UNITED STATES
DEPARTMENT OF TRANSPORTATION

DOT's CAFE Rulemaking Analysis

Kevin Green
Chief, CAFE Program Office
Volpe National Transportation Systems Center

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Roadmap

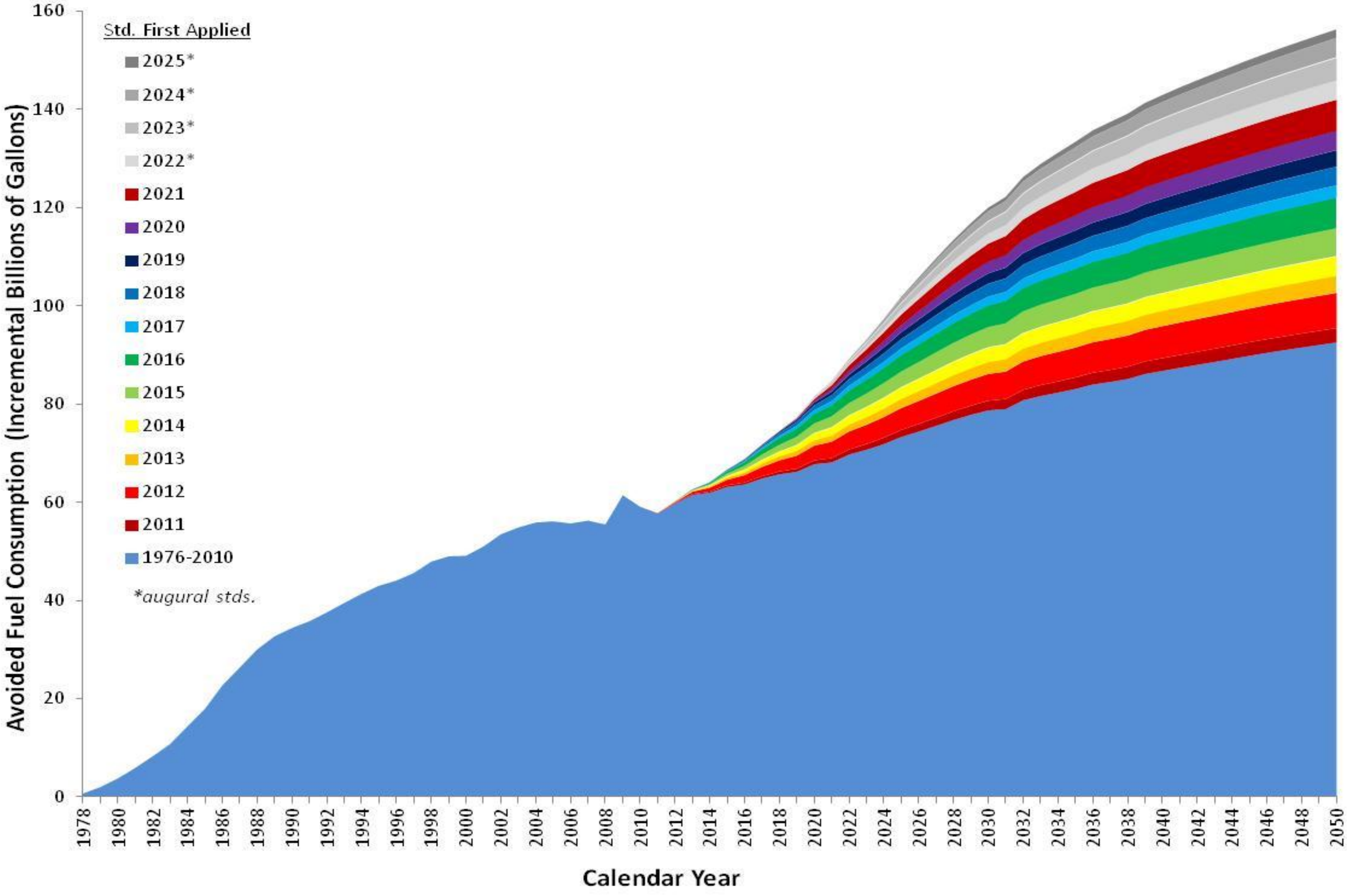
- What does DOT need to consider in setting CAFE standards?
- How does DOT use the CAFE Compliance and Effects Modeling System to help analyze potential CAFE standards?
- How might DOT approach the next round of CAFE standards for MYs 2022 and beyond?

For starters, what is CAFE?

