REGULATORY ANALYSIS OF POWERTRAIN TECHNOLOGIES: ONE PATHWAY FOR COMPLIANCE WITH CAFE AND GHG EMISSIONS STANDARDS

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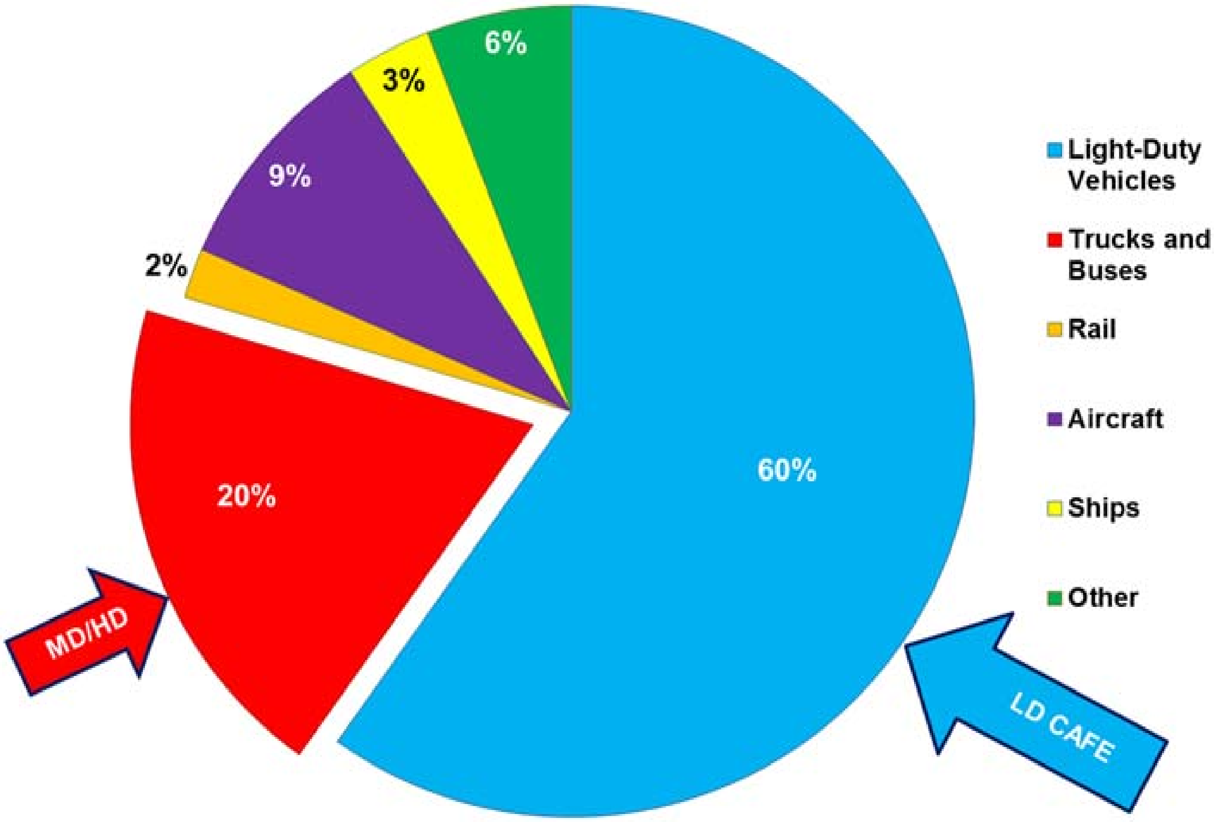
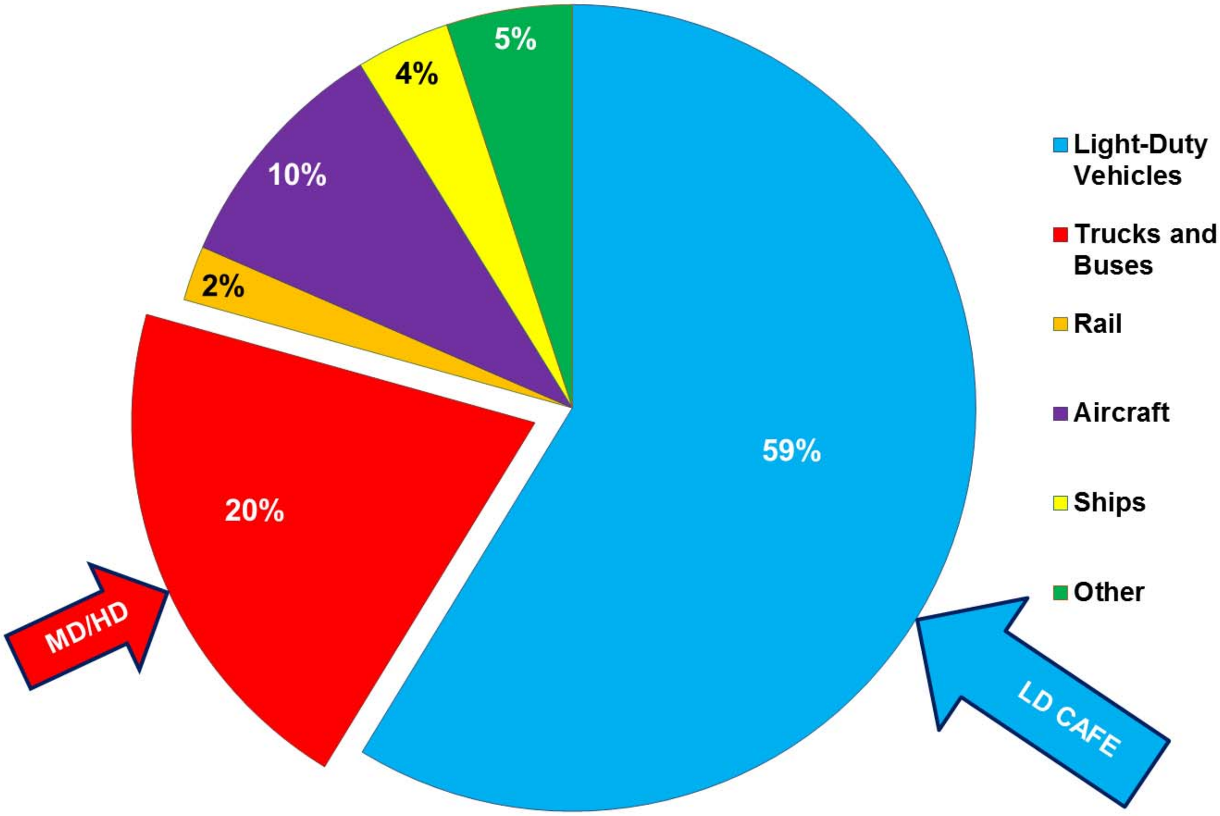
US Transportation Sector Energy Use in 2012



