EPA's Technology Assessment for the 2025 GHG Standards

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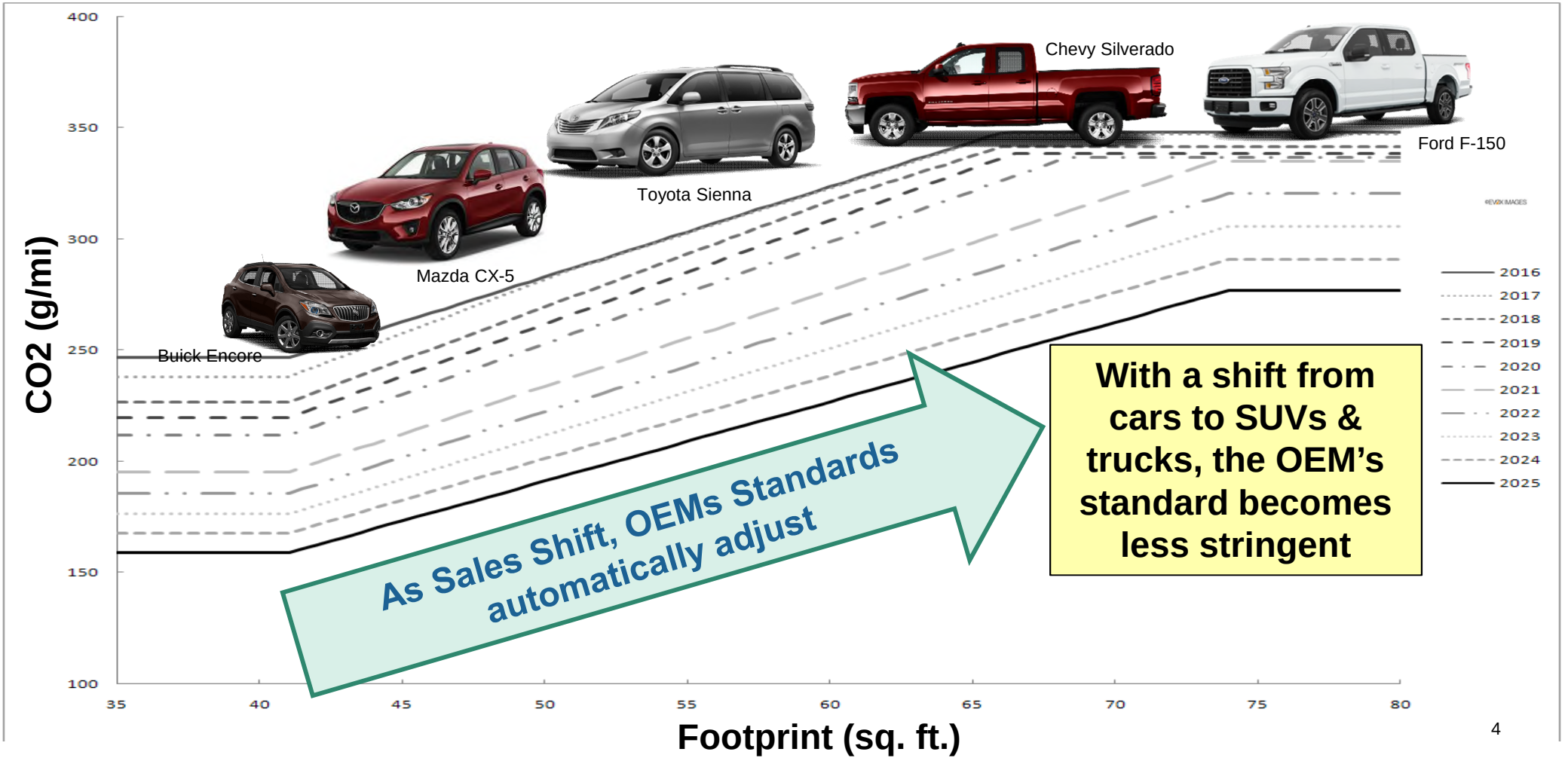
Overview

- How the EPA GHG Standards Work
- Industry Progress-to-Date and Contribution of Powertrain Improvements
- How EPA Considers Transmission Technologies for 2025 Time-Frame
- What might 2025 look like?
  - EPA technical assessment (thus far)
- What Comes Next?

How the EPA GHG Standards Work

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

[separate footprint curve for Cars]



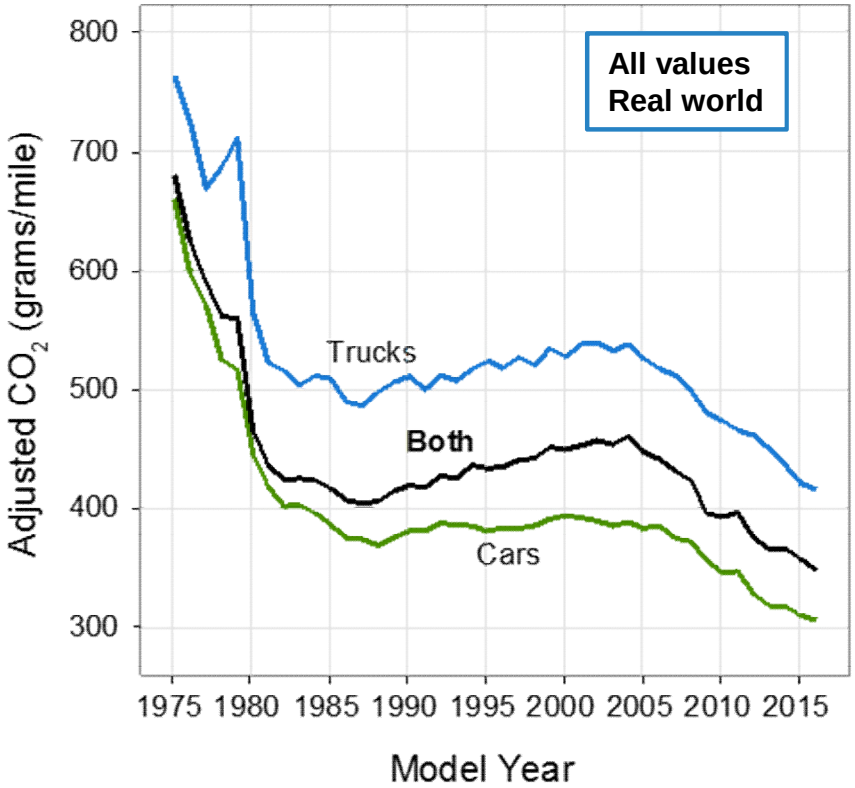
So What is the 2025 EPA Standard?