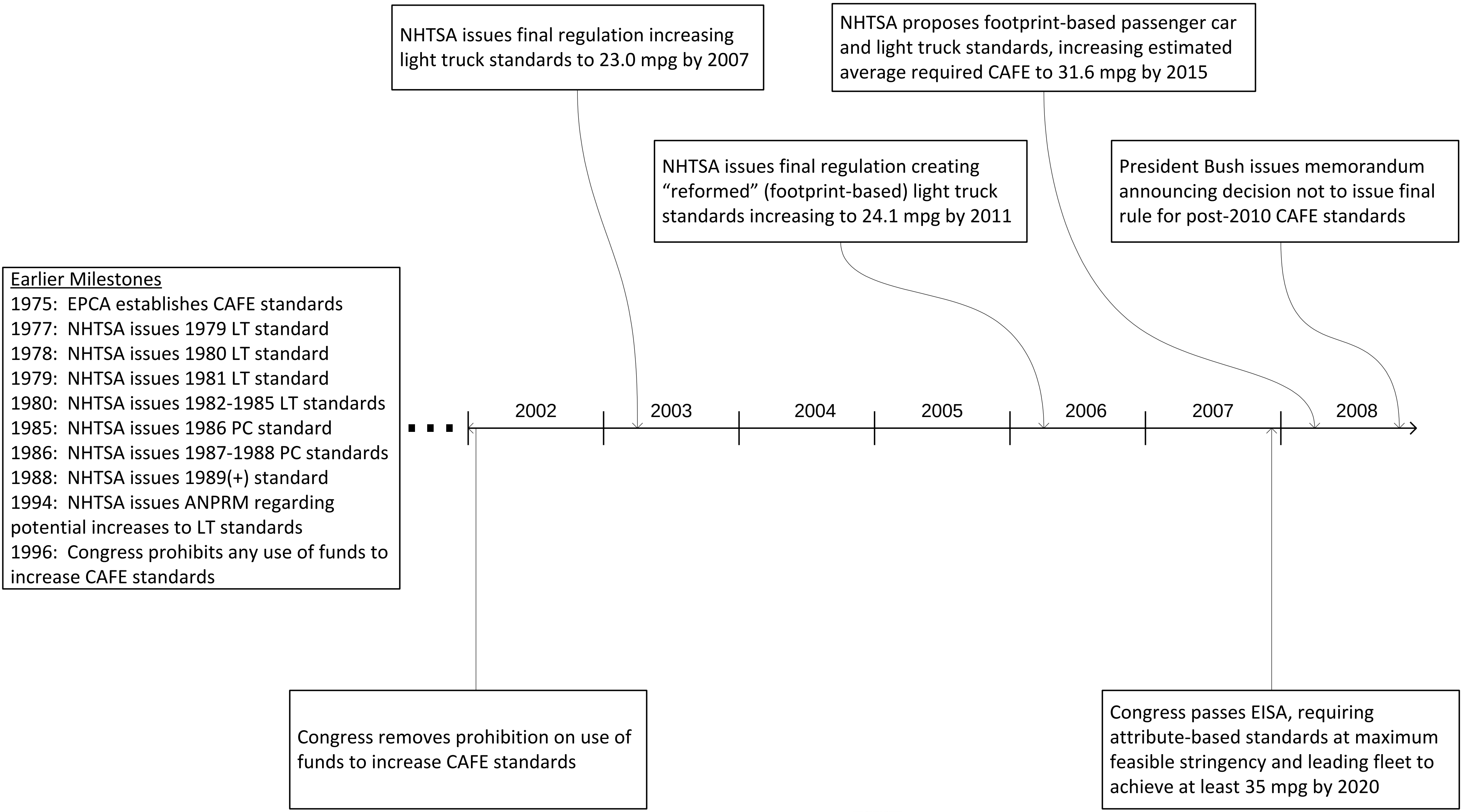
- Corporate Average Fuel Economy
  - “Corporate”
  - “Average”
  - “Fuel economy”

- Why do we have CAFE standards?
  - Congress wanted vehicles to go further on each gallon of gas, in order to reduce energy consumption and our dependence on imported oil

What has CAFE accomplished since the 1970s?



CAFE Milestones During 1975 - 2008



CAFE Milestones Since 2008

2008

President Obama memorandum directing DOT to complete standards for MY 2011 and to coordinate with EPA on CAFE standards for MYs 2012-2016, and directing EPA to reconsider prior EPA decision to deny waiver allowing California to enforce CO2 standards

NHTSA issues footprint-based passenger car and light truck standards increasing estimated average stringency to 27.3 mpg by 2011

EPA and NHTSA issue Notice of Intent to propose light vehicle GHG and CAFE standards, previewing 250 g/mi CO2eq by 2016

2009

NHTSA issues CAFE standards increasing average stringency to 34.1 mpg by 2016; EPA issues GHG standards reaching average stringency of 250 g/mi CO2eq (35.5 mpg equivalent) by 2016

CARB amends light vehicle CO2 standards to allow compliance through compliance with federal CO2 standards

President Obama memorandum requesting DOT and EPA to collaborate with CARB on a technical assessment, and to then develop a coordinated national program for 2017-2025

2010

EPA, NHTSA, and CARB “Interim Technical Assessment Report” evaluating potential “technology pathways” to reduce new vehicle CO2 emissions annually by 3-6% through 2025

