GHG Standards for Light-duty Vehicles

Review of EPA's Technical Assessment and Role of Engineering Plastics for Mass Reduction

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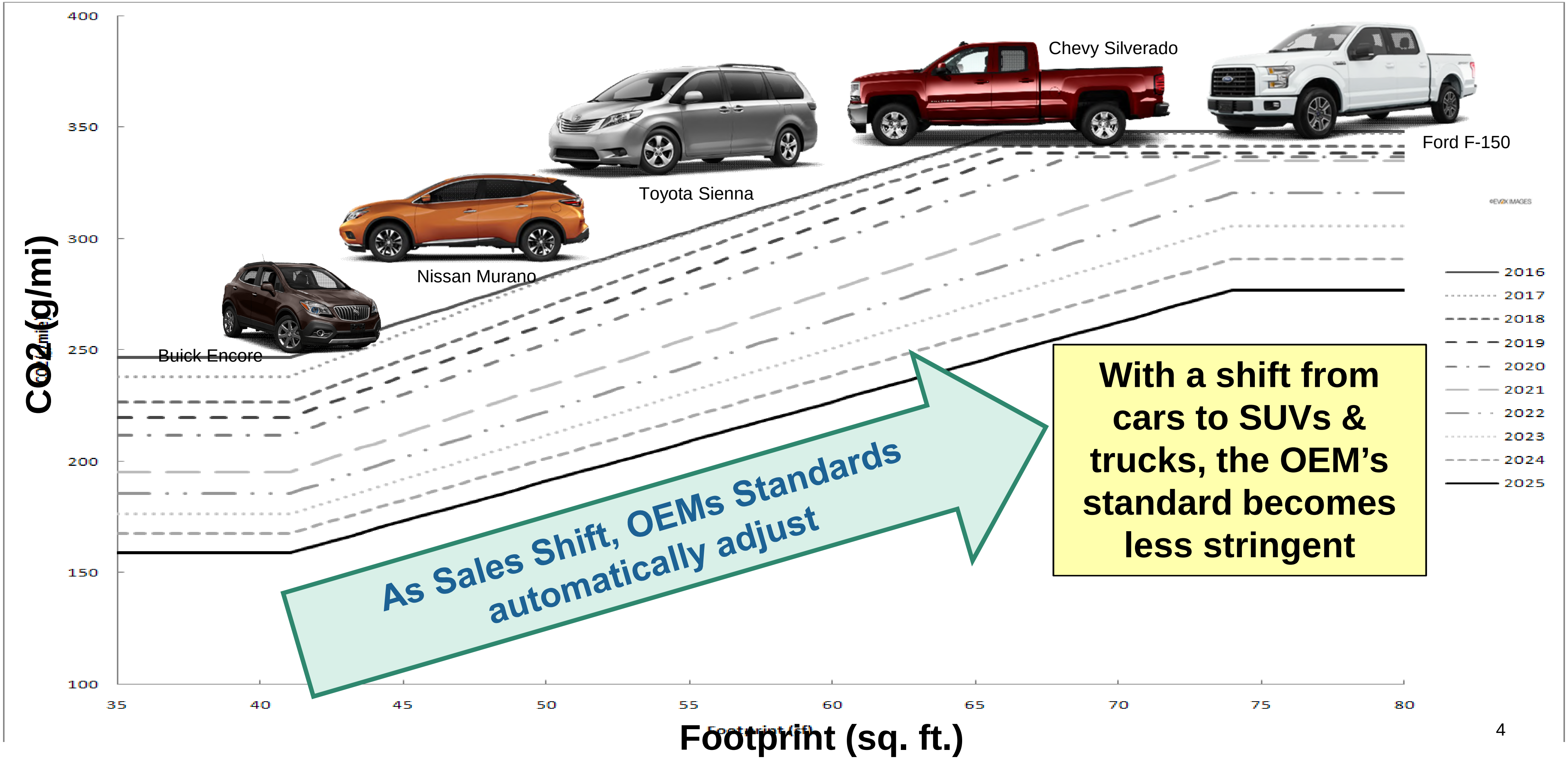
Overview

- **How the EPA GHG Standards Work**
- **Industry Progress-to-Date**
- **What Might the 2025 Time-Frame Look Like**
  - EPA assessment (thus far)
- **What Comes Next**

How the EPA standards work

Footprint-based CO_2 Target Curves for Trucks – "The Standards"

[separate footprint curve for Cars]



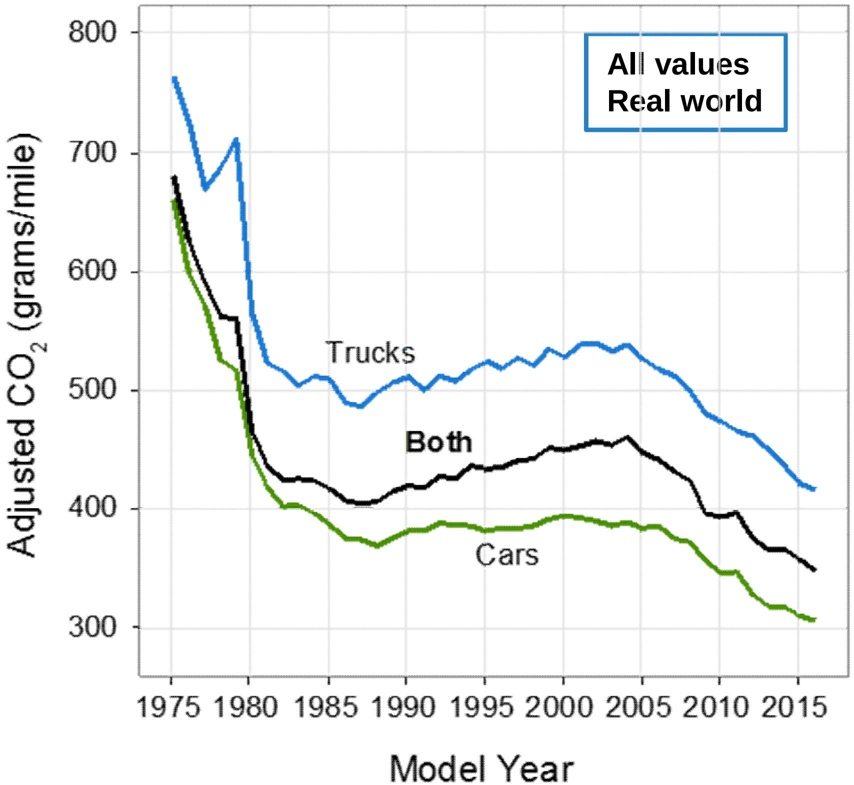
So What is the 2025 EPA Standard?

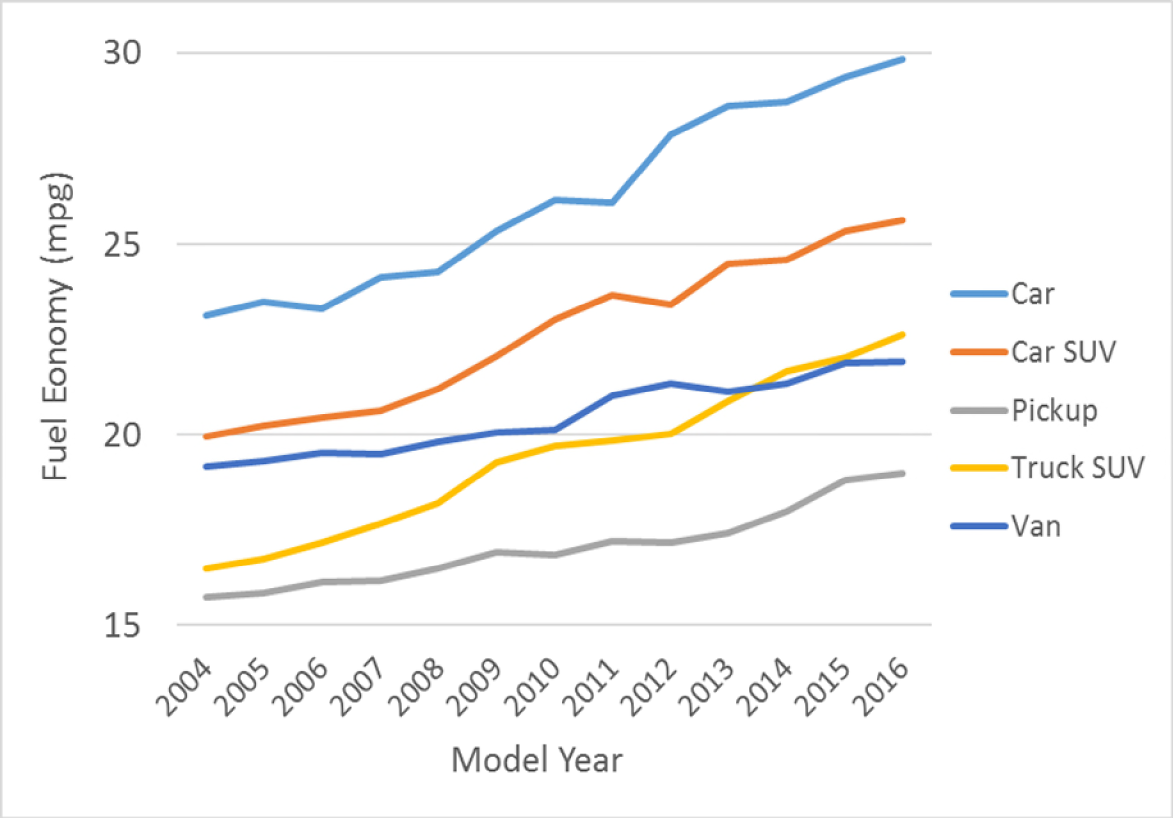
Projections for Model Year 2025 Fleet CO2 Compliance Target
Fuel Prices/Fleet Mix Affect EPA's PROJECTION of 2025 Standard