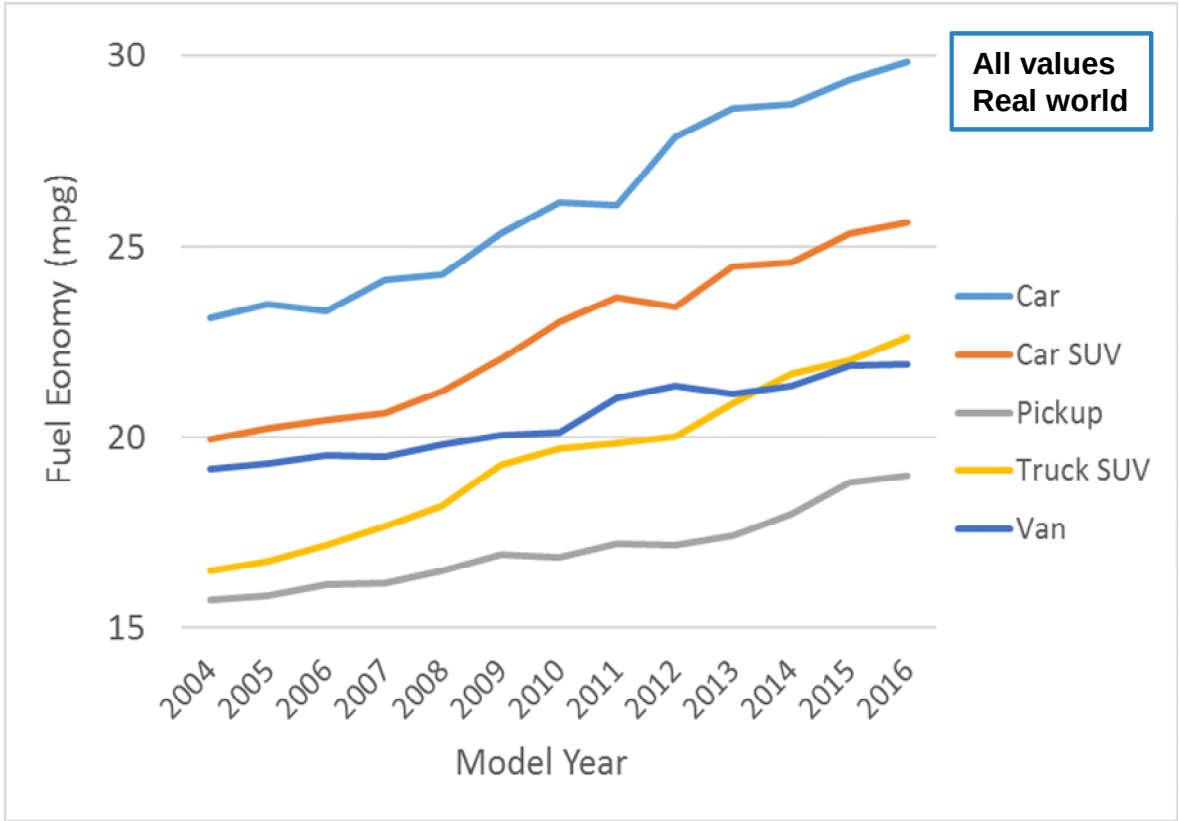
Projections for Model Year 2025 Fleet CO2 Compliance Target
Fuel Prices/Fleet Mix Affect EPA's PROJECTION of 2025 Standard

	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

Industry Progress-to-Date and Contribution of Powertrain Improvements

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



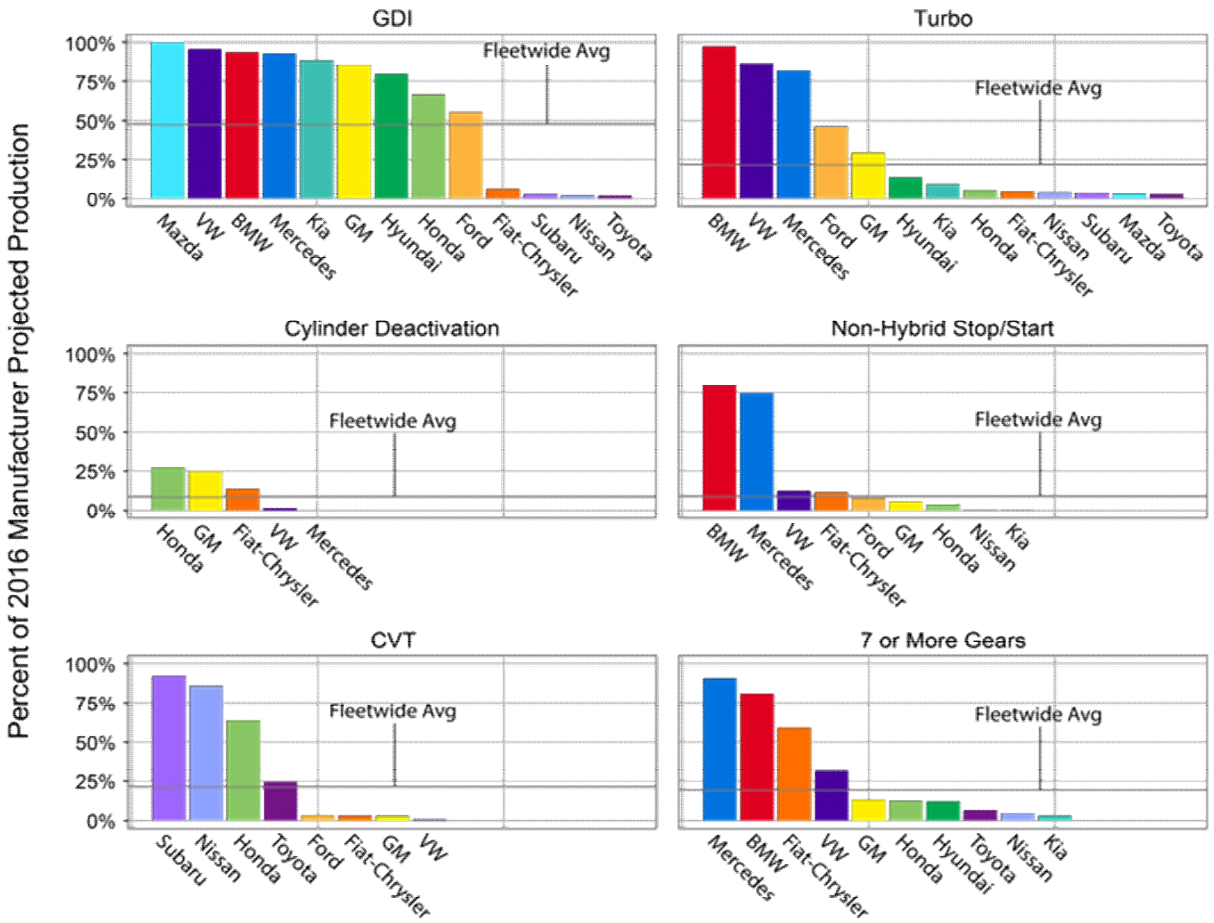


MY2015: 358 g/mi CO_2 (24.8 mpg)
MY 2016 Projected : 25.6 mpg

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

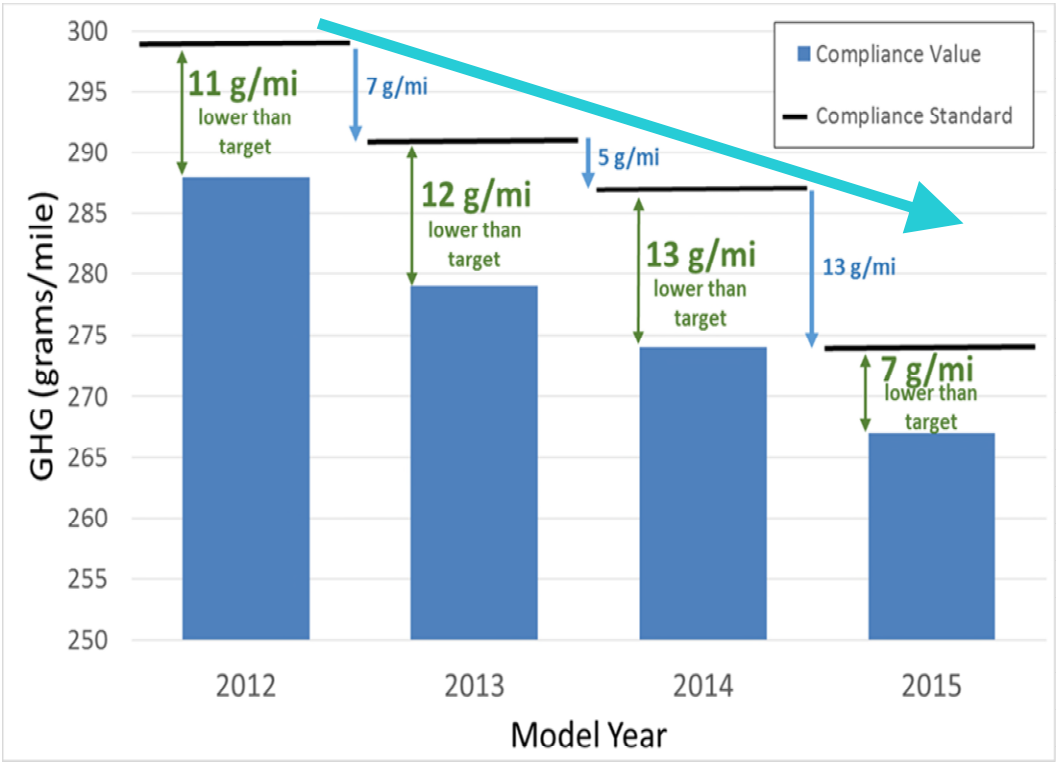
Automakers Adopting a Wide Array of Technologies at Rapid Rates