2011

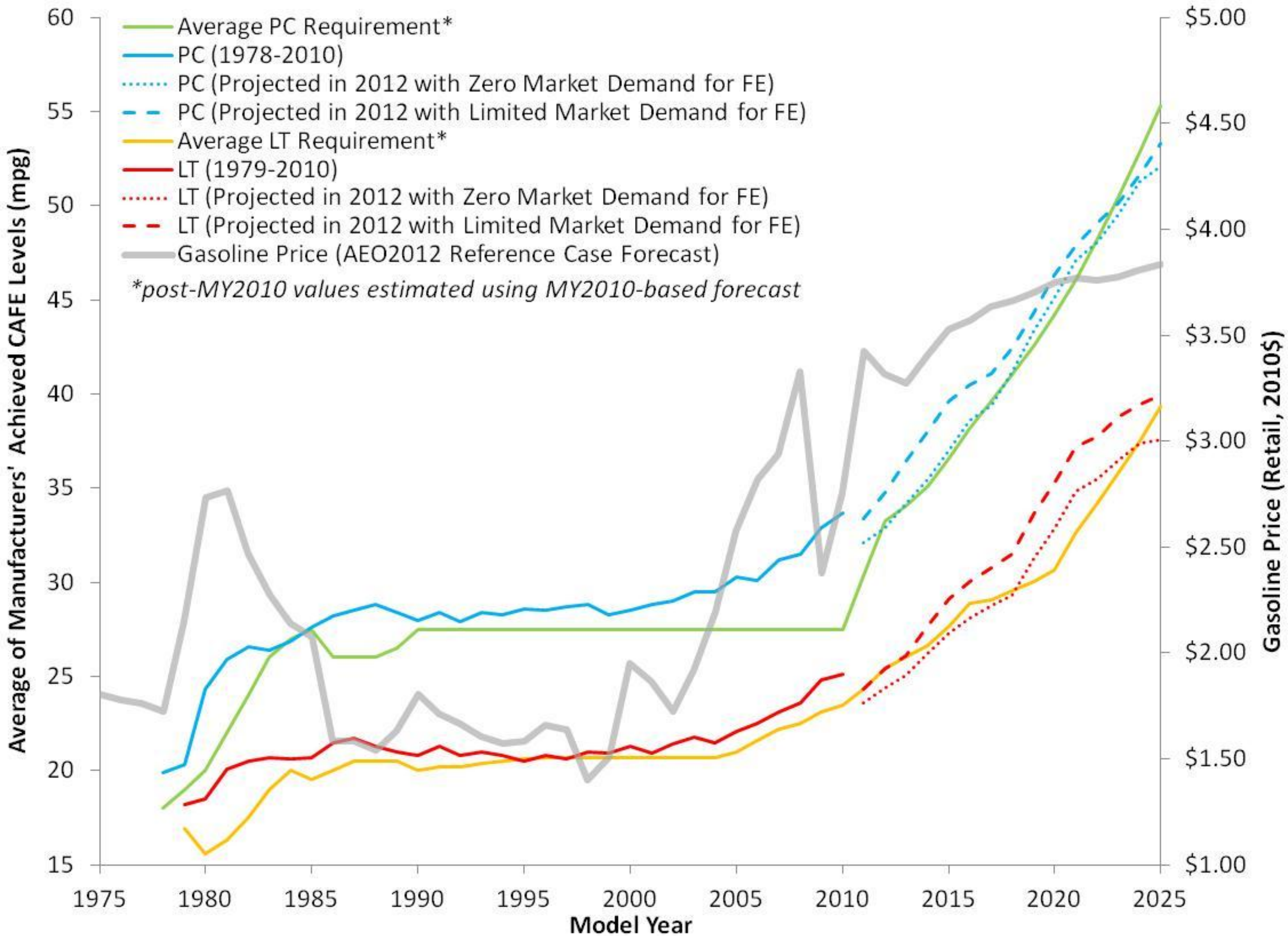
President Obama announces agreement with major automakers on National Program for 2017-2025.

NHTSA proposes standards increasing average stringency to 40.9 mpg by 2021 and 49.7 mpg by 2025; EPA proposes GHG standards reaching average stringency of 163 g/mi CO2eq (54.5 mpg equivalent)

2012

NHTSA issues final standards increasing estimated average stringency to 40.3-41.0 mpg by 2021 and augural standards that, if finalized, would increase estimated average stringency to 48.7-49.7 mpg by 2025; EPA issues GHG standards reaching estimated average stringency of 163 g/mi CO2eq (54.5 mpg equivalent) by 2025; CARB determines to accept compliance with federal standards as compliance with CARB standards

Average Achieved Fuel Economy Levels



What has Congress directed DOT to consider in setting CAFE standards?

- Standards must be “maximum feasible” for each fleet, each year since the late 1970s
  - Balancing technological feasibility, economic practicability, the effect of other motor vehicle standards of the Federal government on fuel economy, the need of the nation to conserve energy, and safety

- Since Congress passed EISA in 2007, standards must also:
  - Increase ratably from MY 2011 to MY 2020
  - Be attribute - based and defined by a mathematical function
  - Cause the combined national fleet to reach 35 mpg by 2020
  - Include a minimum standard for domestic passenger cars

Attribute - Based CAFE Standards

- Attribute has to be related to fuel economy
  - DOT has used vehicle footprint
  - Footprint = area within rectangle bounded by tires

- Mathematical function relates mpg to the attribute
  - Every vehicle footprint has a fuel economy target

  - Required CAFE level for each of a manufacturer's fleet = production - weighted average of fuel economy targets for vehicles produced

  - Compliance determined by comparing actual CAFE level of fleet to required CAFE level (avg of vehicles' targets)

