Overview of U.S. GHG Regulations:

Final Rule for the 2012~2016 MY and Proposed Rule for 2017~2025 MY

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Agenda

- **Background on U.S. EPA's Office of Transportation and Air Quality (OTAQ)**

- **2012~2016 MY GHG Regulation**
  - Joint regulation – EPA/NHTSA/CARB
  - Final standards and program elements

- **Proposed 2017~2025 MY GHG Regulation**
  - Final standards and program elements

- **Core Analytical Work**
  - Technology Effectiveness
  - Technology Costs
  - Modeling Tools

EPA's Office of Transportation and Air Quality

- **OTAQ has authority under US Clean Air Act (1970) to regulate emissions from all mobile sources**
- **The Office of Transportation and Air Quality (OTAQ) is divided between EPA's headquarters in Washington, D.C., and the National Vehicle and Fuel Emissions Lab (NVFEL) in Ann Arbor, Michigan**
- **Over 400 employees (approximately ½ of the employees are engineers)**
- **The NVFEL is a world-class state of the art testing & research facility**
- **Major elements of CAFE data collection administered by EPA.**

U.S. Vehicle Emissions History

- **U.S. was regulatory pioneer in 1970's**
  - In Clean Air Act, Congress gave EPA "technology forcing" powers and California ability to set its own standards

- **Since then successful and cost-effective regulations have come from OTAQ**
  - OTAQ rules responsible for 57% of benefits derived from all major federal rules
  - Tier 0, 1 & 2 criteria as well as toxics exhaust and evaporative light-duty emissions standards
  - Gasoline and Diesel Fuel Standards
  - Fuel economy labeling rule
  - 2012~2016 MY GHG regulations

- **EPA's principles**
  - Identify feasible and cost-effective technology
  - Set performance standards to drive innovation and allow flexible compliance
  - Allow lead time for normal business investment cycles
  - Comprehensive approach with all subsectors and fuels
  - Open and transparent process with broad stakeholder involvement

Corporate Average Fuel Economy (CAFE) vs GHG Regulations

- 1975: Congress passed Energy Policy and Conservation Act (EPCA) giving National Highway Traffic Safety Administration (NHTSA, part of DOT) mandate to establish Corporate Average Fuel Economy (CAFE) standards
- With CO_2 having been established as a threat to human health, EPA is able to promulgate rules regulating GHG's under Clean Air Act (CAA)
- Both GHG and CAFE Performance are measured using two test procedures:
  - Federal Test Procedure (FTP) – representing average city driving
  - Highway Fuel Economy Test (HFET) – representing average highway driving
- CAFE is required by EPCA to use the same test procedures used for model year 1975
- CAA provides greater flexibility to EPA
  - Example: Advanced Technology credits for Electric Vehicles
  - Fleet-wide CO_2 standard could be met partially through credits from improved air conditioner (A/C) operation
    - A/C credits include CO_2 & hydrofluorocarbon (HFC) refrigerant reductions
    - HFC refrigerant is a powerful GHG

How do EPA/CARB/NHTSA Collaborate?

- Each agency is regulating the same fleet of vehicles
  - EPA and CARB regulating criteria pollutants and GHG's under CAA
  - NHTSA establishing CAFE requirements under EPCA and Energy Independence and Security Act (EISA)
- All 3 agencies draw from a similar set of vehicle performance data and analyses and have meetings with all stakeholders, both unilaterally and as a group.
- Goal has been to create one national program which sets harmonized requirements for GHG's and CAFE for the US
  - To this end CARB has deemed that compliance with the EPA program results in compliance with California's GHG standards.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

2012~2016 MY GHG Regulation

US 2012~2016 MY CO_2 Standards

- EPA's standards estimated to achieve a fleet-wide level of 250 grams/mile (155 g/km) of CO2 in model year 2016
  - Standards have begun phase in during model year 2012
- The 250 gram/mile CO2 standard corresponds to 35.5 mpg "equivalent" if all reductions resulted from fuel economy improvements (6.6 L/100km)
- NHTSA also adopted new CAFE standards which would lead to an estimated fleet average level of 34.1 mpg (6.9 L/100km) in 2016
  - The difference between the EPA and NHTSA standards lies mostly in the air conditioning technologies manufacturers are projected to use