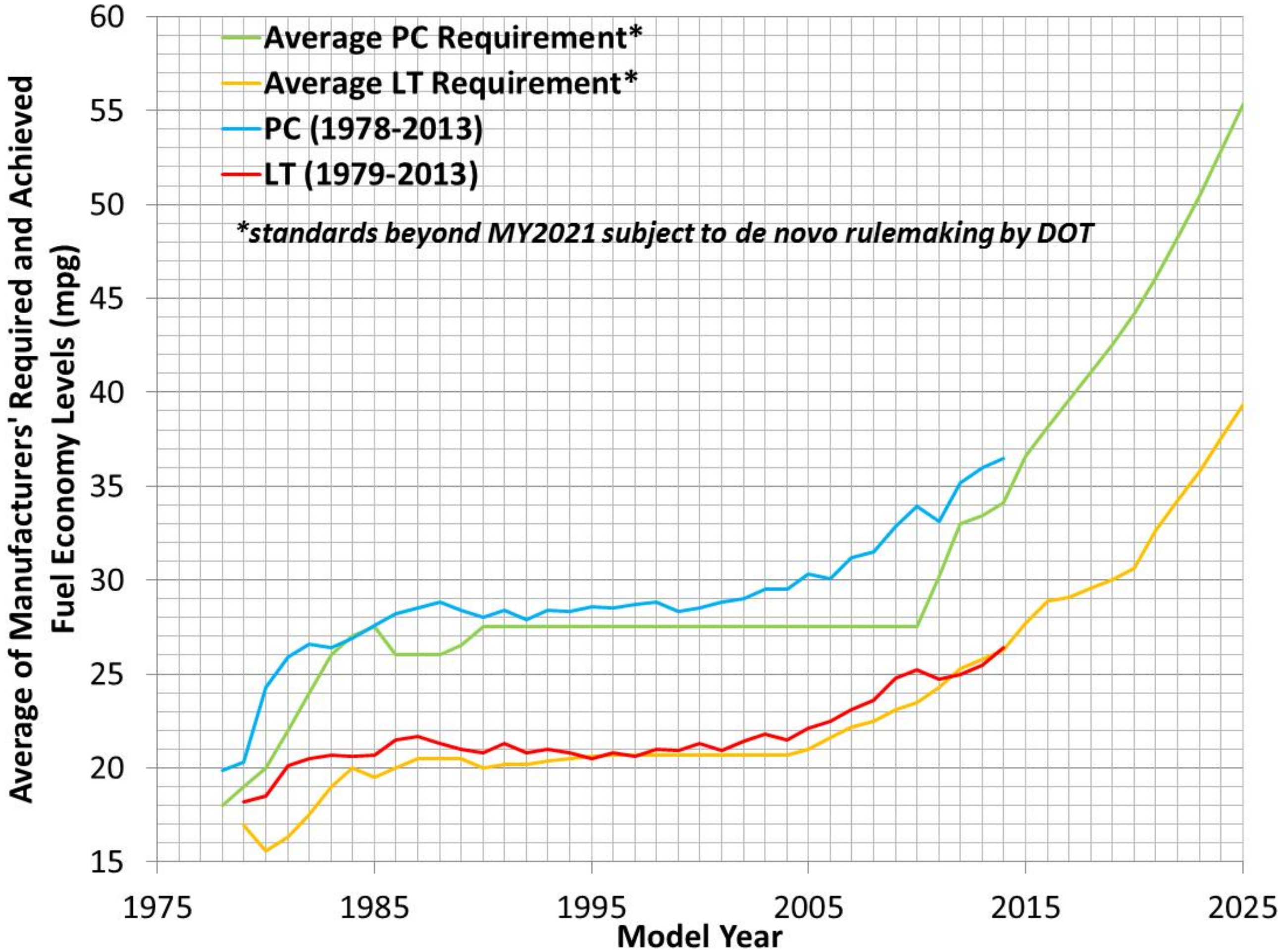
Source: U.S. Energy Information Administration, Annual Energy Outlook 2014