	2012 Projection	Summer 2016 Projection	Fall 2016 Projection
Fuel Price ($/gallon)	$3.87	$2.95	$2.97
Car/truck mix	67/33%	52/48%	53/47%
2025 Fleet CO_2 Compliance Level (g/mi, 2-cycle)	163	175	173
MPG-e (2-cycle)	54.5	50.8	51.4

Progress-to-Date and Contribution of Mass Reduction

Vehicle CO_2 Emissions at Record Low – every major vehicle category improving



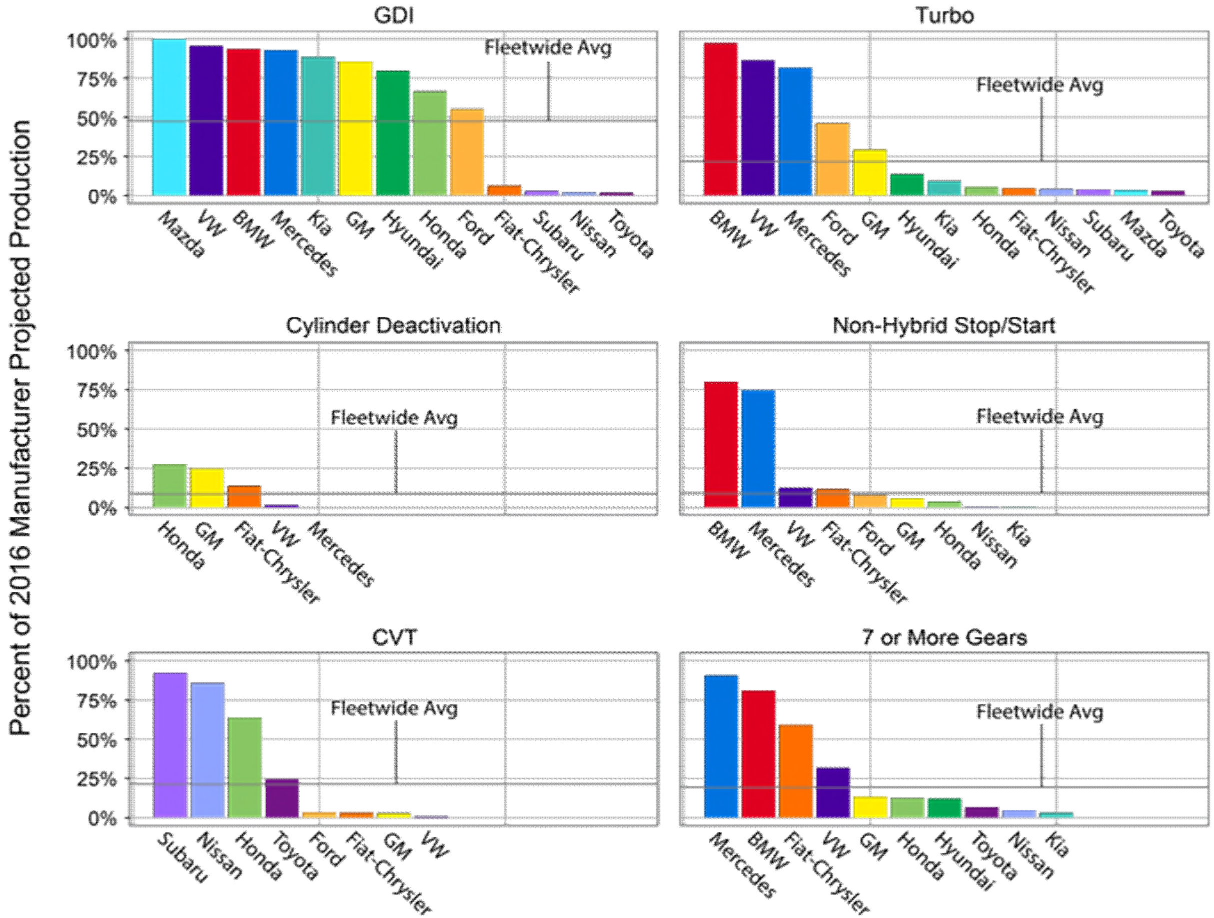


MY2015: 358 g/mi CO_2 (24.8 mpg)
MY 2016 Projected : 25.6 mpg

Truck SUVs highest % improvement since 2004, up 33%
Pickups improved most in past year, up 0.8 mpg to 18.8 mpg

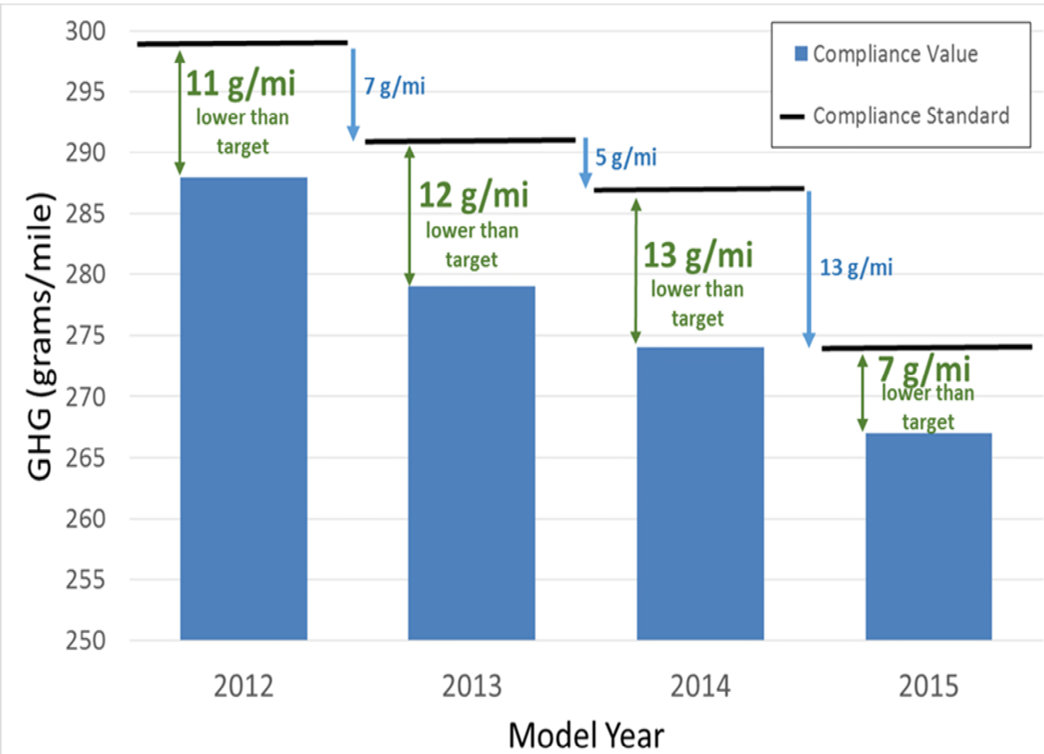
Automakers Adopting a Wide Array of Technologies at Rapid Rates

- **GDI** use on nearly half of all vehicles (up from 3% in MY2008), with Mazda at 100%, 6 more OEMs above 75%
- ~20% fleet use **7+ speed transmissions**, led by Mercedes, BMW, and Fiat-Chrysler
- >20% fleet use **CVTs**, led by Subaru, Nissan, and Honda

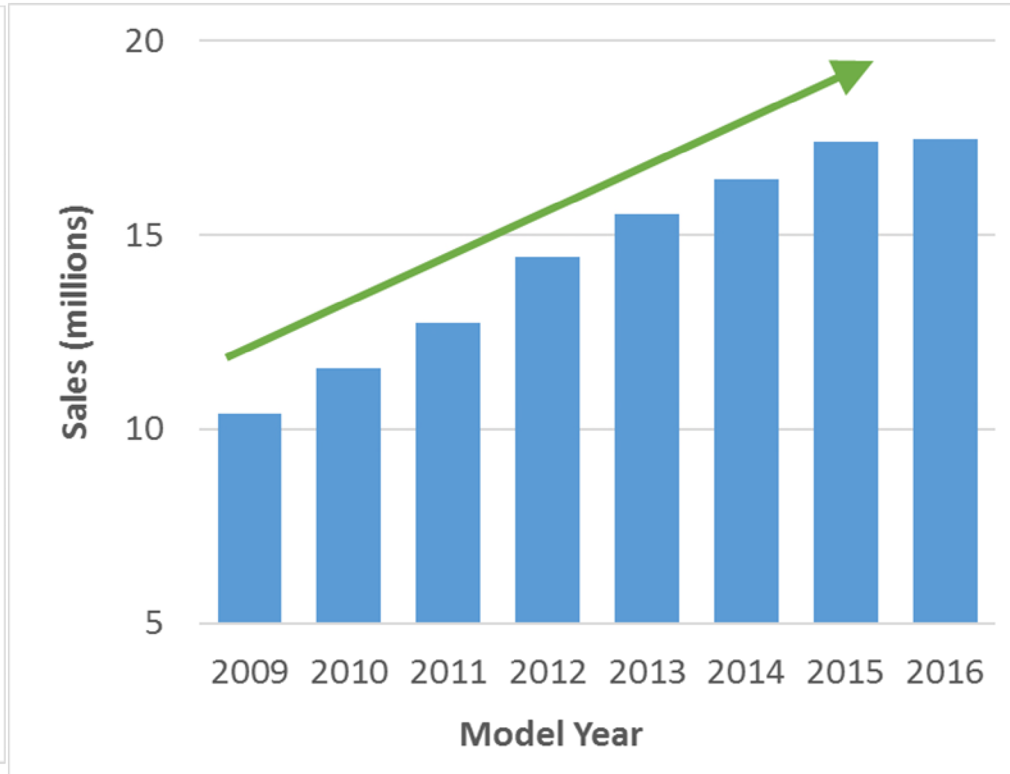


Early Years of Program Producing Positive Results

Industry Outperforming Standards



7 Years of Sales Increases Thru 2016 First Time in 100 Years



What Happens to the Over Compliance?