Standards are Footprint Attribute-based

- Each manufacturer's standard based on the footprint of the vehicles produced – actual standards are curves which equate a vehicle size to its specific CO2 or MPG target.
- Each companies "standard" are footprint curves

Vehicle Type	Example Models	Example Model Footprint (sq. ft. / **sq. m**)	CO_2 Emissions Target (g/mi / **g/km**)	Fuel Economy Target (mpg / **L/100 km**)
Example Passenger Cars				
Compact car	Honda Fit	40 / **3.7**	204 / **127**	41.4 / **5.7**
Midsize car	Ford Fusion	46 / **4.3**	228 / **142**	37.3 / **6.3**
Fullsize car	Chrysler 300	53 / **4.9**	261 / **162**	32.8 / **7.2**
Example Light-duty Trucks				
Small SUV	4WD Ford Escape	44 / **4.1**	258 / **160**	32.8 / **7.2**
Midsize crossover	Nissan Murano	49 / **4.6**	278 / **173**	30.6 / **7.7**
Minivan	Toyota Sienna	55 / **5.1**	303 / **188**	28.2 / **8.3**
Large pickup truck	Chevy Silverado	67 / **6.2**	347 / **216**	24.7 / **9.5**

EPA Program Flexibilities

- Emission banking and trading elements
- Flex-fuel vehicle (FFV) credits
  - MY2012 – 2015 credits similar to CAFE, MY2016+ credits based on actual E85 fuel use
- Air conditioning HFC and CO2 reduction credits
- Early credit opportunities for doing better than California or CAFE
- Advance technology credits (electric vehicles)
- Innovative technology credits
- Manufacturers with limited product lines and/or have traditionally paid fines to NHTSA may be especially challenged technologically in the early years of the program
  - *Under the Clean Air Act, manufacturers cannot pay fines in lieu of complying with motor vehicle emissions standards*