US Transportation Sector CO_2 Emissions in 2012



Source: U.S. Energy Information Administration, Annual Energy Outlook 2014

CAFE: Required Fleet Fuel Economy and Actual Fuel Economy



Key Gasoline Engine Technologies

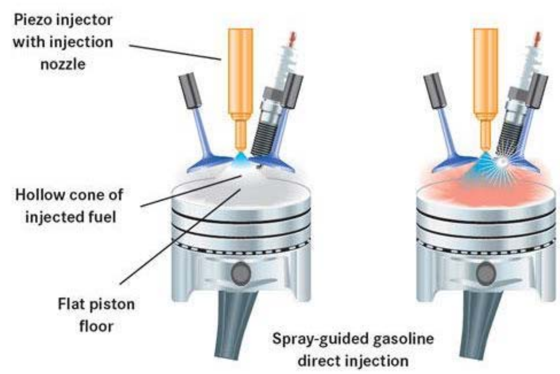
- Spray Guided Gasoline Direct Injection (GDI)
- Variable Valve Timing, Variable Valve Lift
- Turbocharging with Engine Downsizing
- High BMEP: 24 bar BMEP available beginning in 2012, 27 bar BMEP in 2017
- Cooled EGR (option for 24 bar engines, assumed required for 27 bar engines)
- Relative to fixed-valve naturally aspirated gasoline engine:

  Projected Effectiveness: 20 - 27% for 24 bar BMEP
  24 - 28% for 27 bar BMEP (low usage in 2025)

  Projected Cost in 2025: $650 - $2300

Turbocharger

EGR Cooler



Gasoline Direct Injection

Advanced Diesel Engine

- **Common Rail Fuel Injection**
- **Selective Catalytic Reduction (SCR) Aftertreatment**
- **Higher Injection Pressures**
- **Advanced Controls**
- **Reduced Friction**
- **Relative to fixed valve naturally aspirated gasoline engine:**

  Projected Effectiveness: 28 - 31%

  Projected Cost in 2025: $2300 - $3400

Key Transmission Technologies

- Greater than 6 speeds
- Dual Clutch Transmission
- High Efficiency Gear Box
- Optimized Shift Control
- Relative to a 5- speed automatic transmission:

  Projected Effectiveness: 16% - 19%

  Projected Cost in 2025: $285 - $360

P2 Hybrid Electric Vehicles

- Stop/Start
- Regenerative Braking
- Electric Assist and Short EV Range
- Effectiveness*: 45 – 49%

Hyundai Sonata Hybrid

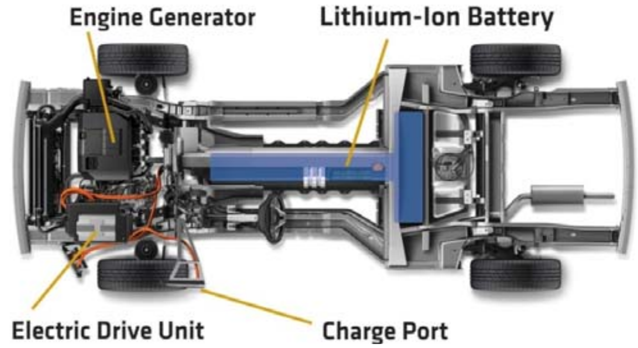
MY 2025 P2 Hybrid	Vehicle Class					
	Compact	Midsize Car	Large Car	Small Truck	Minivan	Large Truck
Motor/battery power (kW)	19	28	51	24	37	47
Battery Cost	$ 822	$ 908	$ 1,066	$ 885	$ 985	$ 1,143
Non-Battery System Cost	$ 1,809	$ 2,019	$ 2,391	$ 1,947	$ 2,229	$ 2,353
Total Cost (2009 $)	$ 2,631	$ 2,927	$ 3,458	$ 2,832	$ 3,214	$ 3,496
Battery Unit Cost ($/kW)	$ 43	$ 32	$ 21	$ 37	$ 27	$ 24

(All table values assuming 2010 baseline fleet)

* Relative to a fixed valve naturally aspirated gasoline engine with a 5-speed automatic transmission

Plug-In Hybrid Electric Vehicle

- **High capacity Li-ion battery**
- **All electric accessories**
- **Regenerative braking**
- **Effectiveness*: 68 – 70%**



Not used for CAFE standard setting

Electricity use accounted for by Petroleum Equivalency Factor

MY 2025 PHEV 30	Vehicle Class		
	Compact	Midsize Car	Large Car
Motor size (kW)	95	142	254
Battery Energy (kWh)	10.4	12.8	15.2
Battery Cost	$ 4,710	$ 5,626	$ 7,461
Non-Battery System Cost	$ 3,173	$ 3,990	$ 5,748
Total Cost (2009 $)	$ 7,883	$ 9,617	$ 13,210
Battery Unit Cost ($/kWh)	$ 453	$ 440	$ 491