- **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



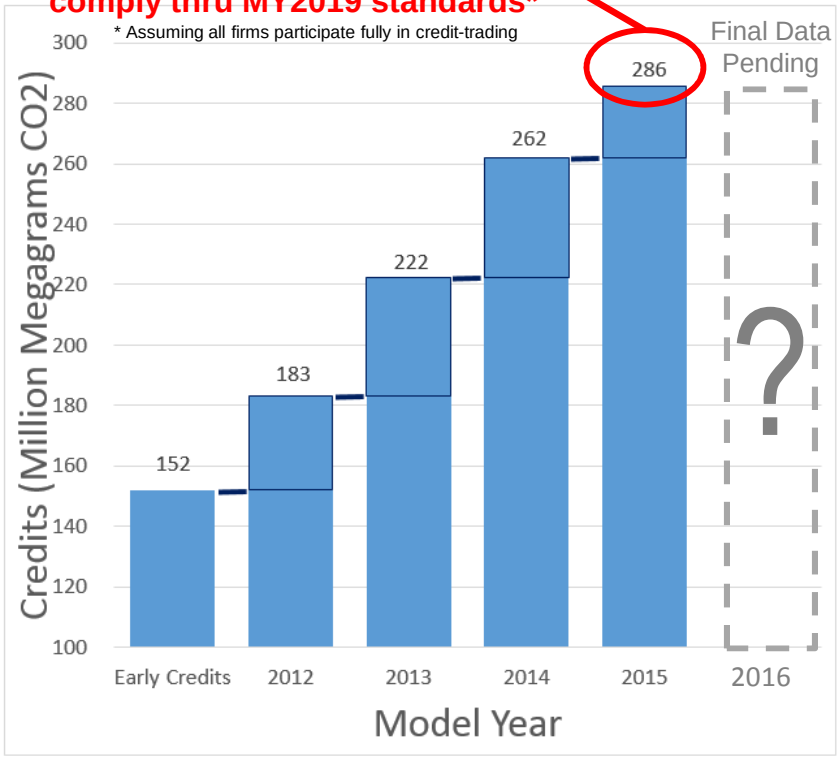
Early Years of Program Producing Positive Results

Industry Outperforming Standards



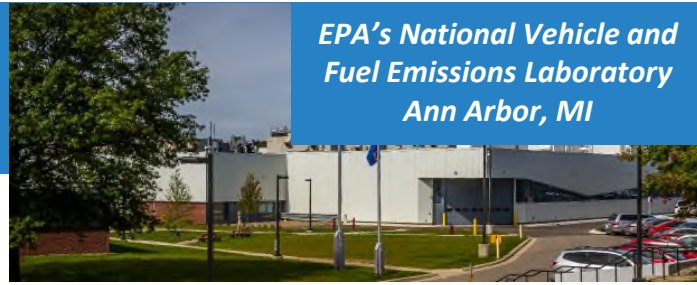
Large Industry-wide Bank of Credits

Enough credits for MY2015 fleet to comply thru MY2019 standards*



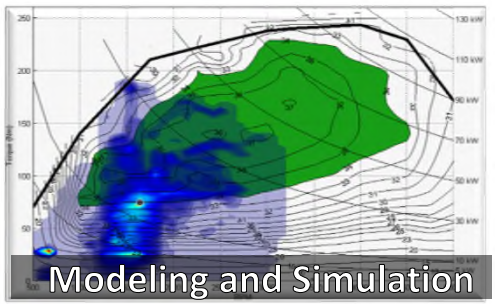
How EPA Considers Transmission Technologies for 2025 Time-Frame

Overview of Technology Assessment


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

- **Midterm Evaluation**
  - Review of Final Rulemaking assessment of MY2022-2025 standards
  - Technology assessment has been ongoing since 2012
- **EPA made significant investment in new tools and studies**
  - Laboratory benchmarking of 30 of the most efficient vehicles in the world, allowing us to generate engine and transmission maps
  - In-house ALPHA vehicle simulation model allowing physics-based projections of effectiveness of various technology packages
  - Cost teardown studies of key powertrain components by contractor used by automakers
- **Supplemented by more intensive information collection and sharing**
  - Hundreds of meetings with automakers and suppliers
  - Review of hundreds of technical papers and reports
  - EPA authorship of 30 peer-reviewed papers and technical reports


Tethered Engine testing


Modeling and Simulation

Transmission Data Sources for Latest EPA Technology Assessment

EPA Vehicle level benchmarking

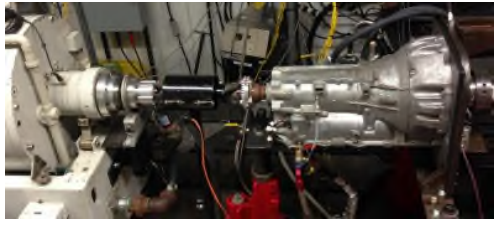
- Analyzed solenoid control signals during driving maneuvers on road
- Determined main line pressures as basis for bench testing
- Characterized transmission shift schedules, torque convertor lock-up, and overall transmission effectiveness
- Vehicles: 2013 GM Malibu – 6-speed, (2) 2014 Dodge Chargers – one equipped with a 5-speed, the other with an 8-speed, 2015 Volvo S60, Ford F150, GM Silverado, Ram 1500 HFE, 2016 Honda CVT, 2016 ILX 8 speed DCT with TC, and more than a dozen other late model vehicles

Transmission Maps provided by outside sources

- DCT 6-speed (from supplier), DCT 7-speed (from supplier), CVT (from OEM), Jatco CVT8 (from supplier), Toyota CVT (from supplier)

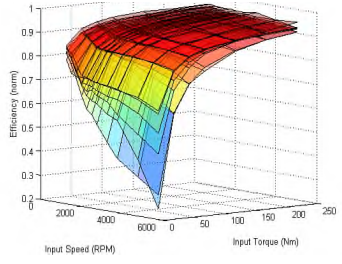
EPA Component benchmarking

- Implemented transmission controls observed in vehicle to control transmission on test bench
- Eliminated TCM in the controls
- Vehicles: GM 6T40 6-speed AT from 2013 Malibu, GM 6L80 6-speed AT from 2014 Silverado, FCA 845RE 8-speed AT from 2014 Ram 1500, Jatco CVT7 from 2013 Nissan Altima
- Assessed transmission efficiency at various loads, speeds, and temperatures



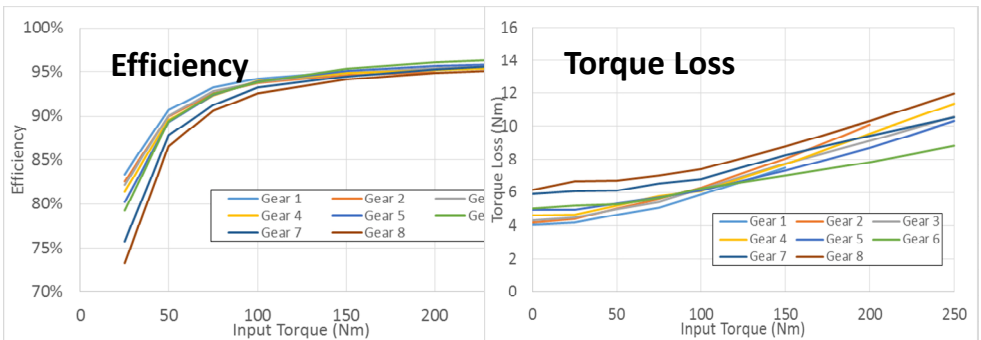
Quantity	Range
Torque	0 Nm to 250 Nm
Speed	500 rpm to 5000 rpm
Temp.	35°C, 60°C,100°C

