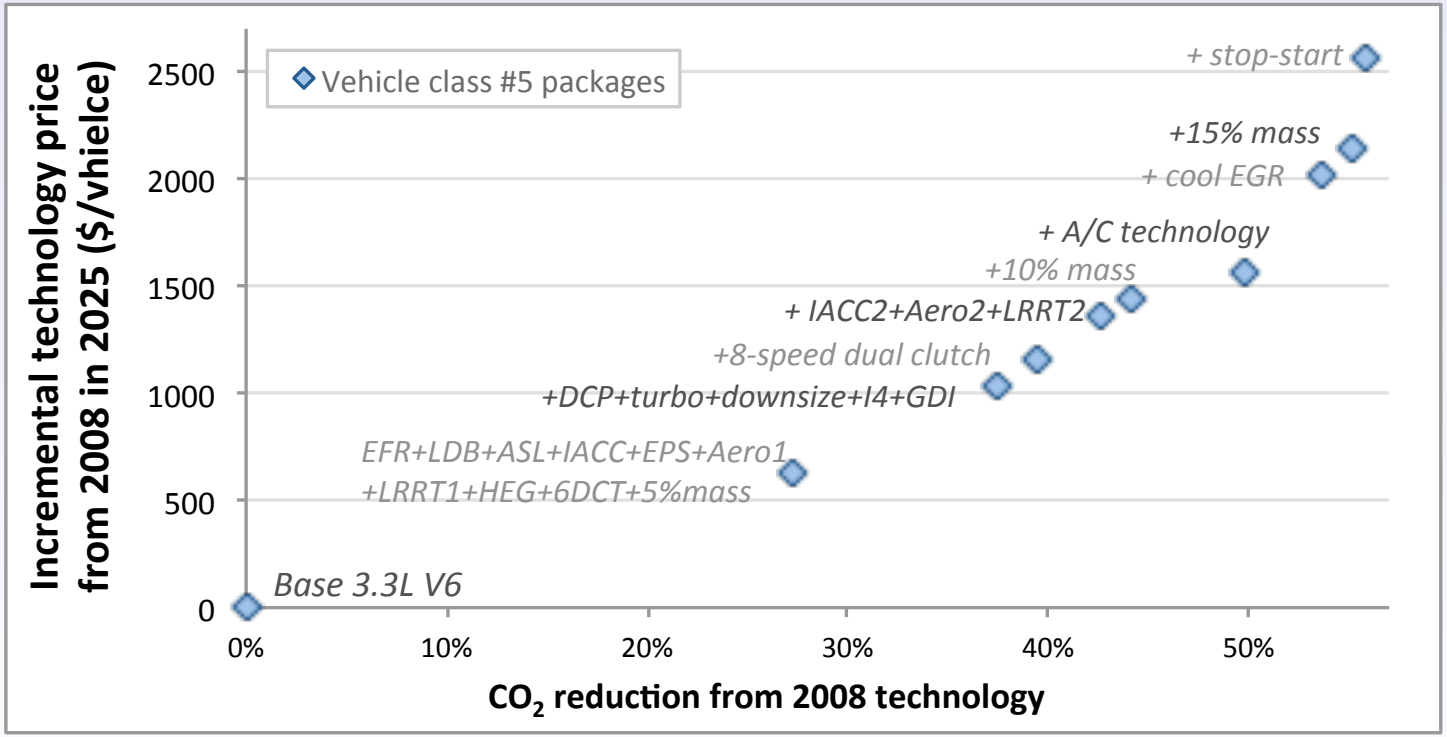
- Representative "mid-size vehicle" with increasing technology adoption
  - Various packages available for ~50% GHG reduction (~2025 goals)



Notes: Vehicle class #5 (out of 19 classes) is shown; Emission levels based on combined 55% city / 45% highway US test procedure; plug-in electric vehicles are evaluated on California electricity grid; See CARB ISOR and US EPA NPRM for technology details

Example: Technology Cost-vs-GHG Walk-Up

- Representative "mid-size vehicle" technology-cost progression
  - Increasing cost with increasing technology adoption



Notes: Vehicle class #5 (out of 19 classes) is shown; Emission levels based on combined 55% city / 45% highway US test procedure; See CARB ISOR and US EPA NPRM for technology details

Results: Technology Adoption

- Compliance with US GHG standards is projected to primarily result from increased adoption of advanced gasoline efficiency technologies
  - Federal and California rulemakings utilize same underlying technical assumptions
  - California's ZEV program also includes electric-drive vehicle requirements

Technology for CO_2 reduction		Technology share, 2021 [USEPA]	Technology share, 2025 [USEPA]	Technology share, 2025 [CARB]
Engine	Improvements in low friction lubrication; engine friction reduction, variable valve timing/lift	>50%	>90%	>90%
	Turbocharged gasoline direct injection	63%	85%	51%
	Cooled EGR, turbocharged GDI	12%	66%	14%
Driveline	Early torque converter lock-up, high efficiency gearbox, optimized shifting, 8-speed	>50%	>90%	>90%
	Dual-clutch, automated manual	55%	55%	56%
Accessory	Electric power steering; efficient alternator, air conditioning; low-leak, low GWP refrigerant	>90%	>95%	>90%
Load reduction	Aerodynamic, low RR tires, low-drag brakes	>60%	>95%	>95%
	Mass reduction *	7%	12%	8%
Advanced	Hybrid electric	7%	15%	6%
	Plug-in hybrid, electric, fuel cell	1%	3%	15%

See CARB ISOR and US EPA NPRM for technology details

** Mass reduction is fleet average (not percent new vehicle technology share, like other technologies listed)*

Results: Compliance Cost, Savings

- Federal and California rulemakings project similar overall increase in vehicle price and consumer fuel saving benefits

		Federal U.S. GHG / CAFE proposal	California proposal (GHG, criteria, ZEV)
Assumptions	Fuel price ($/gallon in 2025)	$3.50	$4.00
	Vehicle median life	14 years	15 years
	Vehicle median lifetime mileage	230,000	205,000
	Consumer fuel saving discount rate	3%/7%	5%
Technology cost	Baseline (2016 v. 2008)	$750	$1150
	New technology (2025 v. 2016)	$1750 (NHTSA) $1950 (USEPA)	$1900
Consumer savings	Payback period	4 years	3 years
	Lifetime fuel savings per vehicle	$5200 (7%) $6600 (3%)	$5900
	Net lifetime savings per vehicle (fuel savings minus technology cost)	$3000 (7%) $4400 (3%)	$4000

Values approximate, involve rounding; see CARB ISOR and US EPA NPRM for technology details

Conclusion

- This presentation summarizes major technical steps and findings from the US greenhouse gas regulations
- The federal (US EPA / NHTSA) rulemaking
  - Proposed in November 2011
  - Set to be finalized in July 2012
- California (CARB) rulemaking
  - Includes GHG, criteria pollutant (NOx, HC, PM), and ZEV regulations
  - Proposed in December 2011
  - Board approved January 27, 2012
- Full technical and regulatory details are available at US EPA, NHTSA, and CARB rulemaking websites