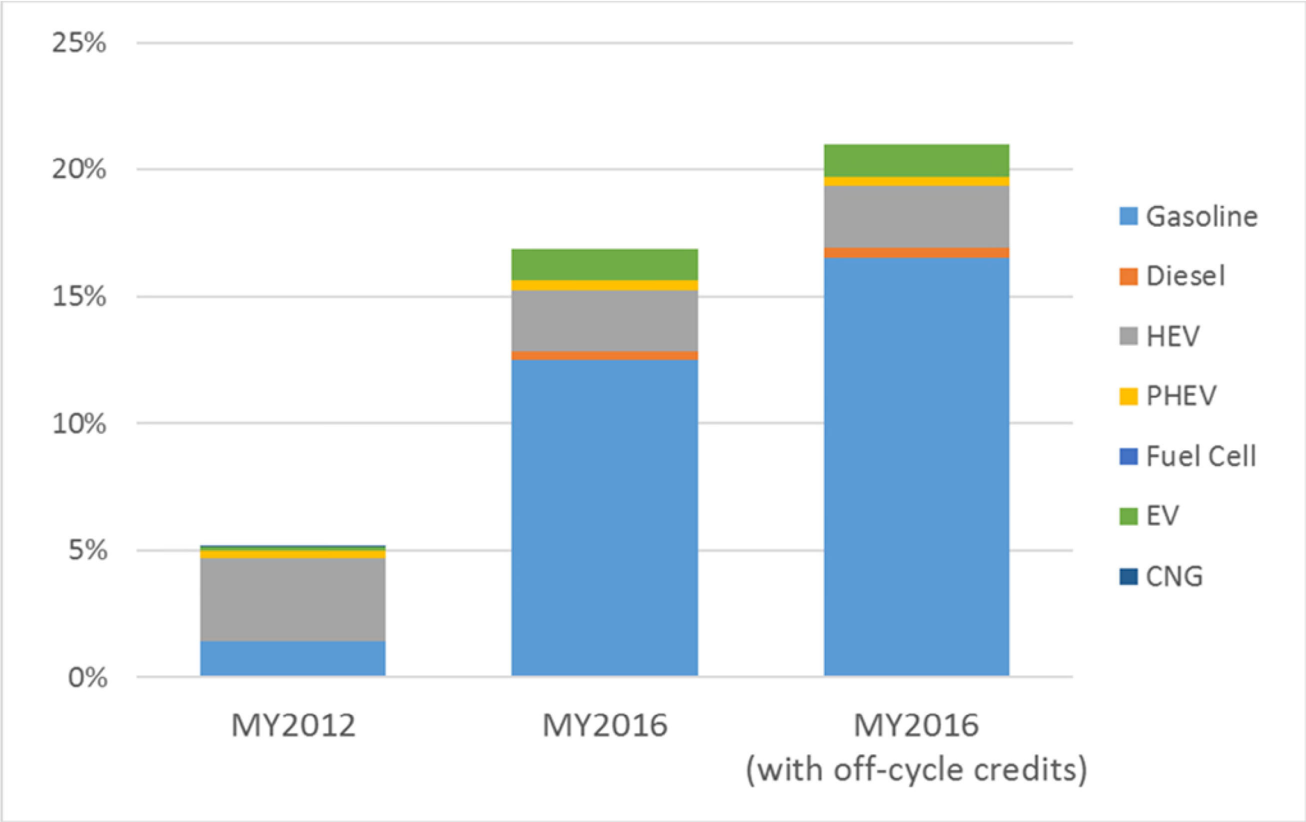
GHG Program is a Multi-Year Program, multiple layers of flexibility for OEMs

- No single year determines compliance.
- Program includes emissions banking and trading
- Credits last at least 5 model years, and early credits last longer.
- Debits can be carried forward for 3 model years.
- Today, the bank is **280 Million Megagrams CO2**
  - o What's a Megagram?
  - o 280M worth about **80 grams CO2/mile** for the entire U.S. fleet
  - o Would allow the MY2015 fleet to comply with EPA standards through 2019, if all firms participated fully in credit trading
  - o Through MY2015, 12 OEMs involved in credit trading

Advanced Gasoline Vehicles can Take the Industry Much Further …

many vehicles already meet future targets

Vehicle Production that Meets or Exceeds MY2020 CO_2 Targets



With fleet averaging, in any given model year, only about 50% of vehicles would need to meet/exceed their target, depending on sales volumes.

What might 2025 look like: EPA technical assessment (thus far)

EPA's Assessments are Informed by a Wide Range of Information

- **Technical research performed by EPA**
  - Benchmarking testing of **30 vehicles** across wide range of powertrains & segments (with more to come)
  - Published more than **30 peer-reviewed papers and technical reports**
  - Vehicle simulation modeling, cost teardown studies, mass reduction feasibility/cost studies, manufacturer "learning by doing" costs, research on consumer issues, economic inputs, others

- **Extensive reviews of the literature**
  - **100's of reports/papers** from the literature published since 2012, including major studies such as the 2015 National Academy of Sciences report

- **Stakeholder outreach & collaboration**
  - Hundreds of meetings with automakers, suppliers, NGOs, consumer groups, labor, states/local governments, others
  - Collaboration with NHTSA, CARB, DOE, Transport & Environment Canada

EPA Most Recent Assessment –
Standards can be Met Mostly with Advanced Gasoline Technologies

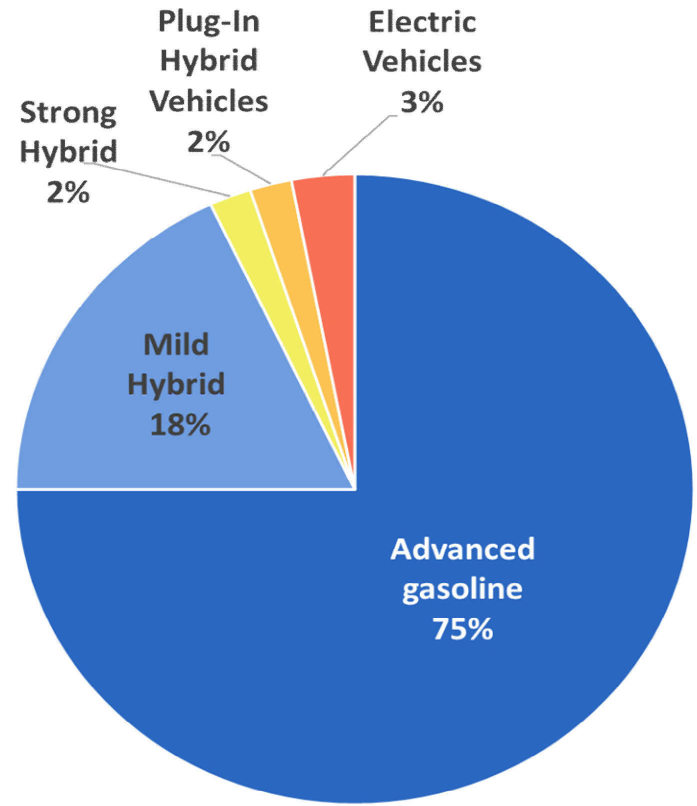
Cost estimate of $875/vehicle

- ✓ **Advanced engines and transmissions**
- ✓ **Vehicle light-weighting**
  7% Average Mass Reduction from MY2015
- ✓ **Improved aerodynamics**
- ✓ **More efficient accessories**
- ✓ **Low rolling resistance tires**
- ✓ **Stop-start technology**
- ✓ **Mild hybrid (e.g., 48 volt systems)**
- ✓ **Small levels of strong HEV, EV, PHEV**

Fuel Savings Offsets Cost increase

- ✓ **Net lifetime savings of $1,650**

One possible powertrain pathway



Holistic Vehicle Mass Reduction Studies Completed Since 2012 Final Rule

(NHTSA/EDAG) <u>Midsize Car</u>
(2012)
Baseline: MY2011 Honda Accord
Unibody
3G Optimization
AHSS body structure with Al Closure

(ARB) <u>Midsize CUV</u>
(2012)
Baseline: MY2010 Venza
Unibody
Towing 1000-3500 lbs
Al intensive design

(DOE/Ford/Magna) <u>Midsize car</u>
(2015):
Baseline: MY2013 Fusion
Unibody
Cost study for 40-45%

(EPA/FEV) <u>Midsize CUV</u>
(2012)
Baseline: MY2010 Venza
Unibody
Towing 1000-3500 lbs
2G Optimization; Secondary Mass
HSS body structure with limited use of Al closure

(NHTSA/EDAG) <u>Light Duty Pickup Truck</u>
(2016)
Baseline: MY2014 Silverado
Body on Frame
Towing up to 12,000 lbs
3G Optimization
AHSS frame with Al/AHSS cab structure and closure

(EPA/FEV) <u>Light Duty Pickup Truck</u>
(2015)
Baseline: MY2011 Silverado
Body on Frame
Towing up to 12,000 lbs
2G Optimization; Secondary Mass
Al intensive and HSS frame