* Relative to a fixed valve naturally aspirated gasoline engine with a 5-speed automatic transmission

Electric Vehicle

- **High capacity lithium ion battery**
- **Significant electric range (~ 70-120 miles all electric range)**
- **Effectiveness: 90 – 91%**

Not used for CAFE standard setting
Electricity use accounted for by
Petroleum Equivalency Factor

Nissan Leaf

MY 2025 EV100	Vehicle Class		
	Compact	Midsize Car	Large Car
Motor size (kW)	95	142	254
Battery Energy (kWh)	30.4	37.4	44.4
Battery Cost	$ 9,363	$ 10,742	$ 13,263
Non-Battery System Cost	$ 526	$ 1,626	$ 2,869
Total Cost (2009 $)	$ 9,889	$ 12,368	$ 16,131
Battery Unit Cost ($/kWh)	$ 308	$ 287	$ 299

* Relative to a fixed valve naturally aspirated gasoline engine with a 5-speed automatic transmission

Wide Range of Technologies is Available to Meet the Standards

The agencies assessed more than 50 technologies can be used to improve fuel economy

- Advanced gasoline and diesel engine technologies
- Transmissions with more than 6 speeds and dual-clutch technology
- Hybrids, plug-in hybrid electrics, and all electric vehicles
- Mass reduction
- Improved vehicle aerodynamics
- Reduced rolling resistance tires
- Improved electric accessories
- Improved air conditioning systems

NHTSA Analysis of Technologies

Use a computer model (the CAFE model) to analyze how the industry and each manufacturer could meet more stringent standards

- Optimization program for cost and effectiveness
- Models each manufacture and every vehicle model
- Accounts for redesign cycles
- Accounts for regulatory constraints
- Provides economic and some environmental effects results

Technology Projections

NHTSA analysis projects that most manufacturers could comply in 2025 by producing an overall fleet with:

91%	**Advanced gasoline and diesel vehicles**
66%	**Advanced transmissions**
20%	**Idle stop-start**
12%	**Hybrid Electric Vehicles**
1%	**Plug-in Hybrid Electric Vehicles or Electric Vehicles**
4%	**Average passenger car mass reduction**
8%	**Average light truck mass reduction relative to 2011**