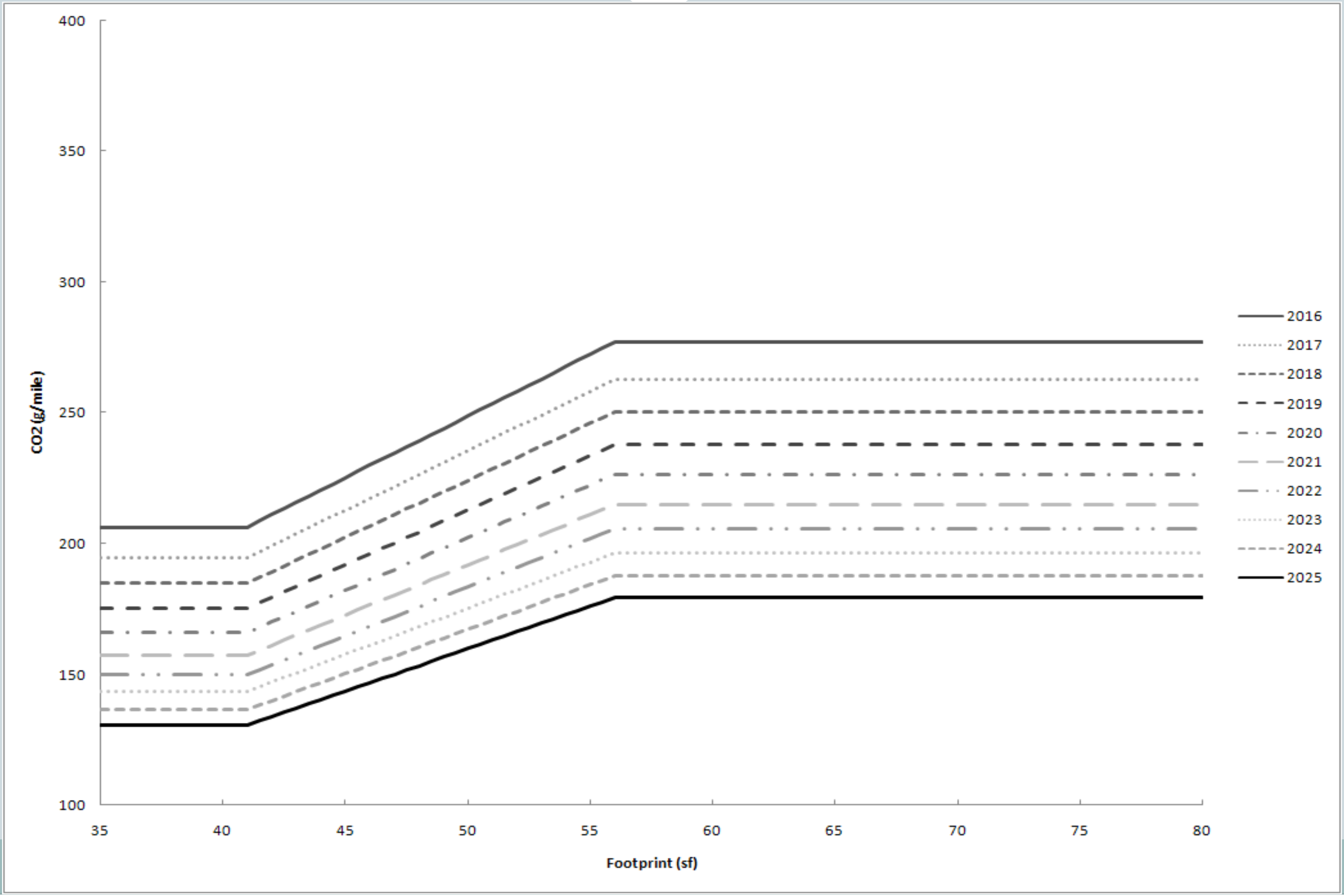
2017~2025 MY GHG Proposed Regulation

US 2017~2025 MY CO_2 Standards

- EPA's proposed standards estimated to achieve a fleet-wide level of 163 grams/mile (101 g/km) of CO2 in model year 2025
  - Standards would begin phase-in during model year 2017
  - 2025 Passenger Car Target = 144 g/mi CO2 (89 g/km)
    - 5% year-over-year reduction in CO2
  - 2025 Light Truck target = 203 g/mi CO2 (126 g/km)
    - 3.5% year-over-year reduction in CO2 from 2017~2021
    - 5.0% year-over-year reduction in CO2 from 2022~2025

- The 163 gram/mile CO2 standard corresponds to 54.5 mpg (4.3 L/100km) "equivalent" if all reductions resulted from fuel economy improvements

Proposed CO2 Target Curves for Passenger Cars



US 2017~2025 MY CAFE Standards

- NHTSA's proposal is expected to result in a 40.9 mpg (5.8 L/100 km) in 2021 MY and 49.6 mpg (4.7 L/100 km) in 2025 MY
  - Standards would also begin phase-in during model year 2017
  - 2025 Passenger Car Target = 56 mpg (4.2 L/100 km)
    - 4.1% year-over-year increase in fuel economy from 2017~2021
    - 4.5% year-over-year increase in fuel economy from 2022~2025
  - 2025 Light Truck target = 40.3 mpg (5.8 L//100 km)
    - 2.9% year-over-year increase in fuel economy from 2017~2021
    - 4.7% year-over-year increase in fuel economy from 2022~2025

Standards are Footprint Attribute-based

- Each manufacturer has a unique car fleet and truck fleet standard, derived from the footprint curves, based on the sales-weighted distribution of vehicles produced
- Footprint curves assign a specific CO2 or MPG target for each vehicle based on it's footprint (roughly the area between the tires)
- See Appendix for the actual CAFE and GHG footprint curves