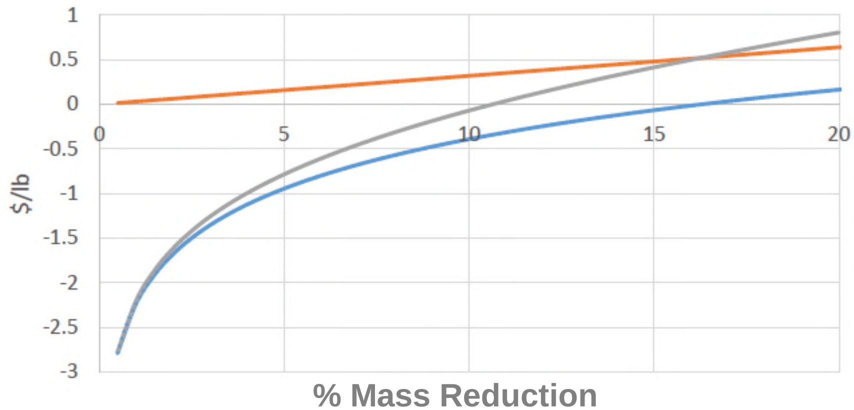
(Transport Canada) <u>Light Duty Pickup Truck</u>
(2015):
Baseline: MY2011 Silverado
Mass impact of meeting IIHS Small Overlap

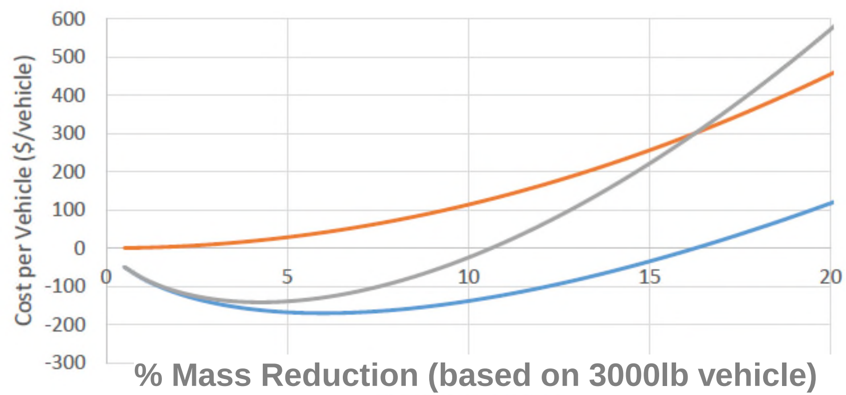
Mass Reduction Cost Curves
(costs for mass reduction applied to typical 2008-vintage designs)

DMC IC TC

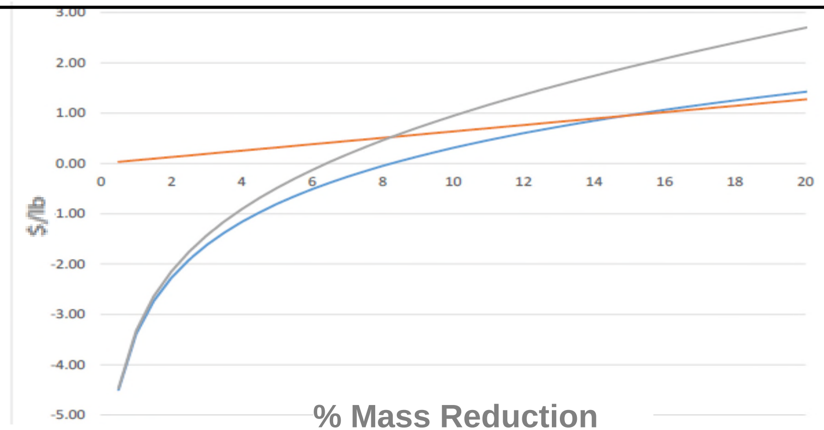
Cost per pound | **Cost per vehicle**

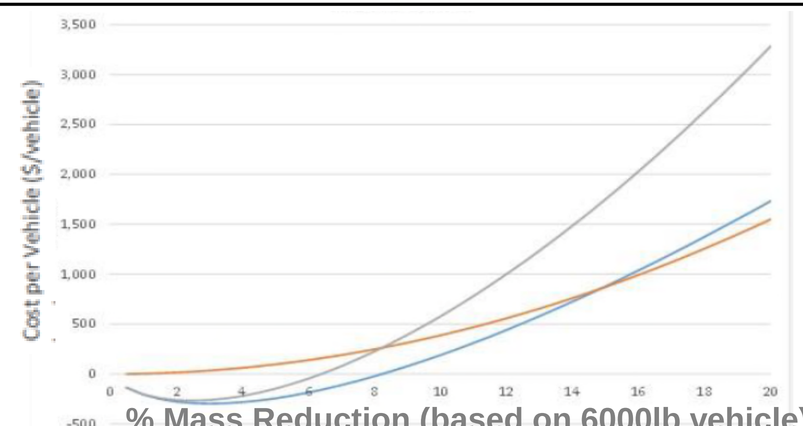
Unibody Vehicles





Body-on-Frame Vehicles





Mass Reduction and Cost Savings

Passenger Cars and CUVs

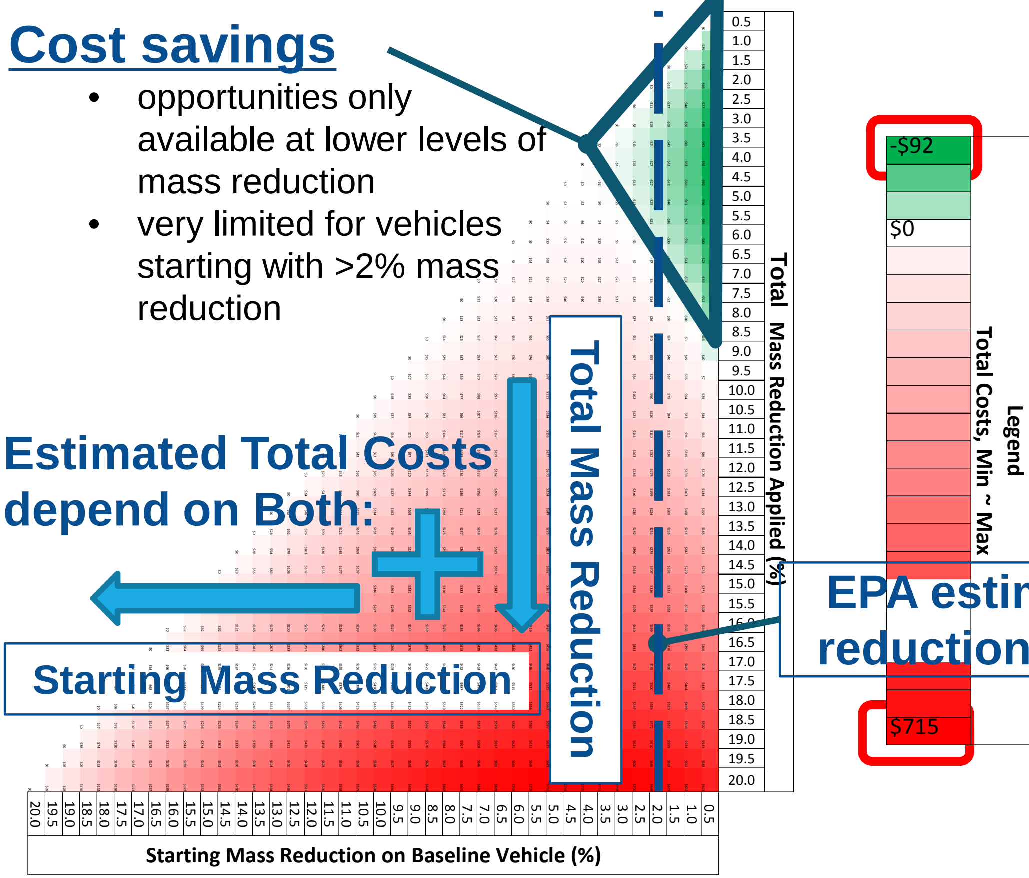
Cost savings

- opportunities only available at lower levels of mass reduction
- very limited for vehicles starting with >2% mass reduction

Estimated Total Costs depend on Both:

Starting Mass Reduction

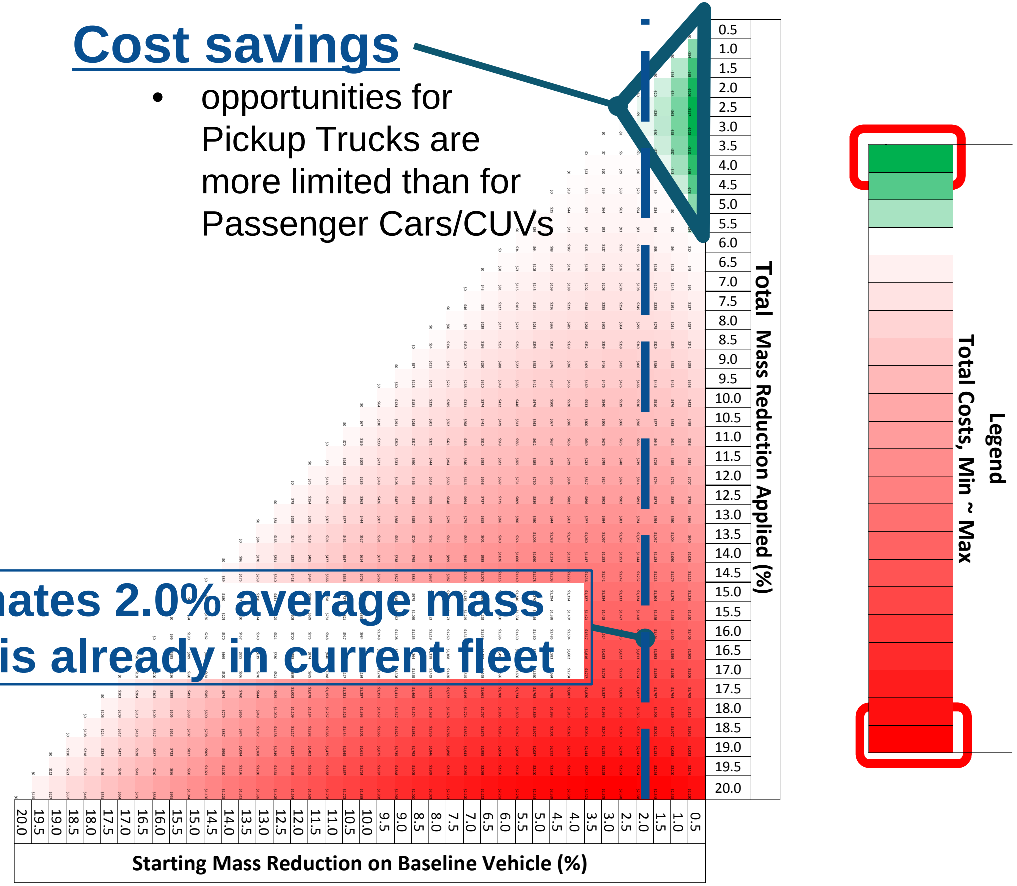
Total Mass Reduction



Pickup Trucks

Cost savings

- opportunities for Pickup Trucks are more limited than for Passenger Cars/CUVs



EPA estimates 2.0% average mass reduction is already in current fleet

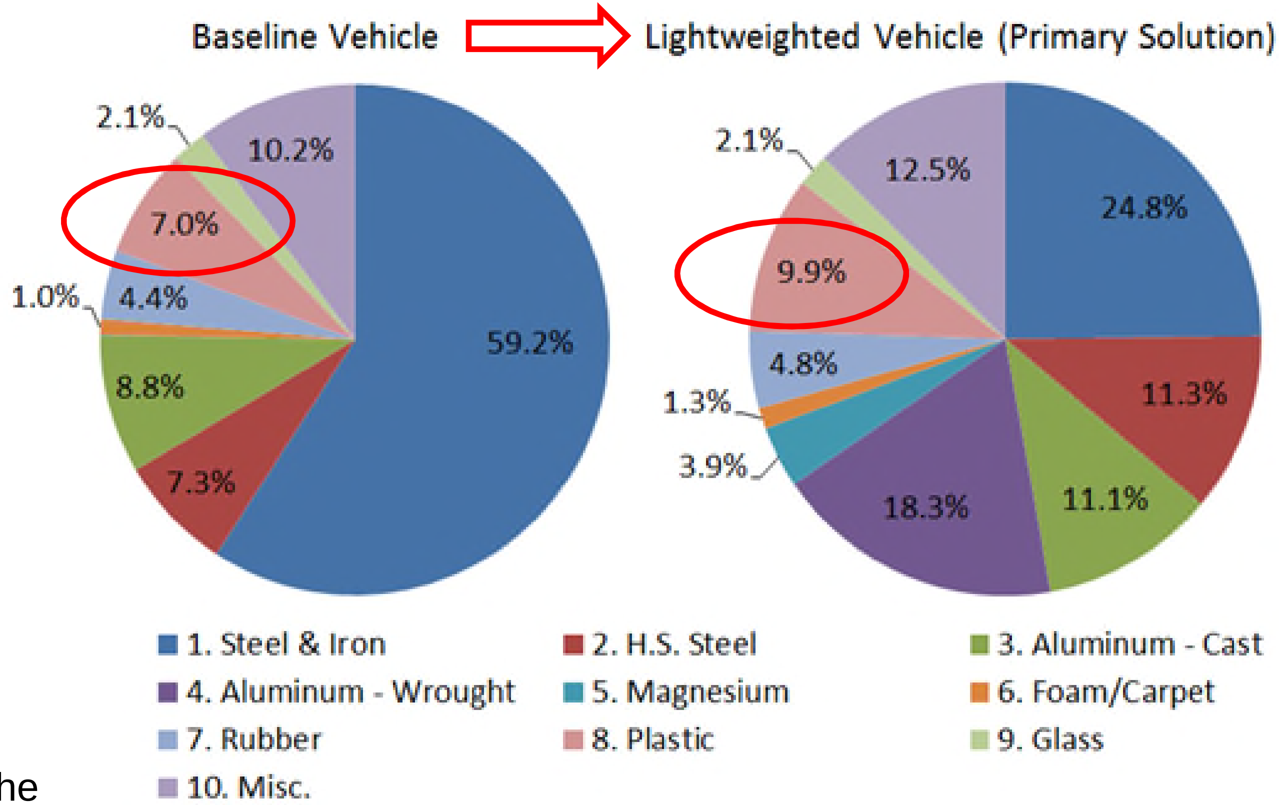
Material Composition – EPA/FEV Silverado Mass Reduction Study

Scope of Study:

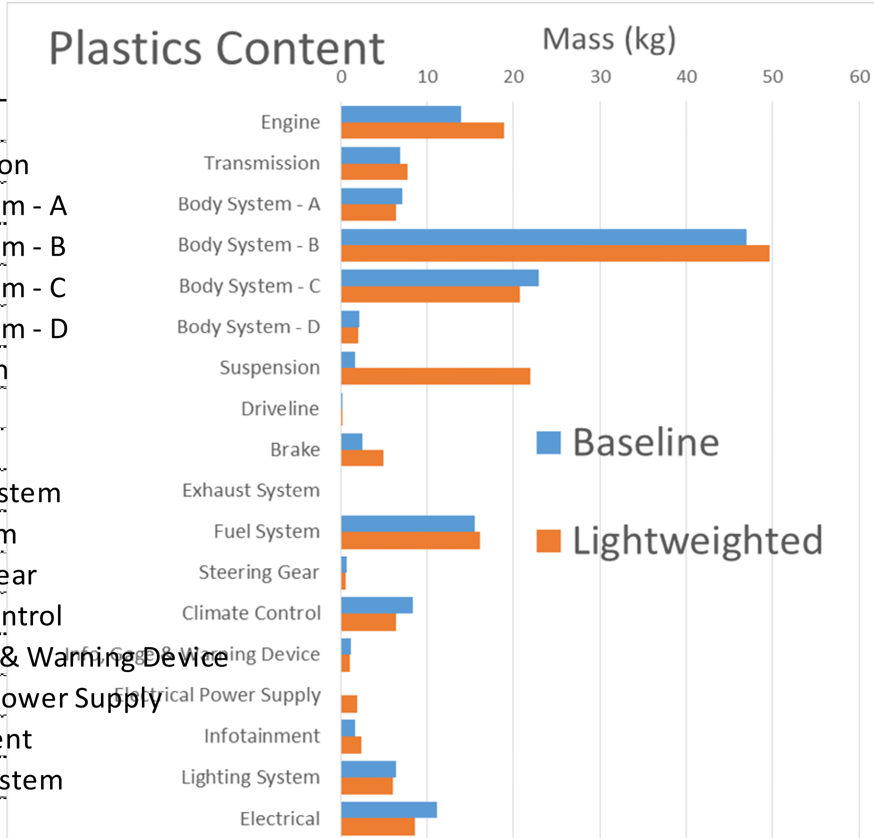
- Baseline: 2011 Silverado 1500, Crew Cab, 4x4
- Contractor: FEV w/Subcontractors EDAG, Munro, etc.

Boundary Conditions

- Maintain function and performance (including payload and towing capacities)
- No degradation in safety from the baseline vehicle
- Capable of being mass produced in the 2020-2025 timeframe (450,000/yr)



EPA/FEV Silverado Study – Plastic Content by System



	Plastic in System, kg (% of system mass)		
	Baseline	Lightweighted	Change
Engine	13.9 (6%)	18.9 (9%)	5.0kg
Transmission	6.9 (5%)	7.7 (7%)	0.8kg
Body System - A	7.1 (53%)	6.4 (51%)	-0.7kg
Body System - B	47.0 (19%)	49.6 (23%)	2.6kg
Body System - C	22.9 (57%)	20.8 (54%)	-2.1kg
Body System - D	2.2 (4%)	2.1 (4%)	-0.1kg
Suspension	1.7 (1%)	21.9 (10%)	20.2kg
Driveline	0.2 (0%)	0.2 (0%)	0.0kg
Brake	2.5 (3%)	4.9 (9%)	2.4kg
Exhaust System	0.0 (0%)	0.0 (0%)	0.0kg
Fuel System	15.5 (59%)	16.1 (65%)	0.6kg
Steering Gear	0.7 (2%)	0.6 (3%)	0.0kg
Climate Control	8.3 (41%)	6.4 (35%)	-1.9kg
Info, Gage & Warning Device	1.1 (72%)	1.1 (83%)	0.0kg
Electrical Power Supply	0.0 (0%)	2.0 (25%)	1.9kg
Infotainment	1.7 (99%)	2.4 (89%)	0.7kg
Lighting System	6.4 (67%)	6.0 (65%)	-0.4kg
Electrical	11.2 (33%)	8.7 (34%)	-2.5kg
Total	**149.5**	**175.9**	**26.4**

Metal to Plastic
➲ Valve Cover

System	Engine
Component	Valve Cover
Component Mass Saving %	44%
Mass Saving	1.16 kg
Cost Saving	$6.06
Value	5.22 $/kg (cost save)

[Base Technology]
Material: Aluminum
Application: Silverado

[New Technology]
Material: Polyamide
Application: Chrysler 4.7L V8
Ford Duratec 2.0L

Metal to Plastic
➲ Front Engine Cover

System	Engine
Component	Front Cover
Component Mass Saving %	32%
Mass Saving	0.42 kg
Cost Saving	-$2.44
Value	-5.88 $/kg (cost increase)

[Base Technology]
Material: Aluminum
Application: Silverado

[New Technology]
Material: Polyamide
Application: GM 4.3L Vortec

Metal to Plastic
➲ Oil Pick-up Tube

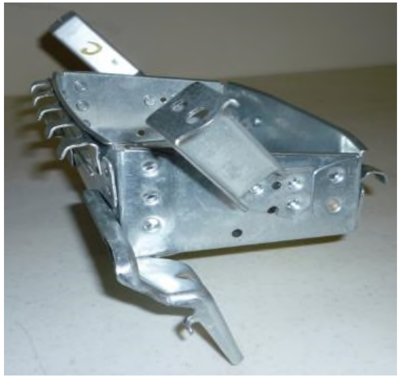
System	Engine
Component	Oil Pick-up Tube
Component Mass Saving %	25.5%
Mass Saving	0.07 kg
Cost Saving	-$0.33
Value	-4.48 $/kg (cost increase)