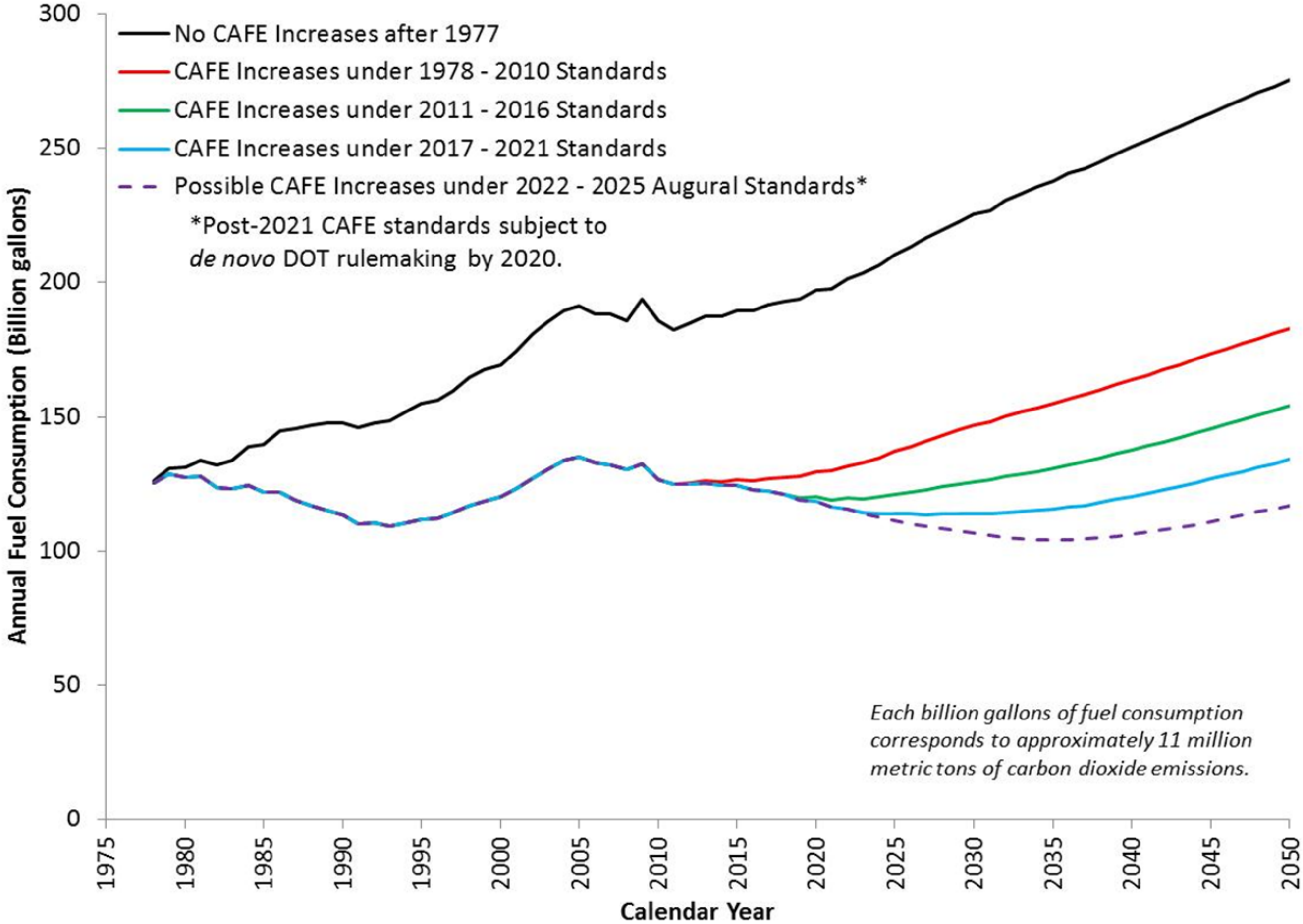
NOTE: the standards are performance standards, not technology mandates. Manufacturers can choose any technologies to meet the standards. The agency analysis projects one pathway for compliance.