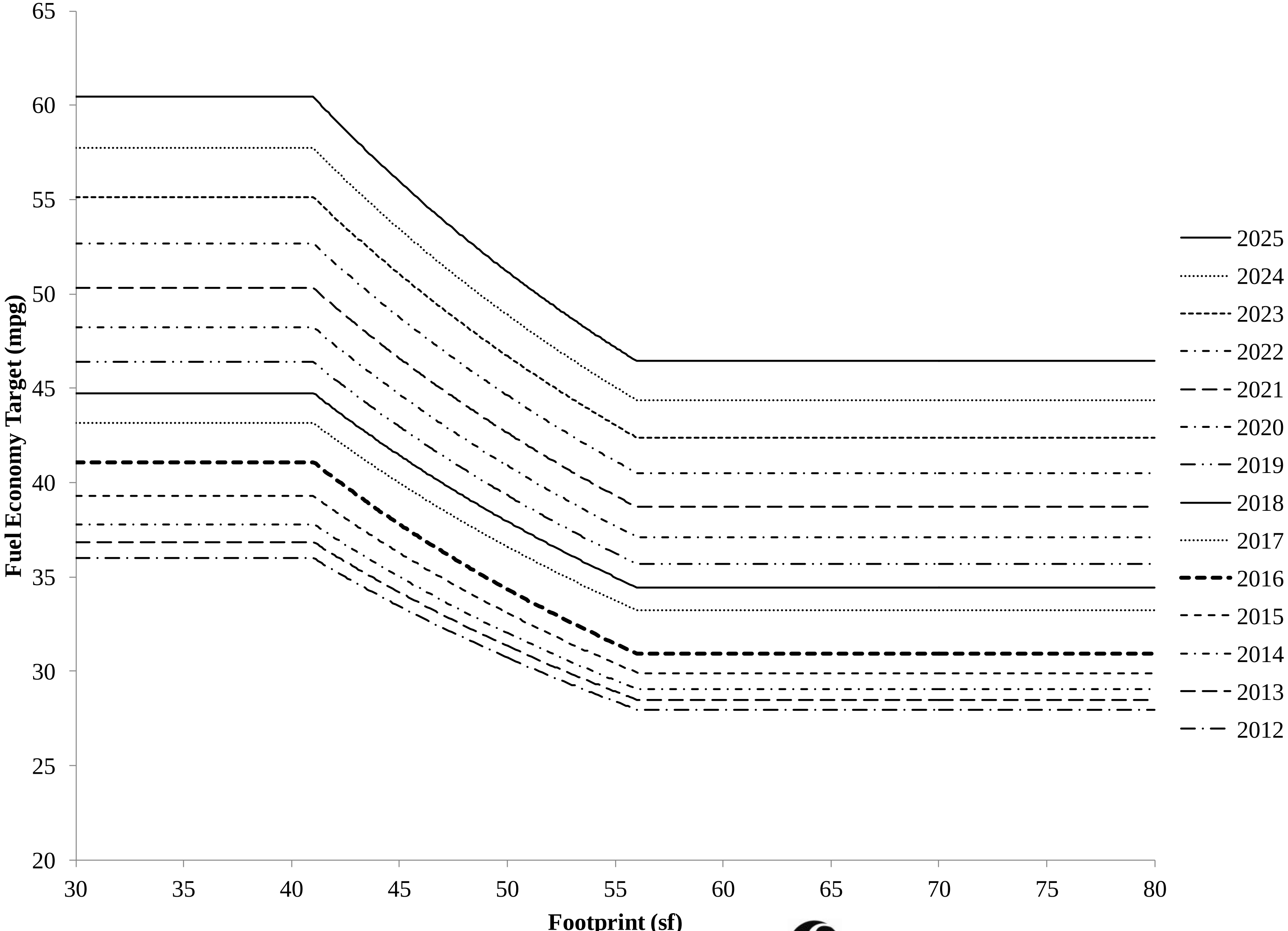
Mathematical Functions DOT has Used

$$T = \frac{1}{\frac{1}{a} + \left(\frac{1}{b} - \frac{1}{a}\right)\frac{e^{(x-c)/d}}{1+e^{(x-c)/d}}}$$

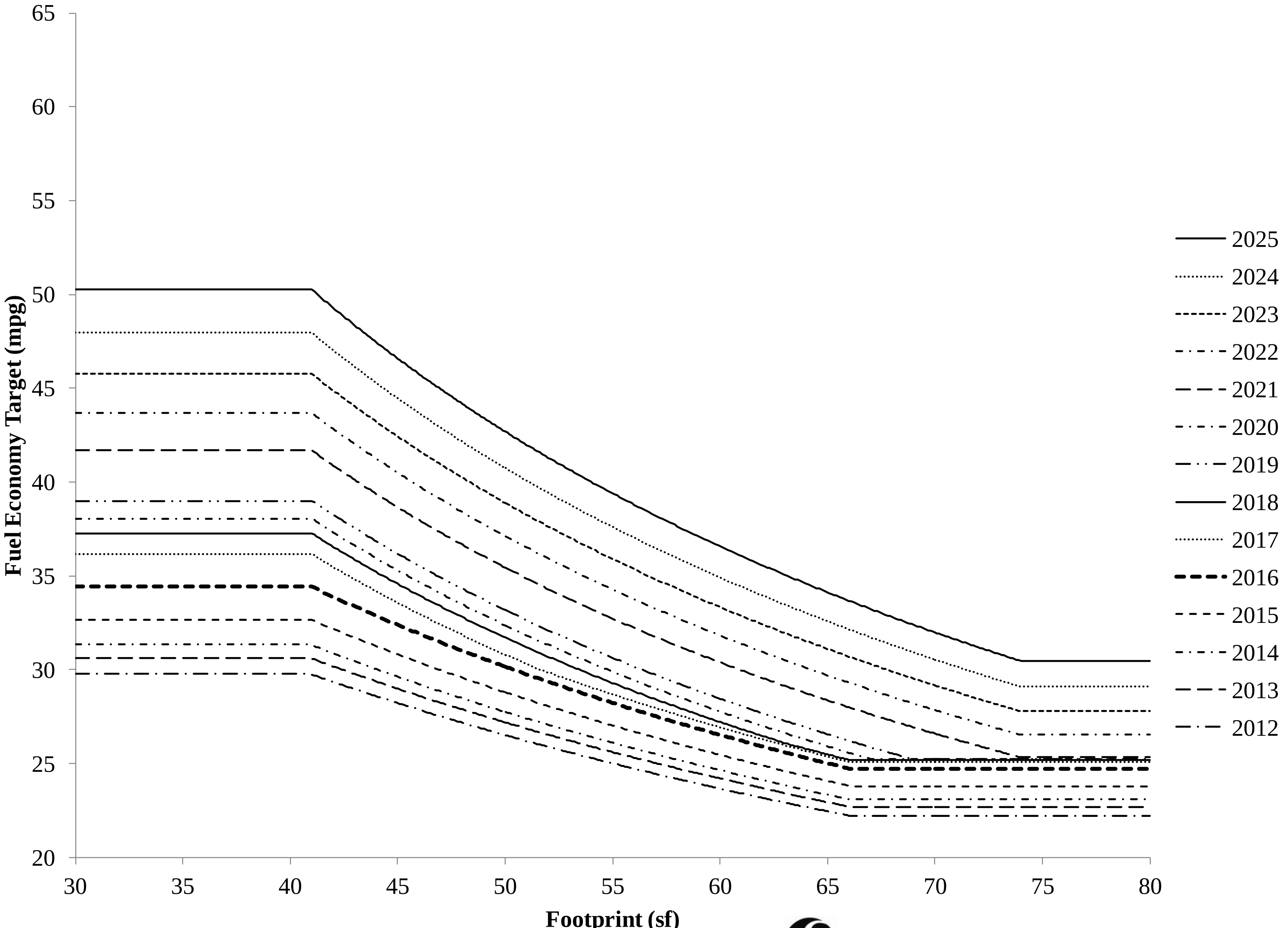
$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

$$TARGET = MAX\left(\frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}, \frac{1}{MIN\left[MAX\left(g \times FOOTPRINT + h, \frac{1}{e}\right), \frac{1}{f}\right]}\right)$$