Vehicle Type	Example Models	Example Model Footprint (sq. ft. / **sq. m**)	2025 CO_2 Emissions Target (g/mi / **g/km**)	2025 Fuel Economy Target (mpg/**km/100**)
Example Passenger Cars				
Compact car	Honda Fit	40 / **3.7**	131 / **81**	61.1 / **3.9**
Midsize car	Ford Fusion	46 / **4.3**	147 / **91**	54.9 / **4.3**
Fullsize car	Chrysler 300	53 / **4.9**	170 / **106**	48.0 / **4.9**
Example Light-duty Trucks				
Small SUV	4WD Ford Escape	44 / **4.1**	170 /**106**	47.5 / **4.9**
Midsize crossover	Nissan Murano	49 / **4.6**	188 / **117**	43.4 / **5.4**
Minivan	Toyota Sienna	55 / **5.1**	209 / **130**	39.2 / **6**
Large pickup truck	Chevy Silverado	67 / **6.2**	252 / **157**	33.0 / **7.1**

Midterm Review

2017 2021 2022 2025

EPA — *Final unless changed by rulemaking*

NHTSA — **2017-2021 Final**

2022-2025 Conditional

NHTSA + EPA + California Air Resources Board — *Joint Technical Assessment Report*

Vehicle Technology Projections

- EPA/NHTSA technology assessment indicates the MY 2017-2025 standards can be met with a wide range of technologies
  - Advanced gasoline engines (turbocharged/downsized) and transmissions (8-speed transmission and high efficiency gear box)
  - Vehicle mass reduction
  - Lower tire rolling resistance
  - Improved aerodynamics
  - More efficient vehicle accessories
  - Improved air conditioning efficiency & alternative refrigerants
  - Some increased hybrids, EVs, PHEVs

- EPA projects that MY2017-2025 vehicles will be 82% advanced gasoline, 15% hybrids, and 3% EV/PHEVs

Key Program Elements

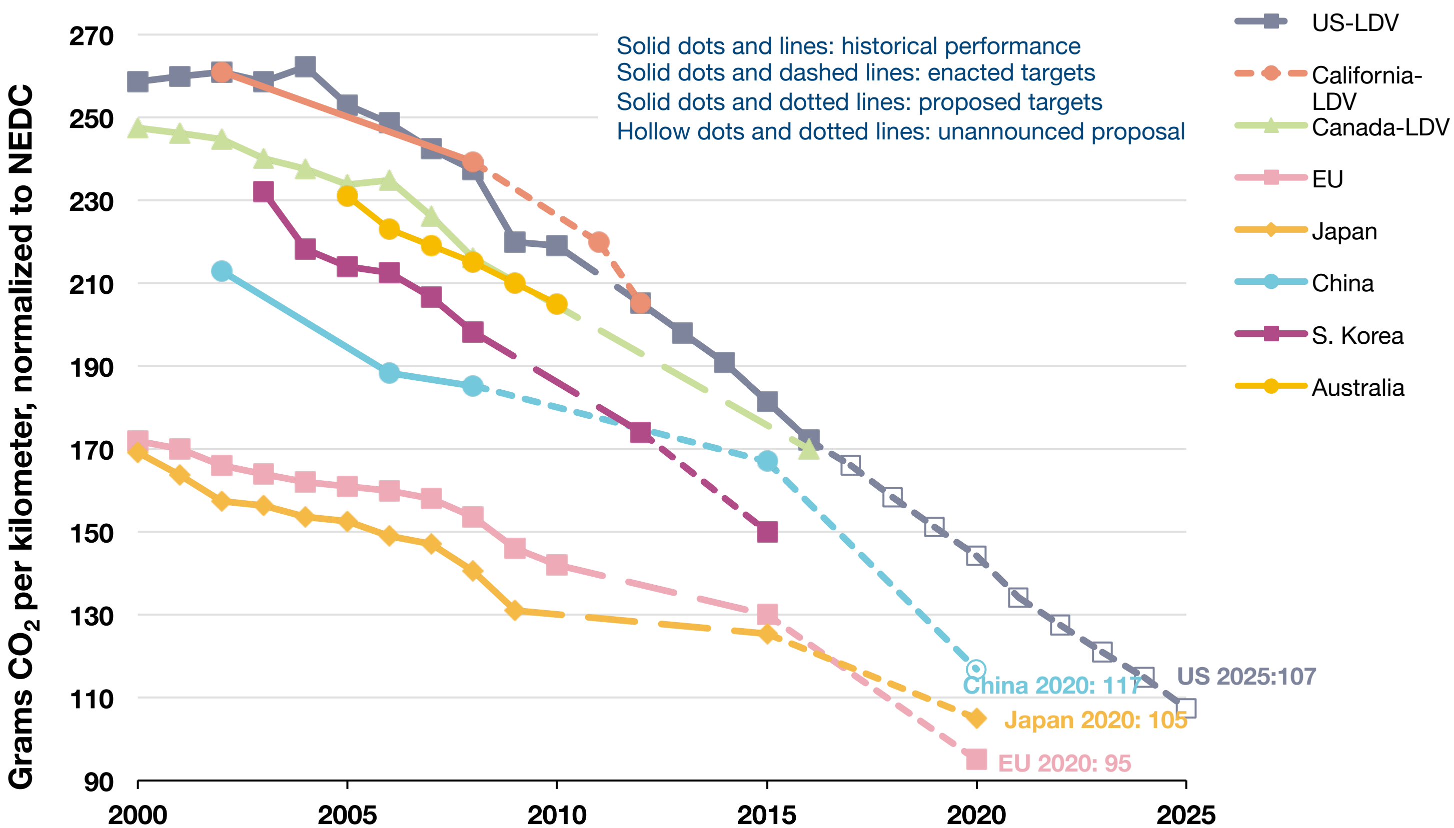
- 2012~2016 proposed GHG rule includes many program flexibilities, including:
  - Multiplier for Advanced Technology Vehicles
  - Off-cycle Credits
  - Accounting for Upstream Emissions
  - Incentive for Hybridization of Full-size Pick-ups