[Base Technology]
Material: Steel
Application: Silverado

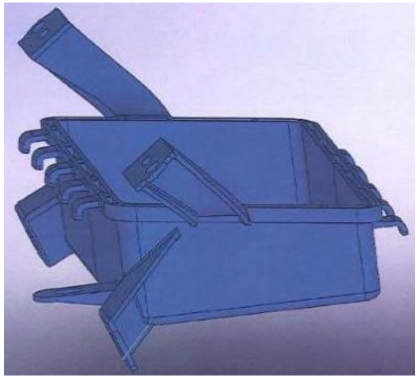
[New Technology]
Material: Polyamide
Application: BMW 2.0L Diesel

Metal to Plastic
➲ Passenger Airbag Housing

System	Body
Component	Passenger Airbag Housing
Component Mass Saving %	15.4%
Mass Saving	0.62 kg
Cost Saving	$0.99
Value	1.60 $/kg (cost save)



[Base Technology]
Material: Steel
Application: Silverado



[New Technology]
Material: PA6 GF40
Application: Ford Explorer

Metal to Plastic
➲ Rear Leaf Spring

System	Infotainment
Component	Rear Leaf Spring
Component Mass Saving %	56.2%
Mass Saving	35.7 kg
Cost Saving	-$113.47
Value	-3.17 $/kg (cost increase)

[Base Technology]
Material: Steel
Application: Silverado
Weight: 26.2kg

[New Technology]
Material: Glass fiber reinforced plastic
Application: Sprinter
Weight: 10.5kg

Engineered Plastics to Lightweight Engineered Plastics ➲ Intake Manifold

System	Body
Component	Intake Manifold
Component Mass Saving %	4.6%
Mass Saving	0.28 kg
Cost Saving	-$0.81
Value	-2.93 $/kg (cost increase)

[Base Technology]
Material: PA66 GF20
Application: Silverado

[New Technology]
Material: PA66 GF20 with 5%Glass Bubbles
Application: Various exterior components and mouldings

Engineered Plastics to Lightweight Engineered Plastics ➲ Foamed Plastic Applications

System	Interior Trim and Ornamentation (Body System C)
System Mass Saving %	--%
Mass Saving	2.06 kg
Cost Saving	$6.84
Value	3.32 $/kg (cost save)

Component	Air Filter Box
System Mass Saving %	15%
Mass Saving	0.66 kg
Cost Saving	$0.27
Value	0.40 $/kg (cost save)

PolyOne used on all class "A" surface plastic parts

- Center Console Trim
- Front and Rear Seat Trim
- Door Trim
- Kick Panels
- A&B Pillar Trim
- Instrument Panel Trim
- Radiator Grill
- Cowl Screen
- Front and Rear Fascia
- Front Air Dam

MuCell used on non-class "A" surface plastic parts:

- Engine Air Intake Components
- Radiator Fan Shroud and Blades

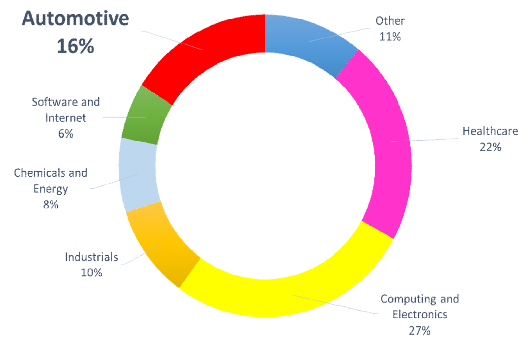
What could aggressive application of technology look like?

EPA could have included even more technology:

- Water injection for knock mitigation – BMW
- Variable Compression Ratio – Nissan
- Electric supercharging – Valeo, Eaton, Audi
- 48 volt P2 hybrids – near strong HEV effectiveness at lower cost
- Lean-burn operation – several manufacturers are investigating
- Delphi-Tula Dynamic Skip Fire Cylinder Deactivation System
- Increased thermal management (e.g., waste heat recovery – as used in HD Rule)
- Additional friction reduction:
  - Cam and crank roller bearings
  - Plasma Vapor Deposition (PVD) cylinder coating – already in production
- Ball-based Continuously Variable Transmissions (Dana)

Auto Industry 3rd largest sector for global R&D investment

> $100 Billion/year, >$270 Million/day



Source: Booz & Co.

***Thompson Reuters* lists Fuel Economy among the 5 "hottest areas" of automotive innovation**

- based on assessment of publications/inventions/ patent filings

Sample of Recent Innovations in Engineered Plastics from the Trade Press

Sabic

- Structural foaming IP carrier
- Plastic-metal hybrids

https://www.sabic.com/en/news/6122-lightweight-pp-and-plastic-metal-hybrid-solutions-among-those-sabic-featuring-at-germany-s-vdi-congress

http://www.ptonline.com/articles/several-firsts-among-2015-spe-automotive-innovation-awards

Teijin

- Improved chemical hardening of plastic glazing

http://www.ihssupplierinsight.com/news/5239530/teijin-develops-new-hard-coating-technology-for-automotive-plastics-glazing-

LANXESS

- Continuous fiber thermoplastic brake pedal
- PA6 oil pans

http://lanxess.com.au/en/lanxess-media-australia/global-pr-australia/2016-00077e/

Elring Klinger

- Hybrid cross-car beam

https://www.elringklinger.de/en/products-technologies/original-equipment/lightweight-plastic-components-car-body#ui-id-1

Solvay

- Heat performance PA66

http://www.ihssupplierinsight.com/news/5236349/solvay-launches-new-polyamide-based-performance-materials-for-automotive-applications

What comes next?

EPA's Reconsideration of the MTE Final Determination

March 15, 2017 - EPA Administrator Pruitt issued a Notice announcing he will reconsider the EPA Final Determination published in January 2017:

> *" … EPA has concluded that it is appropriate to reconsider its Final Determination in order to allow additional consultation and coordination with NHTSA in support of a national harmonized program."*

> *"In accord with the schedule set forth in EPA's regulations, the EPA intends to make a new Final Determination regarding the appropriateness of the MY 2022-2025 GHG standards no later than April 1, 2018."*

EPA Continues its In-depth Evaluation of Advanced Powertrains

Component benchmarking efficiency maps:

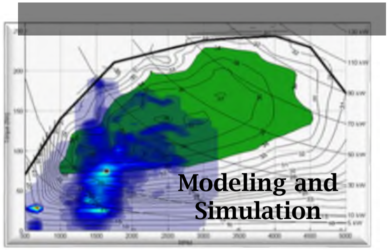
- MY2016 Mazda CX-9 2.5 liter GDI-turbo-charged w/ 6-speed AT
- MY2016 Honda Civic 1.5 liter GDI-turbo-charged 10.6:1 w/ CVT

Vehicle level benchmarking:

- MY2016 Acura ILX w/dual-clutch transmission with torque converter
- MY2017 Ford F150 w/10 speed AT
- MY2016 Chevy Malibu w/1.5 liter GDI-turbo-charged w/ 6-speed AT

Demonstration and Modeling:

- Demonstration of cooled EGR on a modified European Mazda 2.0 liter GDI-naturally-aspirated 14:1 CR engine
- GTPower modeling of a MY2012 PSA 1.6 liter GDI-turbo-charged engine with cooled EGR and an advanced turbo
- GTPower modeling of a MY2016 Honda Civic 1.5 liter GDI-turbo-charged 10.6:1 CR engine
- ALPHA model comparison of several CVTs
- ALPHA modeling of all vehicles included in above component and vehicle benchmarking