Consumer Impacts

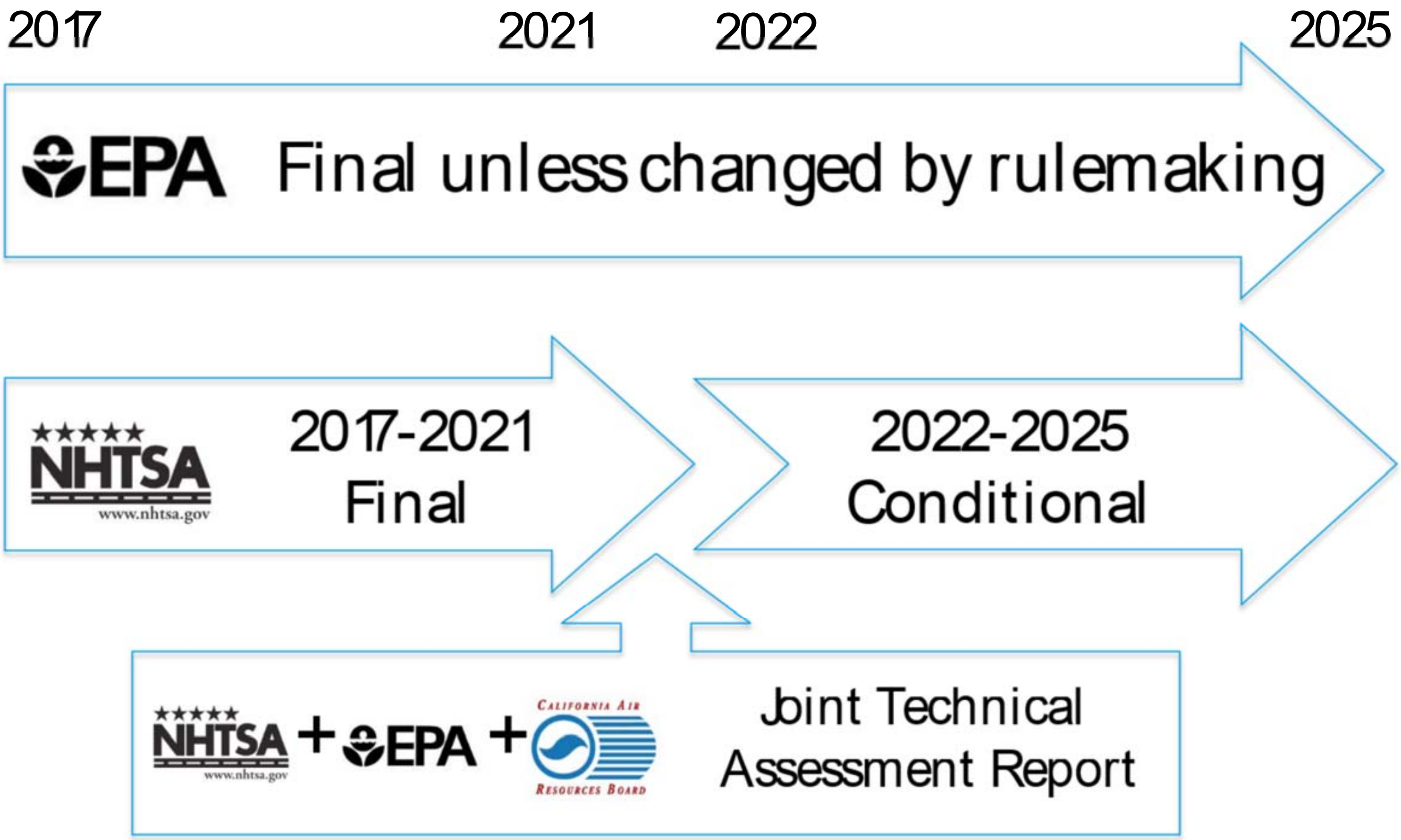
- **Footprint based standards reduce incentives to change vehicle size and help maintain consumer choice**
- **The agency model assumed no change in vehicle utility, except for EV driving range.**
- **Average vehicle cost increase in 2025 $1800 (relative to 2016)**
- **2025 vehicle lifetime fuel savings $5,700 to $7,400**
- **Net lifetime savings $3,400 to $5,000**

Note: all ranges of $ values based on use of a 3% and 7% discount rate

Impact on Fuel Consumed by U.S. Passenger Cars and Light Trucks



Mid Term Evaluation



Summary

1. **CAFE standards are challenging, but there is lead time and the agencies' analyses show a pathway to develop and implement technologies to meet the standards.**
2. **There is a wide range of technologies that manufacturers can use to improve fuel economy.**
3. **There is significant potential for fuel efficiency improvement in gasoline and diesel engines and in transmissions.**
4. **The 2025 fleet could be dominated by advanced gasoline and diesel vehicles, with a modest number of HEVs and a small number of PHEV and EVs.**
5. **The agencies' pathway does not compromise vehicle functionality.**
6. **The standards will provide fuel savings that are estimated to significantly exceed consumer costs.**
7. **NHTSA, EPA and CARB will conduct a mid-term review of the 2022 – 2025 standards. NHTSA will conduct new rulemaking for those years.**