Overview of Regulation Specifications

Country or Region	Target Year	Standard Type	Unadjusted Fleet Target/Measure	Structure	Targeted Fleet	Test Cycle
U.S./California (enacted)	2016	Fuel economy/ GHG	34.1 mpg* or 250 gCO_2/ mi (155 g/km)	Footprint-based corporate avg.	Cars/Light trucks	U.S. combined
U.S. (Notice of Public Rulemaking)	2025	Fuel economy/ GHG	49.6 mpg* or 163 gCO_2/ mi (101 g/km)	Footprint-based corporate avg.	Cars/Light trucks	U.S. combined
Canada (enacted)	2016	GHG	153 (141)*** gCO_2/km	Footprint-based corporate avg.	Cars/Light trucks	U.S. combined
EU (enacted) EU (proposed)	2015 2020	CO_2	130 gCO_2/km 95 gCO_2/km	Weight-based corporate average	Cars/SUVs	NEDC
Australia (voluntary)	2010	CO_2	222 gCO_2/km	Fleet average	Cars/SUVs/light commercial vehicles	NEDC
Japan (enacted) Japan (proposed)	2015 2020	Fuel economy	16.8 km/L 20.3 km/L	Weight-class based corporate average	Cars	JC08
China (proposed)	2015	Fuel consumption	7 L/100km	Weight-class based per vehicle and corporate average	Cars/SUVs	NEDC
S. Korea (proposed)	2015	Fuel economy/ GHG	17 km/L or 140 gCO_2/km	Weight-based corporate average	Cars/SUVs	U.S. combined

** Assumes manufacturers fully use A/C credit*
*** Proposed CAFE standard by NHTSA. It is equivalent to 163g/mi plus CO2 credits for using low-GWP A/C refrigerants.*
*"** In April 2010, Canada announced a target of 153 g/km for MY2016. Value in brackets is estimated target for MY2016, assuming that during 2008 and 2016 the fuel efficiency of the LDV fleet in Canada will achieve a 5.5% annual improvement rate (the same as the U.S.). This estimate is used in the accompanying charts.*

Historical fleet CO_2 emissions performance and current or proposed standards



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
[2] US and Canada light-duty vehicles include light-commercial vehicles.