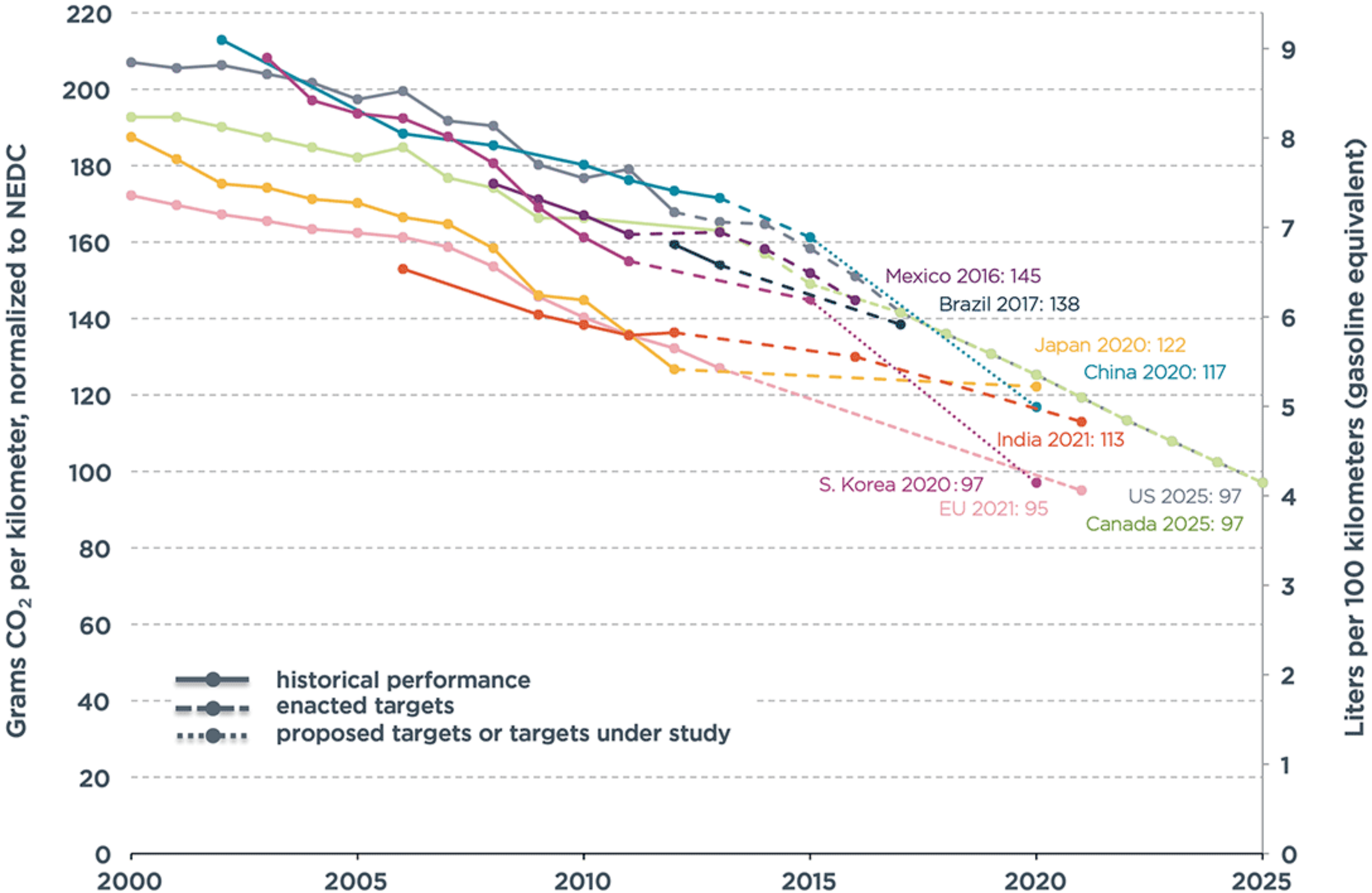
Modeling and Simulation

Additional EPA Work Underway in Many Areas

- **Technology cost teardowns with FEV**: modern GDI turbo-downsized engine, advanced diesel engine, CVT
- Updates to OMEGA **cost-effectiveness optimization model** and ALPHA **full vehicle simulation model**
- Ongoing work to evaluate the **willingness to pay (WTP) for vehicle attributes** (e.g., power, fuel economy, size, etc).
  - Our review of 50+ papers from the last 20 years found very wide variation in these WTP values. Ongoing work evaluates what factors may contribute to this variation.
- **Ongoing evaluation of automotive reviews of MY2015 vehicle fuel efficient technologies**
  - Building upon EPA's study of MY2014 vehicles, we continue to find that positive evaluations for all technologies (70%) exceed negative evaluations of the technologies (18%)
- **Ongoing work to evaluate the vehicle miles traveled (VMT) rebound effect**
- Collaboration with Transport and Environment/Climate Change Canada on **mass reduction** and **aerodynamics**
- Continued evaluation of the vehicle fleet each year to assess technologies, emissions, and compliance – supporting EPA's forth-coming **MY2016 Manufacturer GHG Performance Report** and **2017 CO2/Fuel Economy Trends Report**

Appendix

Global Passenger Car CO2 Standards



Source: International Council for Clean Transportation.

http://www.theicct.org/blogs/staff/improving-conversions-between-passenger-vehicle-efficiency-standards

2025 CO2 Standard is a Function of Car & Truck Production Volume and Vehicle Footprint

Passenger Car Target (g/mi) = (3.26 x **footprint**) – 3.2

- for vehicle footprints >41 and < 56 square feet

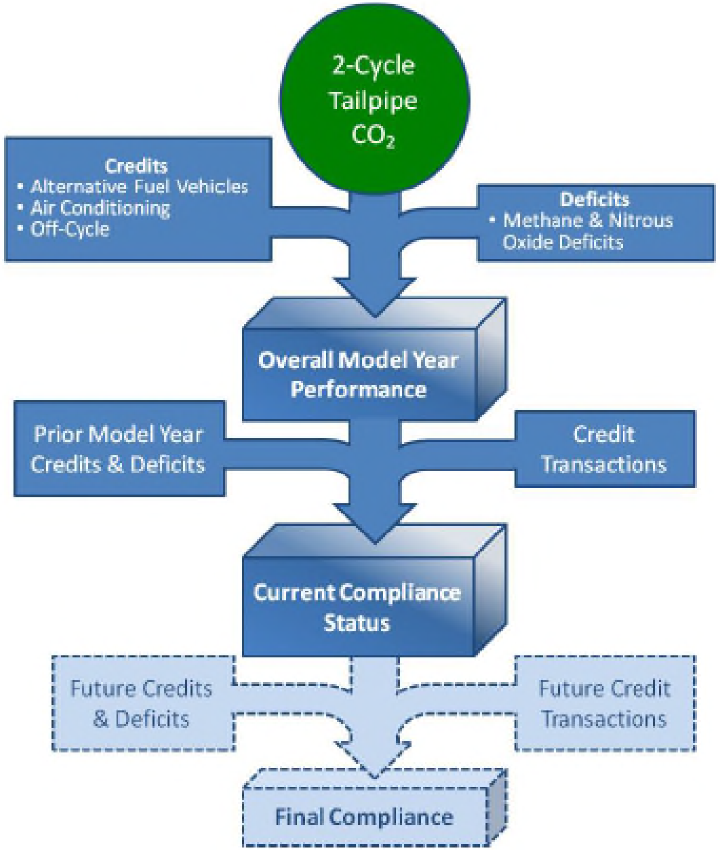
Light-Truck Target (g/mi) = (3.58 x **footprint**) +12.5

- for vehicle footprints >41 and < 74 square feet

For each individual company the Car & Truck standards are a function of the # **vehicles produced** & each vehicle's **footprint**

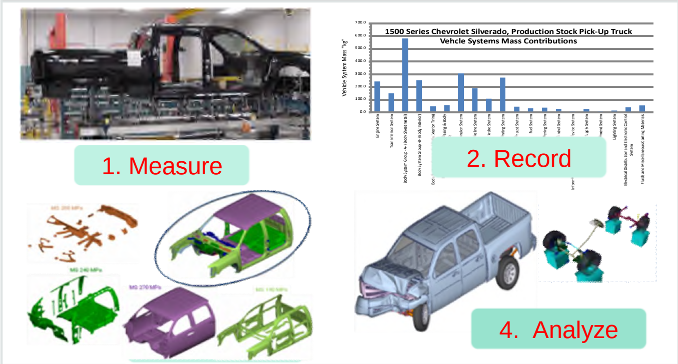
Compliance Determination with Credit Banking and Trading

- **Assist manufacturer planning and phase-in of GHG-reducing technologies, consistent with typical redesign cycles**
- **Unlimited credit transfer across car and truck fleets**
- **Unlimited credit trading between manufacturers**
- **5-year credit carry-forward, with one-time early credit carry forward of CO_2 credits**
  - MY 2010 and later credits can be carried forward to MY 2021
- **3-year credit carry-back**

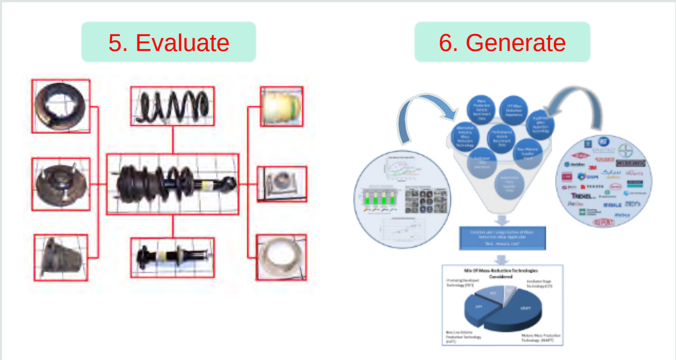


EPA Sponsored Light Duty Pickup Truck Lightweighting Study - Project Methodology

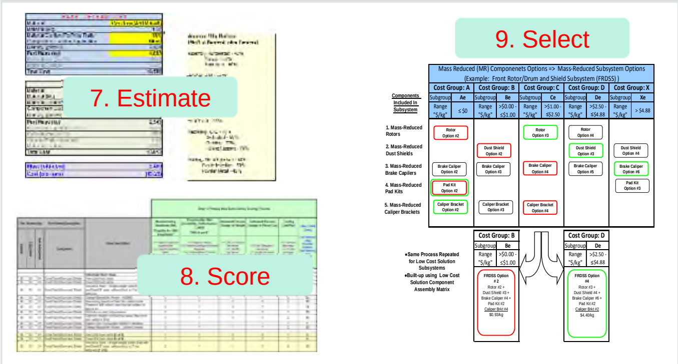
Finger Print Baseline Technology



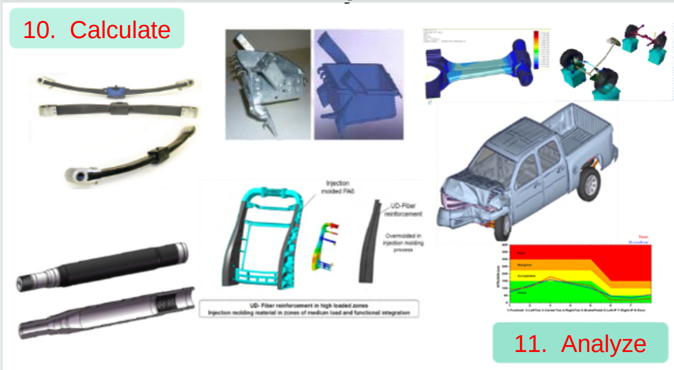
Teardown and Idea Generation



Mass-Reduction and Cost Optimization Process



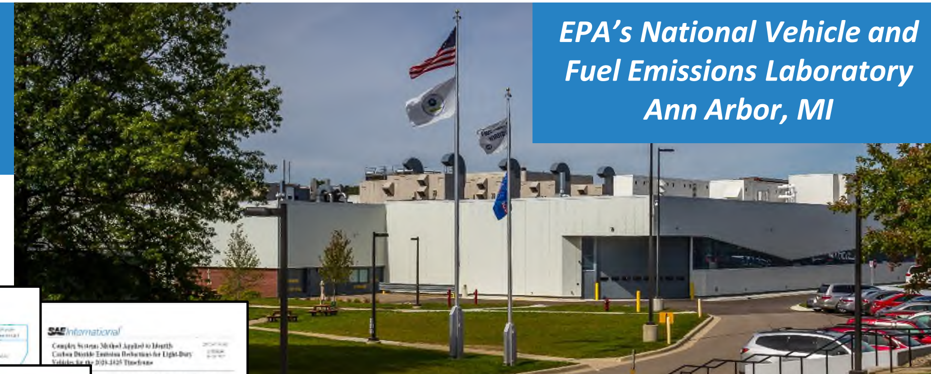
Detailed Mass-Reduction Feasibility and Cost Analysis