Post - MY2011 CAFE Standards (Pass. Cars)



Post - MY2011 CAFE Standards (Light Trucks)



One implication of attribute - based standards? Average requirement depends on fleet mix

Model Year	Passenger Cars	Light Trucks	Combined Fleet
2017	32.7 - 43.6	25.1 - 36.3	25.1 - 43.6
2018	33.8 - 45.2	25.2 - 37.4	25.2 - 45.2
2019	35.1 - 46.9	25.2 - 38.2	25.2 - 46.9
2020	36.5 - 48.7	25.2 - 39.1	25.2 - 48.7
2021	38.0 - 50.8	25.2 - 41.8	25.2 - 50.8
2022	39.8 - 53.2	26.3 - 43.8	26.3 - 53.2
2023	41.6 - 55.7	27.5 - 45.9	27.5 - 55.7
2024	43.6 - 58.3	28.8 - 48.1	28.8 - 58.3
2025	45.6 - 61.1	30.2 - 50.4	30.2 - 61.1

- ranges reflect lower and upper limits of mathematical functions defining standards
- plausible averages of manufacturers' requirements fall in narrower ranges

What needs to go into a CAFE rulemaking analysis?

- range of regulatory alternatives (standards)
- costs, effects (e.g., fuel savings, CO_2 reduction), monetized benefits
- sensitivity analysis (e.g., impact of lower or higher fuel prices)
- uncertainty analysis
- environmental impacts (for EIS issued through NEPA process)

How does the CAFE model meet those needs?

To regulatory documents

<u>Inputs</u>

- market forecast
    - models
    - volumes
    - mpg levels
    - base tech., etc.
- standards
- available technology
    - availability
    - efficacy
    - cost
- economic inputs
    - fuel prices
    - discount rate
    - etc.

<u>Model</u>

- Applies technologies to comply with standards
- Minimizes cost
- Separately for each OEM and model year

<u>Outputs</u>

- “response” fleet
    - applied tech.
    - new mpg levels
    - added cost
- compliance status
    - CAFE levels
    - credits
    - fines (if owed)
- national impacts
    - costs
    - travel (VMT)
    - fuel savings
    - emissions

Manufacturer - Level Forecasts (in 1000s)

Manufacturer	Estimated MY2016 Production		Estimated MY2025 Production	
	MY2008-Based	MY2010-Based	MY2008-Based	MY2010-Based
Aston Martin	1.0	0.6	1.2	0.6
BMW	566.5	423.9	550.7	464.4
Mercedes	381.1	347.7	441.8	380.3
Chrysler/Fiat	889.6	1,518.8	775.9	1,628.1
Ford	2,323.3	2,393.2	2,224.6	2,439.0
Geely (Volvo)	144.5	92.2	143.7	97.4
General Motors	2,835.0	2,893.9	3,197.9	2,958.0
Honda	1,449.8	1,658.1	1,898.0	1,799.3
Hyundai	588.6	983.5	845.4	1,053.3
Kia	636.1	378.2	460.4	388.7
Lotus	0.3	0.4	0.3	0.4
Mazda	470.6	317.8	368.2	315.9
Mitsubishi	140.0	69.8	109.7	83.4
Nissan	1,279.2	1,217.3	1,441.2	1,231.9
Porsche	48.1	39.6	51.9	36.7
Spyker	20.0		26.6	
Subaru	309.6	306.6	331.7	315.2
Suzuki	115.8	46.7	124.5	52.9
Tata (Jaguar/Land Rover)	105.0	81.9	122.2	81.3
Tesla	27.3		32.0	
Toyota	3,202.4	2,502.1	3,318.1	2,543.4
Volkswagen	661.4	589.9	784.4	584.4
Total	16.2	15.9	17.3	16.5

Some Key Modeled Engine Technologies

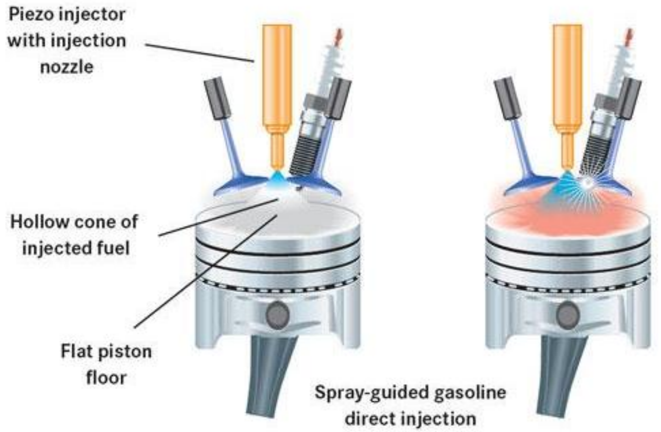
- Stoichiometric Gasoline Direct Injection (GDI)
- Variable Valve Timing, Variable Valve Lift
- Turbocharging with Engine Downsizing
- High BMEP: 24 bar BMEP available beginning in 2012, 27 bar BMEP in 2017
- Cooled EGR (option for 24 bar engines, assumed required for 27 bar engines)
- Relative to fixed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

Projected Effectiveness: 23 - 27% for 24 bar BMEP
24 - 28% for 27 bar BMEP (low usage in 2025)