Core Analytical Work

- **EPA has sponsored and/or performed our own work in a large number of areas relevant for light-duty vehicles and GHGs, including:**
  - Vehicle Miles Travelled (VMT) Rebound Effect
  - Energy Security
  - Social Cost of Carbon
  - Economic Modeling for GHG Standards
  - Climate Modeling
  - Criteria Pollutant Air Quality Modeling
  - Baseline Fleet Projections
- **This presentation focuses on just three elements:**
  - Technology CO2 Effectiveness
    - **Ricardo Vehicle Simulation**
  - Technology Costs
    - **FEV Tear-down analyses**
  - Modeling Tools
    - **EPA OMEGA**

Technology CO2 Effectiveness

Technology CO2 Effectiveness

- Projecting the CO2 reduction potential of individual technologies and their combination is a core part of any future projection
- EPA has sponsored several programs in this area, and published a number of synthesis documents
- Several data sources considered:
  - Published reports/papers in the literature
  - Actual fuel economy data for real vehicles
  - Confidential data from suppliers/OEMs
  - Vehicle simulation modeling
    - *Vehicle simulation modeling is also used by vehicle manufacturers to make product decisions regarding fuel economy and performance.*

2008 Ricardo Vehicle Simulation

- Sponsored by EPA, final peer reviewed report published in 2008
- Used a robust, science-based “full vehicle simulation” analysis to characterize consequences of combining multiple technologies for efficiency gains (e.g., quantify synergistic effects)
- Quantify how the individual technologies, and their combinations, provide different levels of vehicle efficiency improvement in different vehicle classes
- Focused on technologies available in the ~2010-2015 time frame
- Provided a foundation for the 2017~2025 GHG rule.

2011 Ricardo Vehicle Simulation

- **EPA has completed the most comprehensive vehicle simulation to-date to look at CO2 effectiveness for 2020-2025 technologies**
  - Lean-burn gasoline engines
  - GDI turbo-downsize with boosting, cooled EGR, higher BMEP
  - Next generation diesel engines
  - 8-speed AT and DCT transmissions
  - Power-split HEVs
  - P2 HEVs

- **Modeling includes multiple degrees of freedom to examine a range of mass reductions, engine downsizing, and HEV motor size to seek out most efficient combinations under user-defined constraints (e.g., constant performance)**

- **5 vehicle classes from 2008 study, plus a B-segment small car and a 1-ton heavy-duty pickup truck**

2011 Ricardo Vehicle Simulation

- **Goals included[1]:**
  - Extrapolation of selected technologies to their expected performance and efficiency levels in the 2020~2025 MY timeframe.
    - Performance anchored to current and emerging technology
  - Conduct detailed simulation of the technologies over a large design space including:
    - Range of types and sizes vehicles
    - Powertrain architectures
    - Engine designs
    - Parameters describing these configurations: engine displacement, final drive ratio, and vehicle rolling resistance
  - Interpolate the results over the design space using a functional representation of the responses to the varied model input factors.
  - Develop a Data Visualization Tool to facilitate interrogation of the simulation results over the design space.

1. "Project Report Computer Simulation of Light-duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020~2025 Timeframe" Ricardo Inc., 29 November 2011

2011 Ricardo Vehicle Simulation

- **Ricardo employed**
  - Complex System Modeling (CSM)
    - CSM is a rigorous computational strategy designed to mathematically account for multiple input variables and determine their respective significance.
  - Design of Experiment (DoE)
    - DoE approach surveys the design space in a way that extracts the maximum information using a limited budget of simulation runs.
      - Still resulted in 2000 independent simulation runs for each of the 100+ vehicle packages. At 10 Hz output, the data files encompass 2 terabytes!
  - Neural networks
    - Neural network approach was used to quantify the relationships between input and output factors over the design space explored in the simulations.
- **Results of the Ricardo analyses were used to calibrate EPA's lumped parameter model which is a physics based model for evaluating the effectiveness of vehicle packages.**

Technology Costs

Technology Cost Estimation

- Vehicle technology costs quoted in public domain often vary widely
  - Underlying basis for cost estimations are not always clear
  - Are they direct manufacturing costs? Are they retail prices? Are indirect costs included? For how long (what model years) are estimates valid?
  - Estimates often rely on expert opinion, CBI, or surveys of suppliers

- In past three years EPA has undertaken two major studies focused on providing robust, traceable cost assessments which are peer reviewed and the underlying information is open to review by all
  - Indirect cost study with RTI International/U. of Michigan
  - Direct manufacturing cost study with FEV Inc./Munro Assoc.