Resultant Torque/Speed/Efficiency Curve

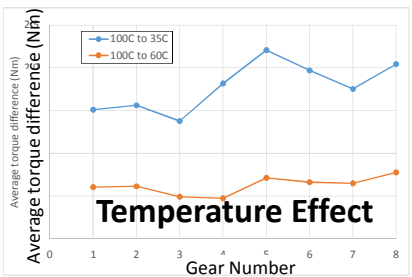


EPA Modeling of Transmissions: ALPHA simulation

- **AT, DCT, and CVT architectures**
- **Built from modular sub-models, with control algorithms unique to each architecture**
- **Allows incorporating benchmarking data and future improvements**



SAE 2016-01-1142



Launch Clutch Model

- Captures effects of accelerating upstream inertias
- Manage clutch slip where appropriate

Torque Converter Model

- Simulation of lockup
- Torque multiplication and resulting engine load

Gearbox Model

- Torque and rotational inertia scale through ratio change
- Torque loss and efficiency in each gear from dynamic lookup tables

Gear Selection (ALPHAshift)

- Rule based, considering engine torque curve, fuel map
- Minimize fuel consumption with constraints for engine speed and torque reserve

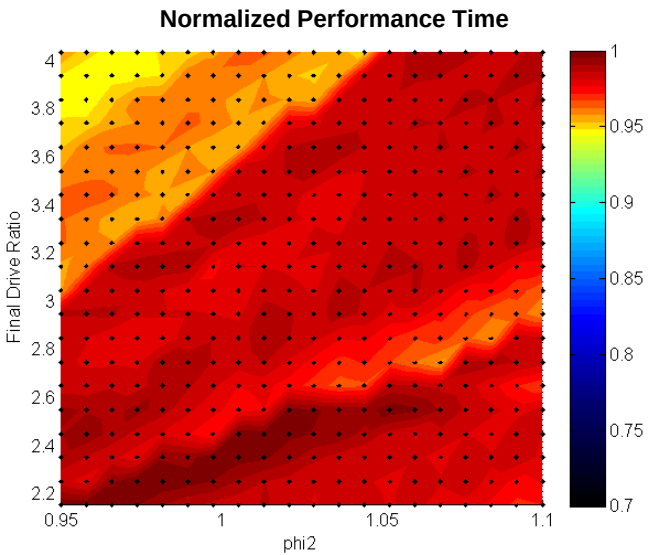
EPA Modeling of Transmissions: Performance Neutrality

Key justification for EPA's performance neutral approach:

"*Estimating the cost of decreasing fuel consumption requires one to carefully specify a basis for comparison. The committee considers that to the extent possible, fuel consumption cost comparisons should be made at equivalent acceleration performance and equivalent vehicle size*" (National Academy of Sciences, 2011)*

Various efficiency technologies tend to improve performance

- Transmission improvements (efficiency, gear count, ratio spread)
- Load reduction (mass, aero, tire improvements)



Two possible "tuning" methods

1. Alter rear end ratio
2. Resize engine — EPA Approach
   - Maintain performance of baseline vehicle by resizing engine
   - Overall performance is calculated from the sum of the 0-60 time, ¼ mile time and passing times (30-50MPH and 50-70MPH)

*Assessment of Fuel Economy Technologies for Light-Duty Vehicles, National Research Council, 2011

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

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

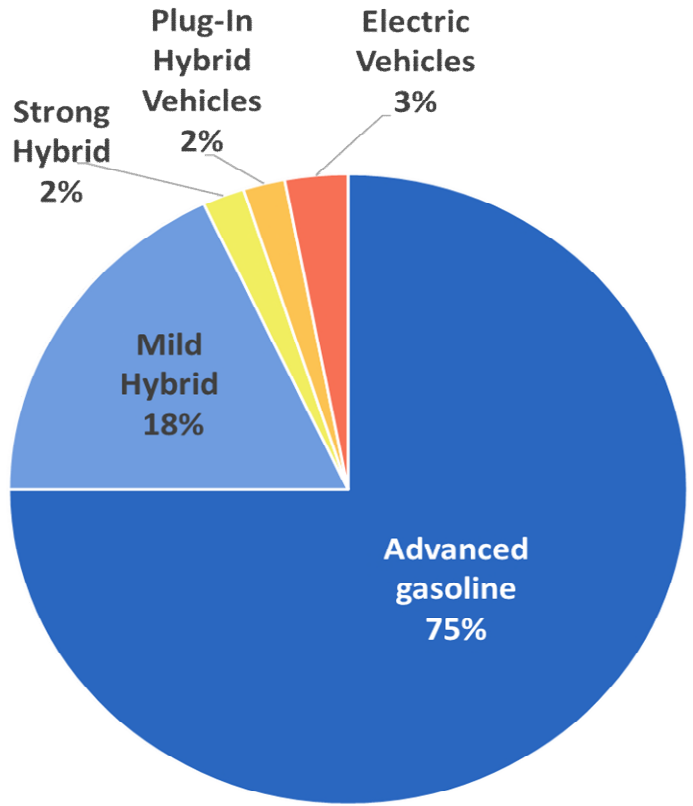
Cost estimate of $875/vehicle

- ✓ Advanced engines and transmissions
- ✓ Vehicle light-weighting
- ✓ 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