Projected Cost in 2025: $800 - $2500

•Turbocharger

•EGR Cooler



•Gasoline Direct Injection

Some Key Modeled 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: 12% - 19%
    - Projected Cost in 2025: $285 - $360

Technology Projections

DOT analysis projects that most OEMs could comply in 2025 by producing an overall fleet with:

Technology	% of MY 2025 fleet
18 bar BMEP turbo charged engines	43-57%
24 bar BMEP turbo charged engines	28-35%
27 bar BMEP turbo charged engines	5-6%
Advanced diesel engines	1%
New transmission with high efficiency gearbox	68-86%
Shift optimizer	66-86%
“Mild” Hybrid	9-17%
“Strong” Hybrid	2-3%
PHEV+EV	<1%

<u>NOTE:</u> 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. Percentages reflect difference in projections depending on MY 2008 vs MY 2010 baseline.

Sample Model-Level Results (MY2025)

- Technologies commonly estimated as added in combination
  - Engine downsizing with SGDI and turbocharging
  - 8-speed AT with more efficient gearbox and further optimized shifting
  - Mass reduction (3.5% for passenger cars, 7.5% for light trucks)
  - Others (e.g., EPS, lower RR tires) varying among vehicles (per initial content)

		Fuel Economy (mpg)		Decrease in Fuel	Curb Weight (lb.)		Curb Wt. Decrease	Cost**
Model	Base Engine	MY2010	MY2025 2-Cycle*	Cons. (gpm)	MY2010	MY2025	(%)	
Crown Victoria	V8 4.6L	24.5	42.8	57%	4,139	3,829	7.5%	$ 2,319
F150 (4wd)	V8 4.6L	20.4	31.0	66%	5,789	5,355	7.5%	$ 2,349
Chevrolet Malibu	V6 3.6L	26.5	41.9	63%	3,629	3,502	3.5%	$ 1,255
Ridgeline 4wd	V6 3.5L	22.0	35.0	63%	4,555	4,213	7.5%	$ 1,471
Genesis	V6 3.8L	28.0	47.1	59%	3,748	3,467	7.5%	$ 1,600
Mazda 6	V6 3.7L	25.8	42.2	61%	3,548	3,424	3.5%	$ 1,500
Altima	V6 3.5L	29.5	46.5	64%	3,355	3,238	3.5%	$ 1,372
Frontier 4wd	V6 4L	20.9	33.8	62%	4,428	4,096	7.5%	$ 1,603
Camry	V6 3.5L	29.6	47.6	62%	3,461	3,340	3.5%	$ 1,520
4runner 4wd	V6 4L	24.1	41.3	58%	4,750	4,394	7.5%	$ 1,787
Tacoma 4wd	V6 4L	22.7	39.1	58%	4,045	3,742	7.5%	$ 1,770

** excludes 0.9-1.6 mpg upward adjustments for AC and other off-cycle improvements*

*** cost includes estimated indirect costs and profit*

Modeled Fuel Economy Levels in MY2025

- Reference case analysis assuming no market - driven fuel economy increases

Fleet	MY2008-Based Forecast	MY2010-Based Forecast
Passenger Cars		
Average Requirement	56.2	55.3
Average Initial* CAFE	30.7	31.5
Average Achieved** CAFE	52.9	52.1
Light Trucks		
Average Requirement	40.3	39.3
Average Initial* CAFE	22.7	23.1
Average Achieved** CAFE	39.0	37.6
Overall Fleet		
Average Requirement	49.7	48.7
Average Initial* CAFE	27.5	28.1
Average Achieved** CAFE	47.4	46.2

** Initial CAFE = average fuel economy given current technology*

*** Achieved CAFE = average fuel economy given added technology*

Sensitivity Analysis (Discrete Side Cases)

- Fuel prices
- Rebound effect
- Value of avoiding CO_2 emissions
- Valuation of CH_4 and N_2O (non - zero)
- Military security benefits (non - zero)
- Consumer benefits (less than 100% of theoretical)
- Battery cost
- Mass reduction cost
- Potential for market - driven fuel economy increases (beyond required by CAFE)
- Exclusion of shift optimizer

See Final RIA, Chapter X (pp. 1084 - 1121)

Side Case with Market - Driven FE Increases

- Reference case assumes no additional fuel economy improvements once manufacturer achieves compliance
- Side cases simulate additional fuel economy improvements being applied as long as payback is achieved quickly (examined 1 - , 3 - , and 5 - year payback periods)
- Impacts average achieved fuel economy
- Impacts penetration rates for various technologies
- Example below is for MY2010 - based market forecast and 3 - year payback period given reference case fuel prices
- MY2025 results shown

Average Achieved Fuel Economy

Fleet	Reference	With Market-Driven FE Increases
Passenger Cars	52.1	53.3
Light Trucks	37.6	39.9
Overall Fleet	46.2	48.0

Penetration Rate

Technology	Reference	With Market-Driven FE Increases
Turbocharging (18 bar)	56.5%	30.8%
Turbocharging (24 bar)	4.2%	20.5%
Cooled EGR (24 bar)	24.2%	31.9%
Cooled EGR (27 bar)	4.9%	10.8%
Shift Optimizer	65.6%	91.7%

Uncertainty Analysis (Probabilistic)