Key Mass Reduction Studies Considered in MTE

	Agency	Description	Completion Date	Reference
Pass Car/ CUV Studies	US EPA	Phase 2 Midsize CUV (2010 Toyota Venza) Low Development (HSS/Al focus)	2012	Final Report, Peer Review and SAE Paper EPA-420-R-12-019, EPA-420-R-12-026, SAE Paper 2013-01-0656
	ARB	Phase 2 Midsize CUV (2010 Toyota Venza) High Development All Aluminum	2012	Final Report and Peer Review http://www.arb.ca.gov/msprog/levprog/leviii/final_arb_phase2_report-compressed.pdf http://www.arb.ca.gov/msprog/levprog/leviii/carb_version_lotus_project_peer_review.pdf
	NHTSA	Passenger Car (2011 Honda Accord)	2012	Final Report, Peer Review, OEM response, Revised Report ftp://ftp.nhtsa.dot.gov/CAFE/2017-25_Final/811666.pdf http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/ci.NHTSA+Vehicle+Mass-Size-Safety+Workshop.print http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/812237_LightWeightVehicleReport.pdf
	DOE/ Ford/ Magna	-Passenger Car (2013 Ford Fusion) Mach 1 and Mach 2 projects -Cost Study for 40-45% Mass Reduction -Mass Reduction Spectrum Analysis And Process Cost Modeling Project	2015	http://energy.gov/sites/prod/files/2015/06/f24/lm072_skszek_2015_o.pdf http://energy.gov/sites/prod/files/2014/07/f17/lm072_skszek_2014_o.pdf http://energy.gov/sites/prod/files/2014/07/f17/lm088_skszek_2014_o.pdf http://avt.inl.gov/pdf/TechnicalCostModel40and45PercentWeightSavings.pdf http://energy.gov/sites/prod/files/2016/06/f33/lm090_mascarin_2016_o_web.pdf SAE papers include:2015-01-0405~0409,2015-01-1236~1240,2015-01-1613~1616
	NHTSA	Passenger Car small overlap mass add	2016	Final Report http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/812237_LightWeightVehicleReport.pdf
Light Duty Truck Studies	EPA	2011 Silverado 1500	2015	Final Report, Peer Review and SAE Paper EPA-420-R-15-006,SAE Paper 2015-01-0559
	NHTSA	2014 Silverado 1500	2016	Final Report November 2016
	Transport Canada	IIHS small overlap mass add on LDT (EPA)	2015	Final Report and Peer Review https://www.tc.gc.ca/eng/programs/environment-etv-summary-eng-2982.html Peer Review (EPA docket)

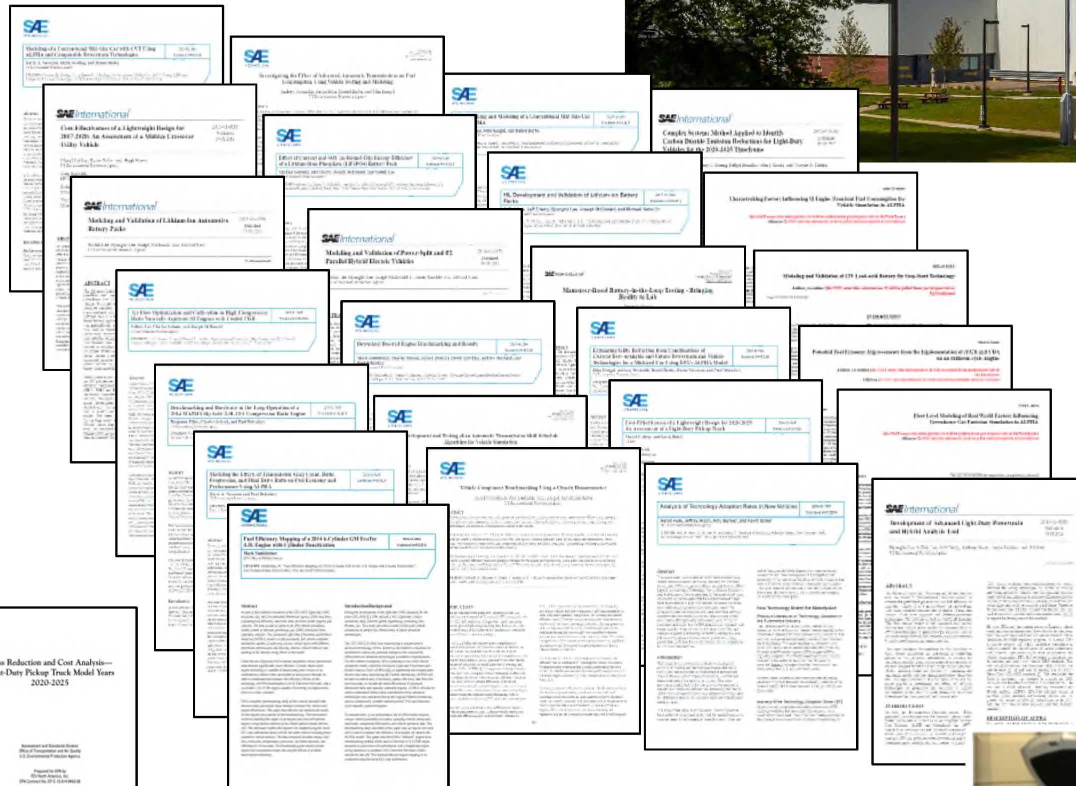
EPA technical information available to all stakeholders/public



EPA's National Vehicle and Fuel Emissions Laboratory
Ann Arbor, MI

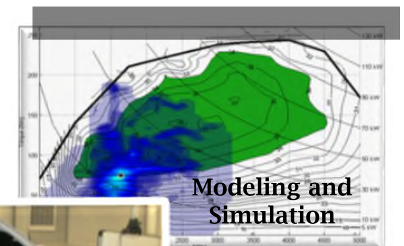
Wide range of peer-reviewed publications and presentations:

- Technical papers, including SAE papers and EPA reports
- Conference presentations
- Modeling workshop



+ more …

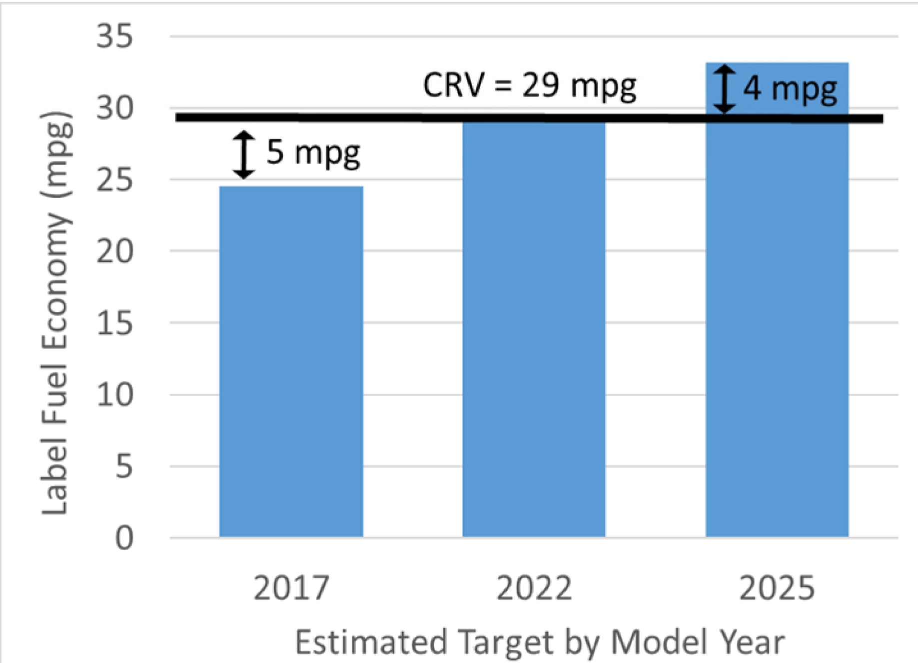
Tethered Engine testing



Modeling and Simulation

Vehicle Dyno testing

Case Study: 2017 Honda CRV 1.5 liter AWD



- Best-selling SUV in U.S.
- AWD versions make up 2/3 of sales
- Advanced Gasoline Technology:
  - Turbocharged GDI 1.5 liter I4 engine
  - Continuously variable transmission
  - No electrification
- Could already meet* 2022 target
  - 5 years ahead
- Within 4 mpg of 2025 target
  - *With 8 years to go*

**Illustrative example only. EPA estimated real-world fuel economy targets from CO_2 compliance targets, assuming A/C credits and 5 g/mi off-cycle credits*