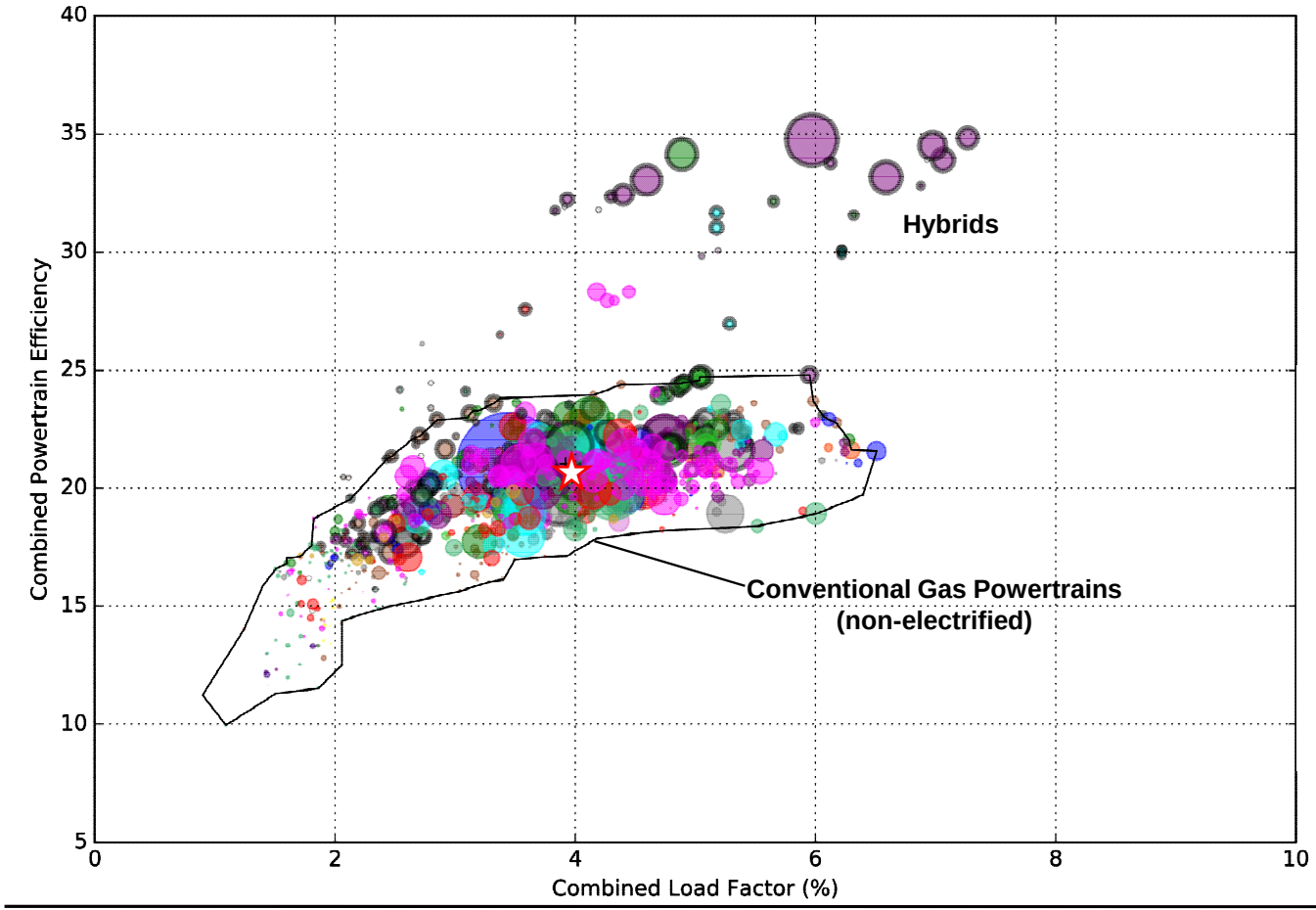
Fuel Savings Offsets Cost increase

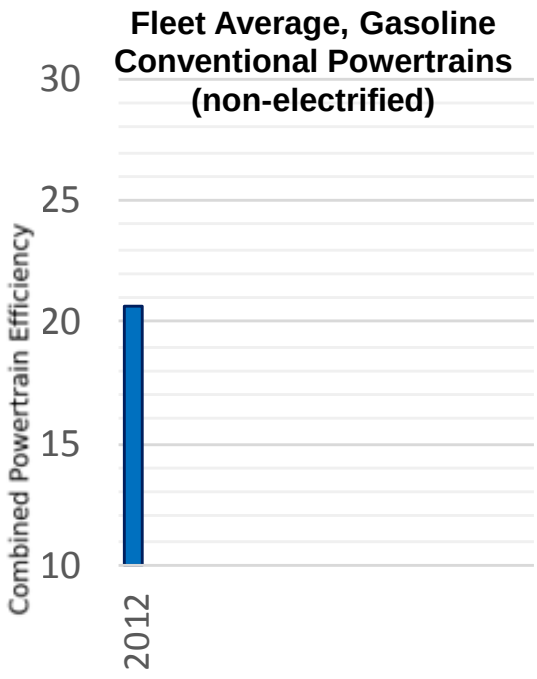
- ✓ Net lifetime savings of $1,650

One possible powertrain pathway



Distribution of Fleet Powertrain Efficiencies MY2012