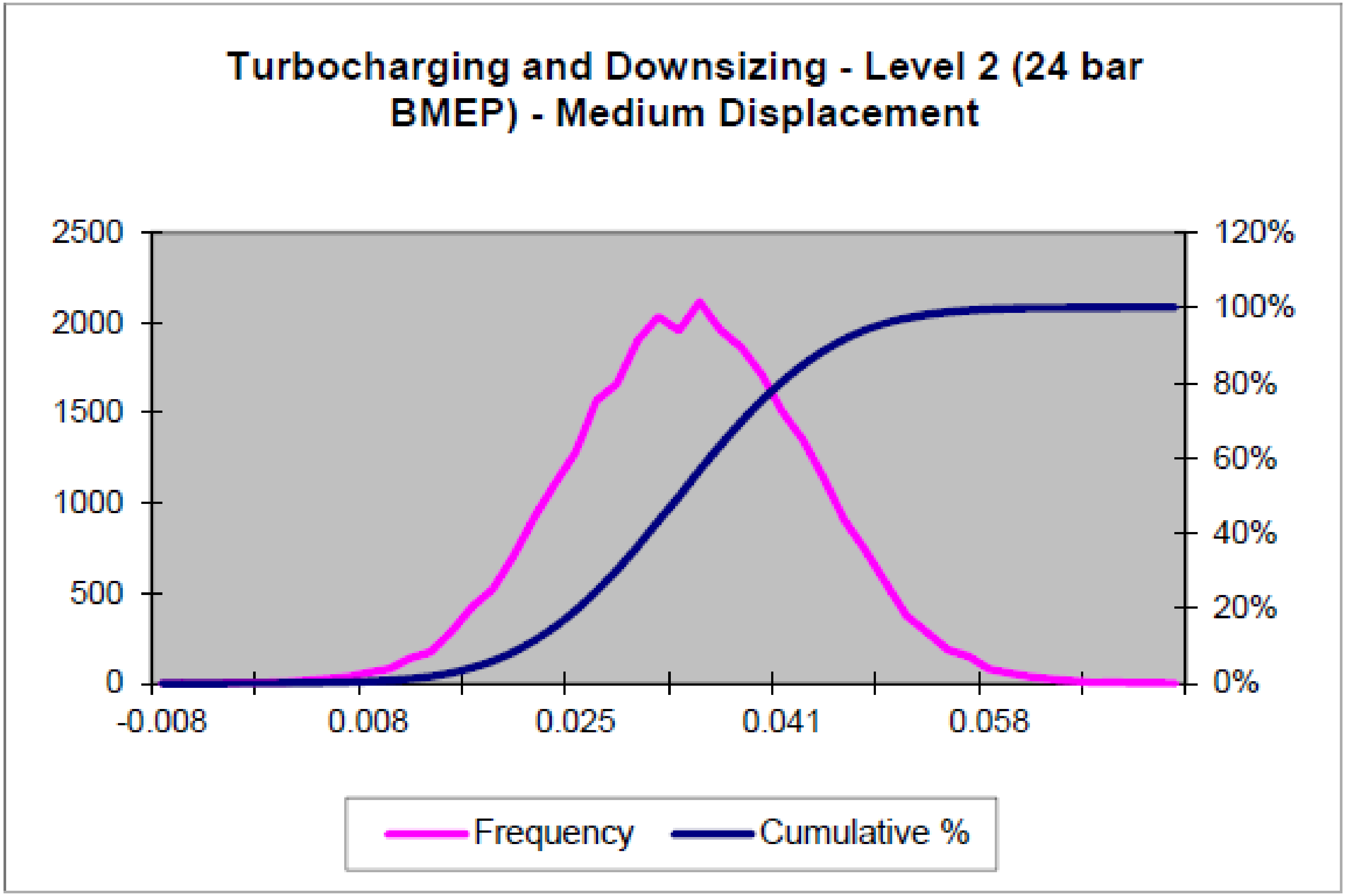
Monte Carlo method used to vary:

- technology costs
- technology effectiveness
- fuel prices
- potential for market - driven fuel economy increases (beyond required by CAFE)
- passenger car share of the new vehicle market
- average vehicle miles traveled per vehicle
- rebound effect
- value of oil consumption externalities

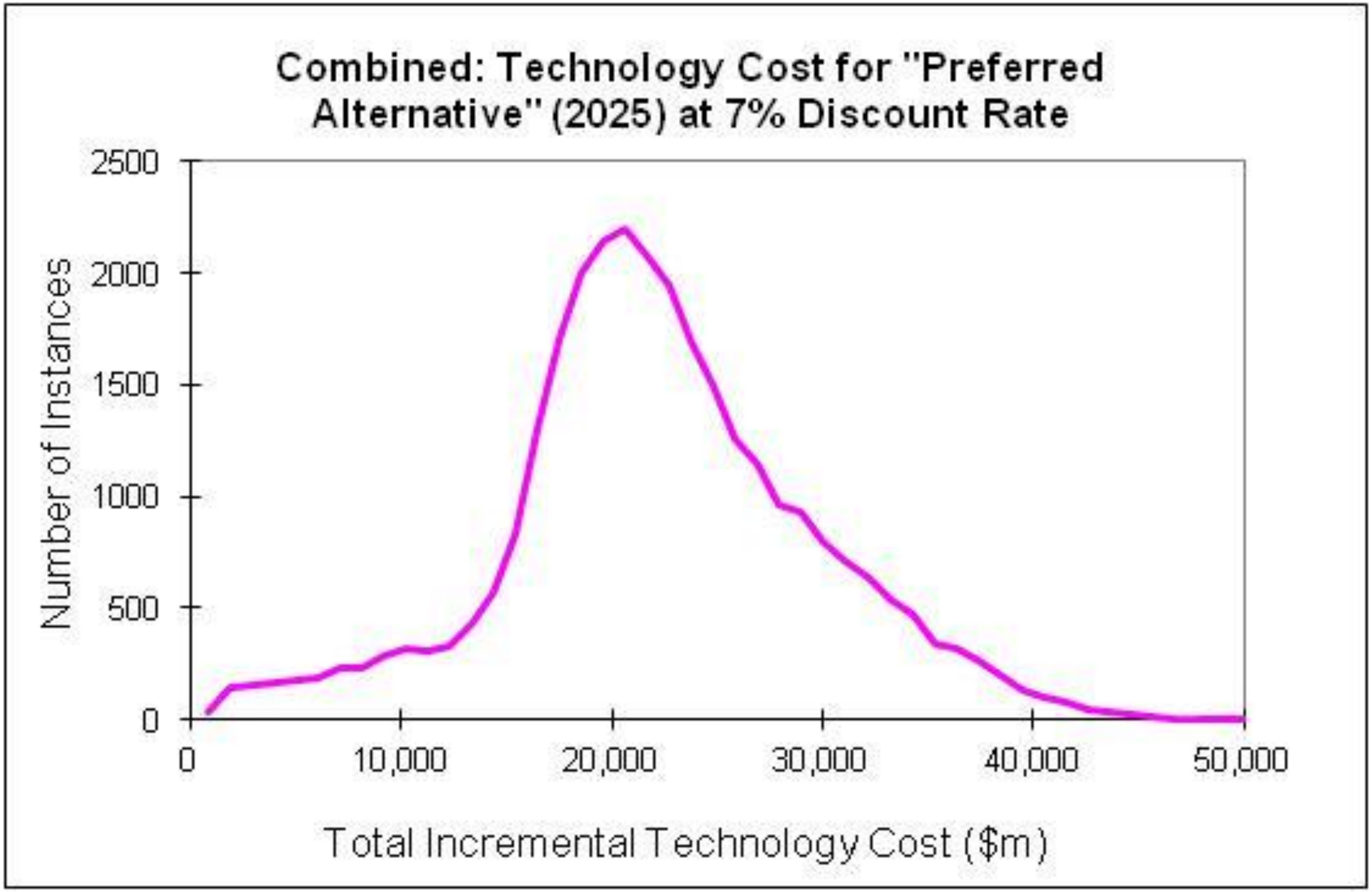
See Final RIA, Chapter XII (pp. 1122 - 1173)