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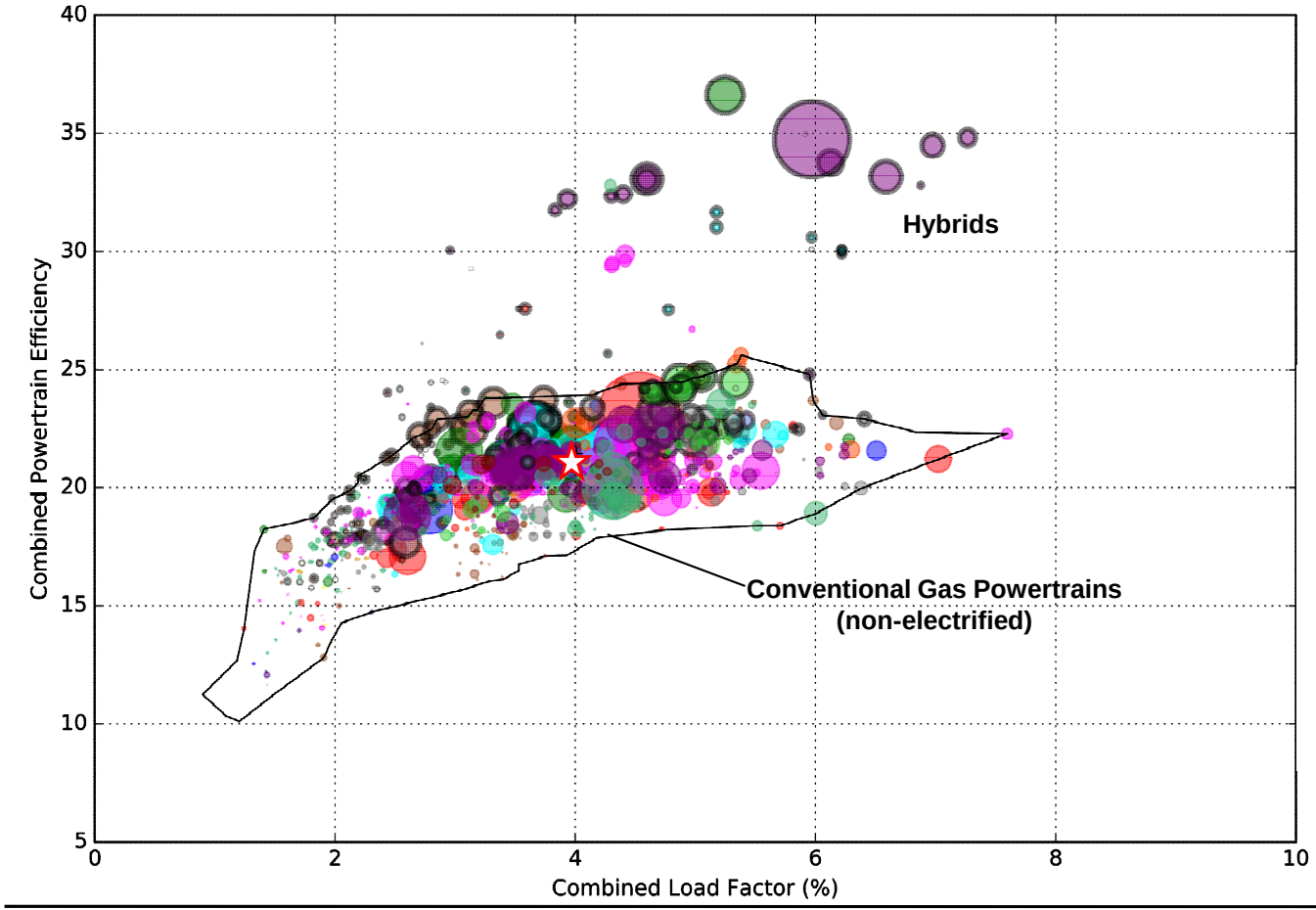
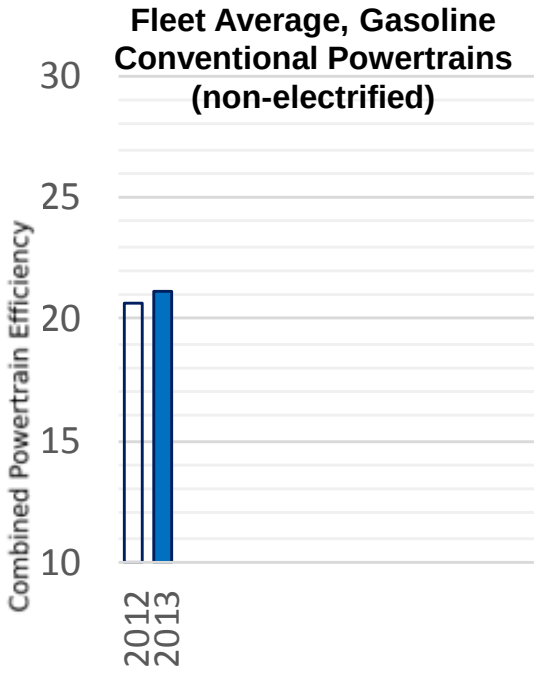
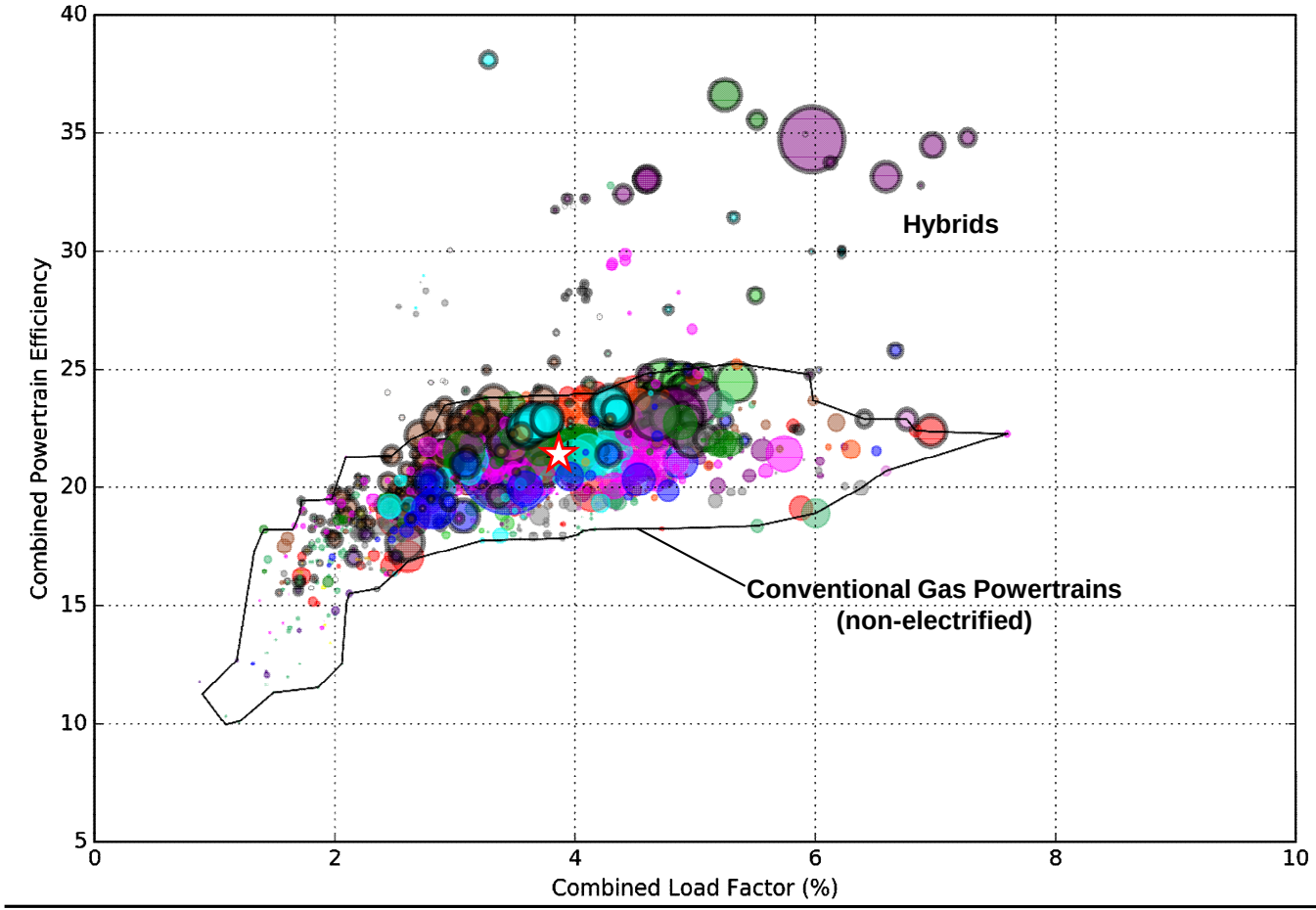
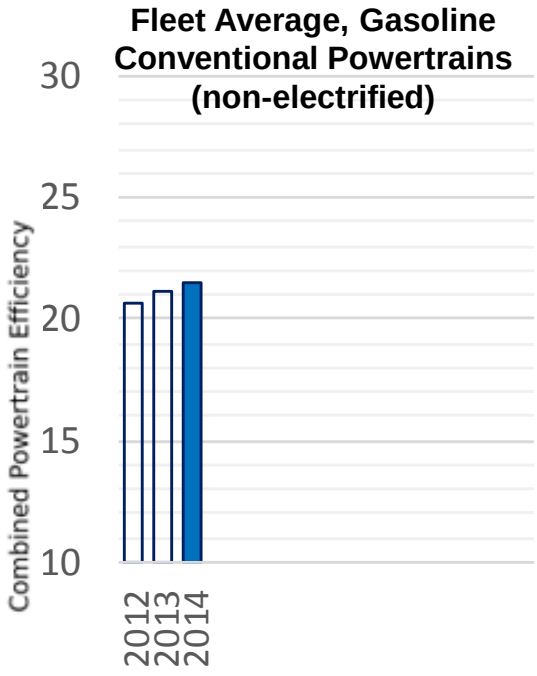