Uncertainty Analysis – Example of Sampling

Monte Carlo Draw Profile, Combined Fleet, Effectiveness



Uncertainty Analysis – Example of Results



Next Round of Evaluation / CAFE Ruelmaking

- Per EISA (2007), each CAFE rulemaking may cover at most 5 model years
  - This is why the MY 2022 - 2025 standards in most recent CAFE final rule are “augural,” not final

- To establish final standards for MYs 2022 and beyond, DOT must undertake new rulemaking
  - Cannot be simply “the augural standards are OK”
  - Must evaluate meaningful range of regulatory alternatives
  - Must prepare DEIS and go through NEPA process
  - Must set standards separately at maximum feasible levels in each model year

- To help inform new rulemaking, agencies and CARB plan for a joint Technical Assessment in 2017/2018
  - NHTSA’s rulemaking will be concurrent with EPA decision on whether to revise 2022 - 2025 GHG standards

Appendix

Relationship between CAFE and GHG Stds.

- Fuel economy determined based on test fuel properties and vehicle's CO_2, CO, and HC emission rates, with upward adjustments for technologies (e.g., more efficient AC systems) that reduce CO_2 emission rates under conditions outside "two cycle" fuel economy test procedures
- GHG determined based on CO_2 emission rate, with corresponding (downward) adjustments for same "off cycle" technologies, and with downward adjustments for technologies (e.g., low - GWP refrigerants) that reduce HFC emissions
- DOT augural MY2025 standard
  - Given MY2008 - based market forecast, average required FE = 49.7 mpg
  - Agencies use value of 8,887 grams CO_2 per gallon of gasoline
  - Assuming all - gasoline fleet, 49.7 mpg is equivalent to 178.8 g/mi CO_2
- EPA MY2025 standard
  - Given MY2008 - based market forecast, average required GHG = 163 g/mi
  - Assuming all - gasoline fleet without any adjustments for HFC - reducing technology, 163 g/mi is equivalent to 54.5 mpg
- Differences (49.7 mpg vs. 54.5 mpg, 178.8 g/mi vs. 163 g/mi) reflect projected adjustments (a.k.a. credits) for reducing HFC leakage and HFC GWP

Earlier Estimates of Potential Response

- 2003 (MY2005 - 2007 Light Truck Standards)
  - Light Truck standard increased from 20.7 mpg in MY2004 to 22.2 mpg in MY2007
  - Projected to be achievable mostly through wider* use of “conventional” technologies
    - Lower - friction lubricants
    - SI engine design (e.g., reduced friction, VVT, OHV→OHC, cylinder deactivation)
    - 5 - and 6 - speed transmissions
    - Reduced rolling resistance and aerodynamic drag

- 2006 (MY2008 - 2011 Light Truck Standards)
  - Light Truck standard reformed and increased to estimated 24 mpg in MY2011
  - Projected to be achievable through wider* use of technologies similar to those in 2003 rule, as well as wider* use of
    - Further SI engine changes (stoic. DI, engine turbocharging/downsizing)
    - 42V systems, reduced accessory loads
    - Hybrids (e.g., ISG) and diesels
    - Reduced vehicle mass

** “Wider use” does not mean “universal” or “dominant” use. For some technologies, analyses suggested significant application for some manufacturers, yet none for other manufacturers.*

Earlier Estimates of Potential Response (cont'd)

- 2008/9 (MY2011 Standards)
  - Attribute - based standards (per EPCA/EISA)
  - Standards increased to estimated average requirement of 27.3 mpg in MY2011
  - Projected to be achievable through wider use of technologies similar to those in 2006 rule, as well as wider use of DCTs and electric power steering

- 2010 (MY2012 - 2016 Standards)
  - Standards increased to estimated average requirement of 34.1mpg in MY2016
  - Projected to be achievable through wider use of technologies similar to those in 2009 rule, as well as wider* use of BISG systems and further vehicle mass reduction