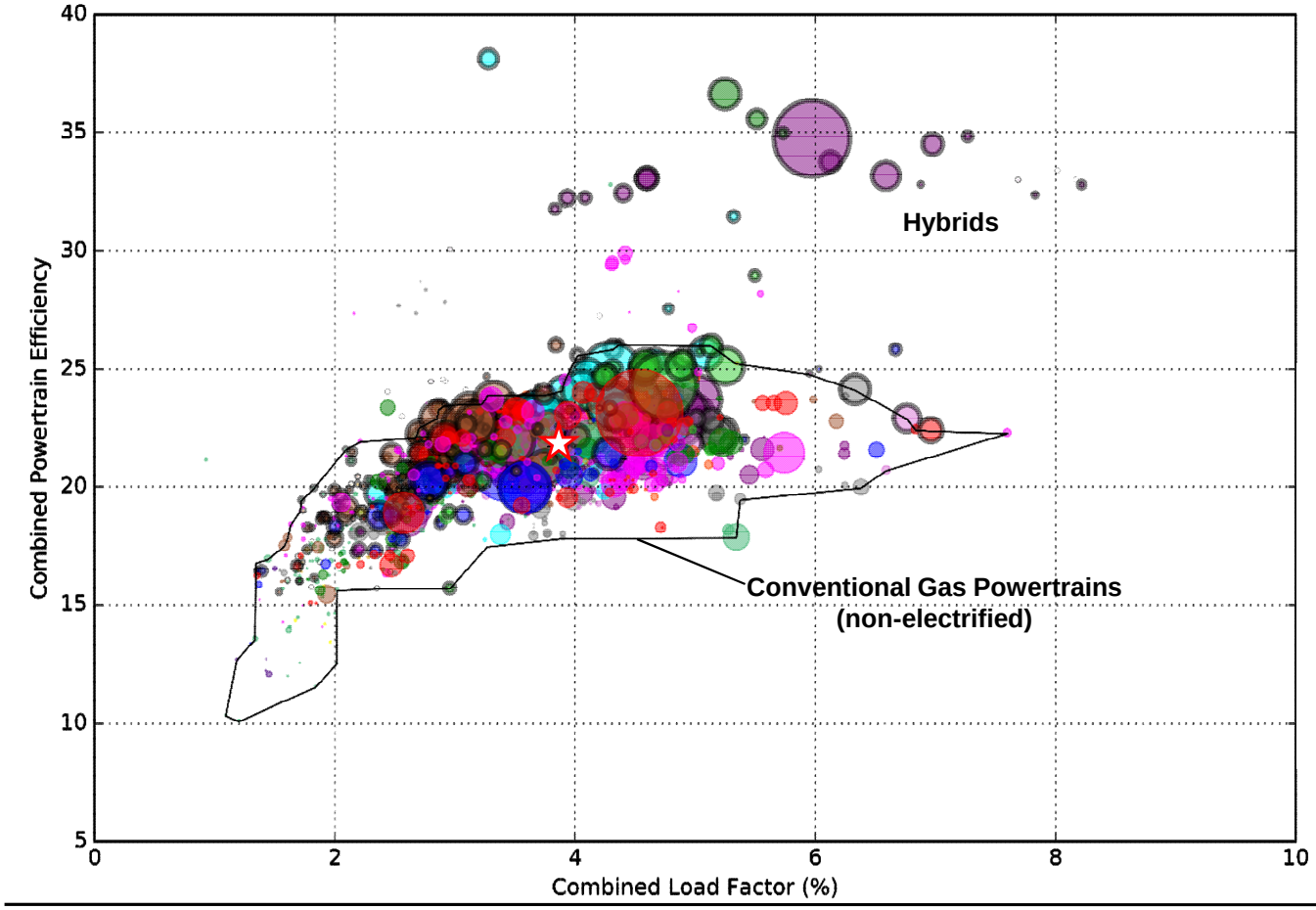


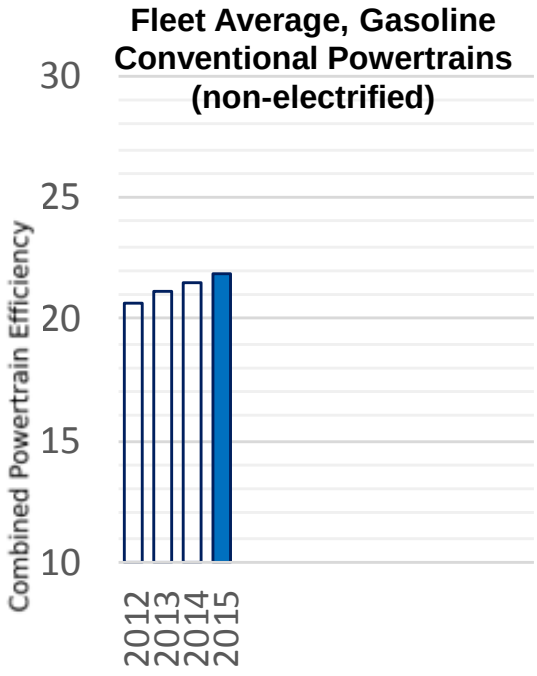
Distribution of Fleet Powertrain Efficiencies
MY2014



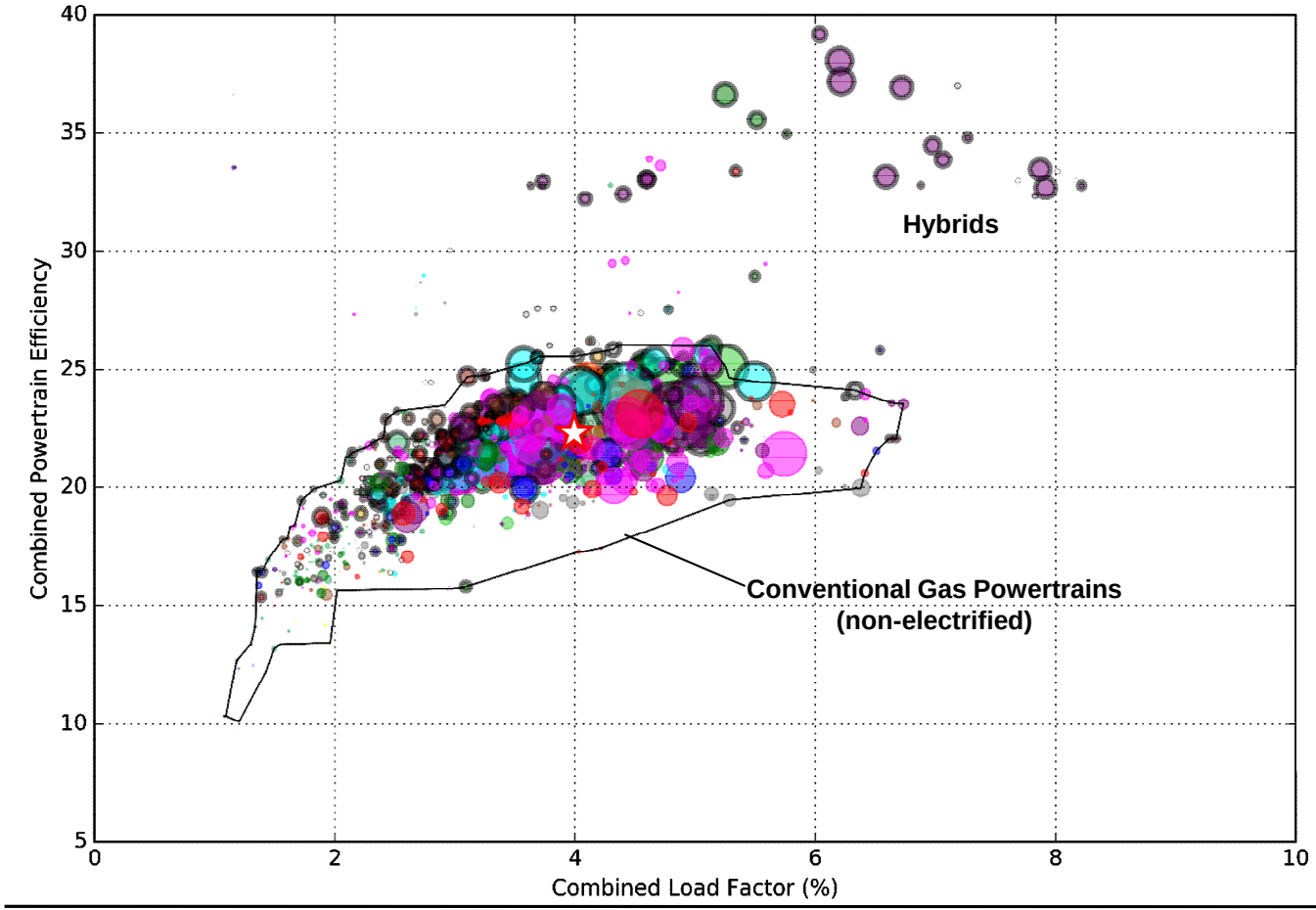


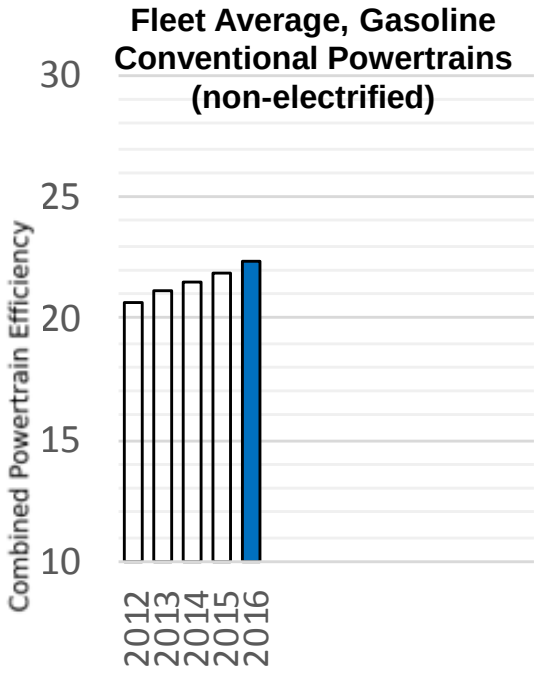
Distribution of Fleet Powertrain Efficiencies
MY2015





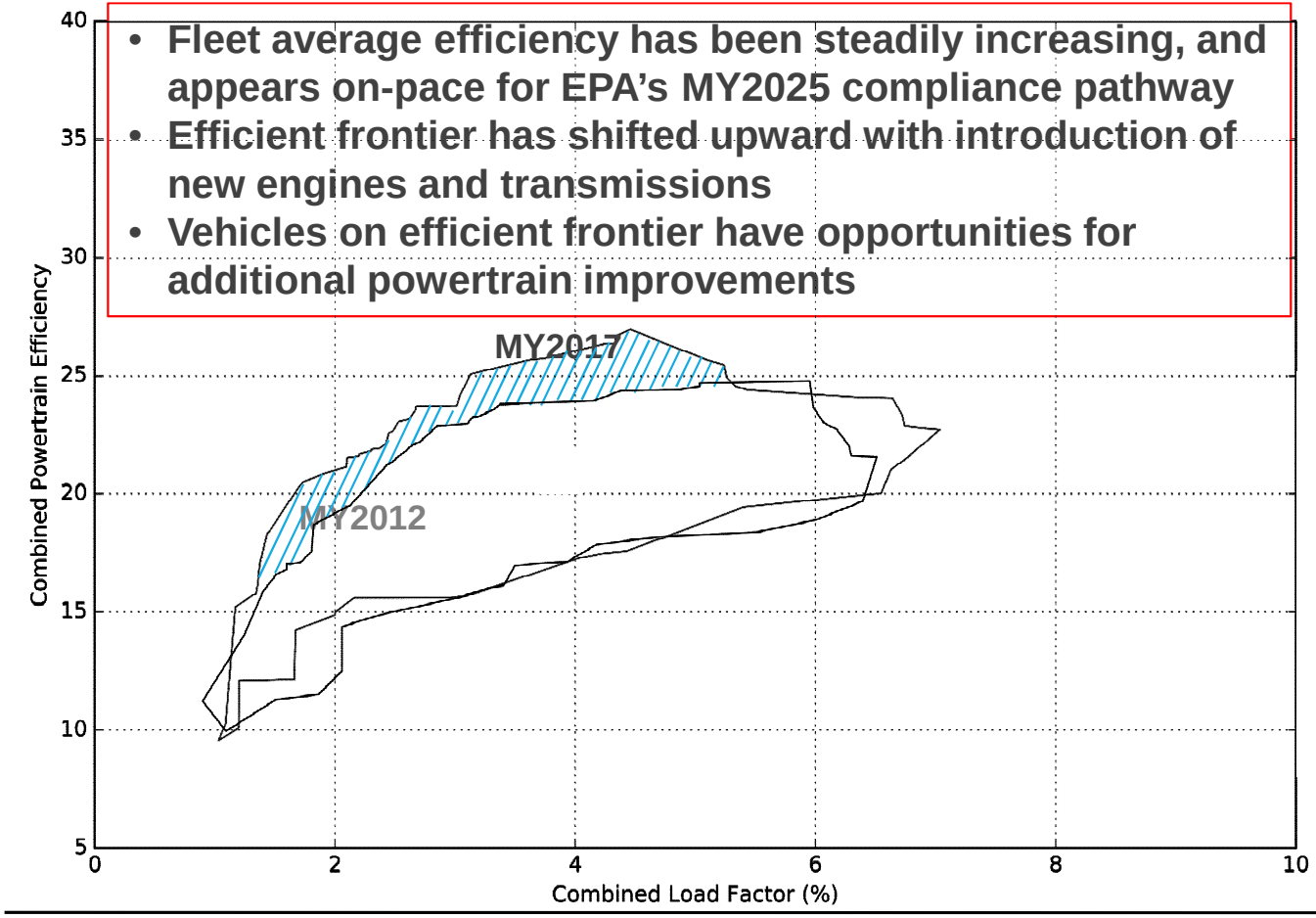
Distribution of Fleet Powertrain Efficiencies
MY2016

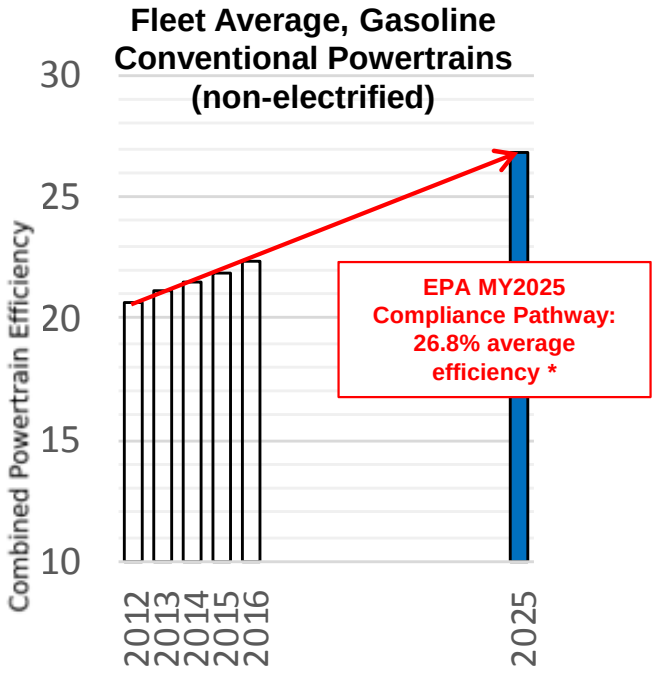




Rate of Improvement in Fleet Powertrain Efficiencies MYs 2012 - 2016

- Fleet average efficiency has been steadily increasing, and appears on-pace for EPA's MY2025 compliance pathway
- Efficient frontier has shifted upward with introduction of new engines and transmissions
- Vehicles on efficient frontier have opportunities for additional powertrain improvements





* EPA November 2016 Proposed Determination

What comes next?

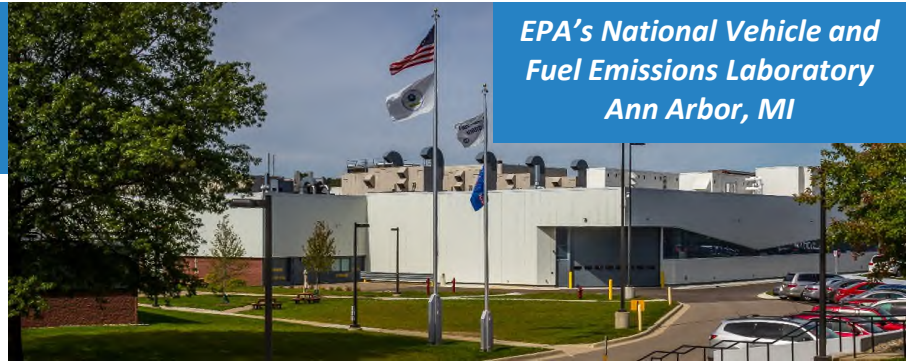
EPA's Reconsideration of the MTE Final Determination

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:

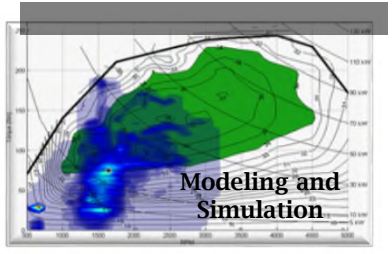
- MY2016 Mazda CX-9 2.5 liter GDI-turbo-charged w/ 6-speed AT
- MY2016 Honda Civic 1.5 liter GDI-turbo-charged 10.6:1 w/ CVT

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

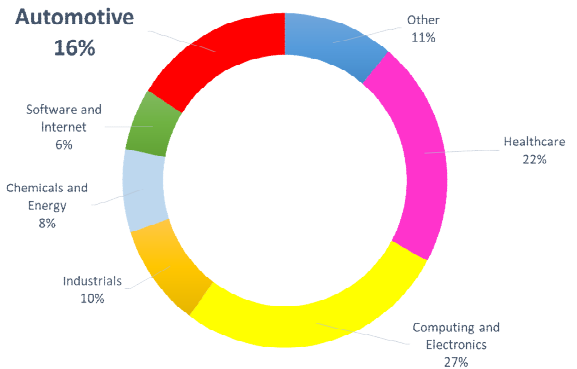
Example technologies EPA has not yet considered in our on-going technical assessment.

Potential to Consider New Technologies:

- 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
- Increased thermal management (e.g., waste heat recovery)
- Additional friction reduction:
  - Cam and crank roller bearings
  - Plasma Vapor Deposition (PVD) cylinder coating – already in production
- Water injection for knock mitigation – BMW
- 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

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**