Two Major Types of Cost: Direct and Indirect

Direct Manufacturing Costs

- The costs to manufacture a product at the production facility, including:
  - Material costs (steel, copper, plastics, etc.)
  - Labor costs
  - Utility costs at the production plant (water, electricity, etc.)

Indirect Manufacturing Costs

- All other costs of running an auto company, including:
  - Capital costs for production facilities
  - Tooling costs for production facilities
  - Research and development
  - Warranty
  - Corporate overhead (e.g. General and Administrative)
  - Pensions
  - Marketing
  - Dealer Support
- Often captured in cost analyses via application of a multiplier to the direct manufacturing costs.

Two Major Types of Cost: Direct and Indirect

Direct Manufacturing Costs

- Established through "tear-down" activities conducted by FEV
  - Identical methodology used by vehicle manufacturers to "benchmark" competitive components and systems
- Bill of Material (BOM) roll-ups that break down direct manufacturing costs into their subsystems and components.
- Confidential Business Information (CBI) used where no other source was available – lacks transparency

Indirect Manufacturing Costs

- Application of Indirect Cost (IC) Multipliers in lieu of Retail Price Equivalent (RPE) Multipliers
- EPA developed in conjunction with RTI and Transportation Research Institute at University of Michigan
- Better reflects the actual impact of an individual technology on indirect costs and includes time element

	Technology Complexity		
Time Frame	**Low**	**Medium**	**High**
Short-term effects	1.05	1.20	1.45
Long-term effects	1.02	1.05	1.26

2011 vs. 2017 CAFE Costs

- Midsize car costs: I-4 PFI, 4-speed ATX
- Direct Manufacturing Costs
- 2017 costs reflect FEV tear-down results

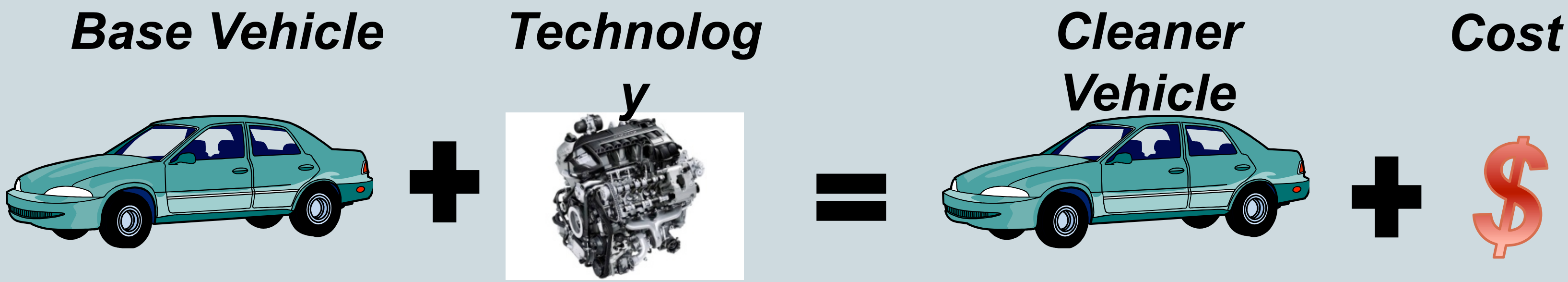
Technology	2011 Cost	2017 Cost
6 speed ATX	$215	-$13
DCT	$145	-$205
Turbo/Downsizing	$815	$478
GDI	$195~$293	$191

Modeling Tools

The OMEGA Model

- Optimization Model for Reducing Emissions of Greenhouse gases from Automobiles
- Purposes
  - Determine the most cost efficient path of adding technology to vehicles in order to achieve regulatory compliance.
  - Quantify the economic and environmental impacts of the changes in the vehicle fleet
- Design
  - Preprocessors (prepare OMEGA inputs)
  - OMEGA core model (calculate cost and compliance)
  - Benefits post-processor (calculate impacts)
- Outputs
  - Achieved compliance level and cost of compliance
  - Impact on fuel consumption and GHG emissions
  - Other impacts: criteria emissions, noise, congestion, accidents, saved refueling time, etc.

How Does OMEGA Work?

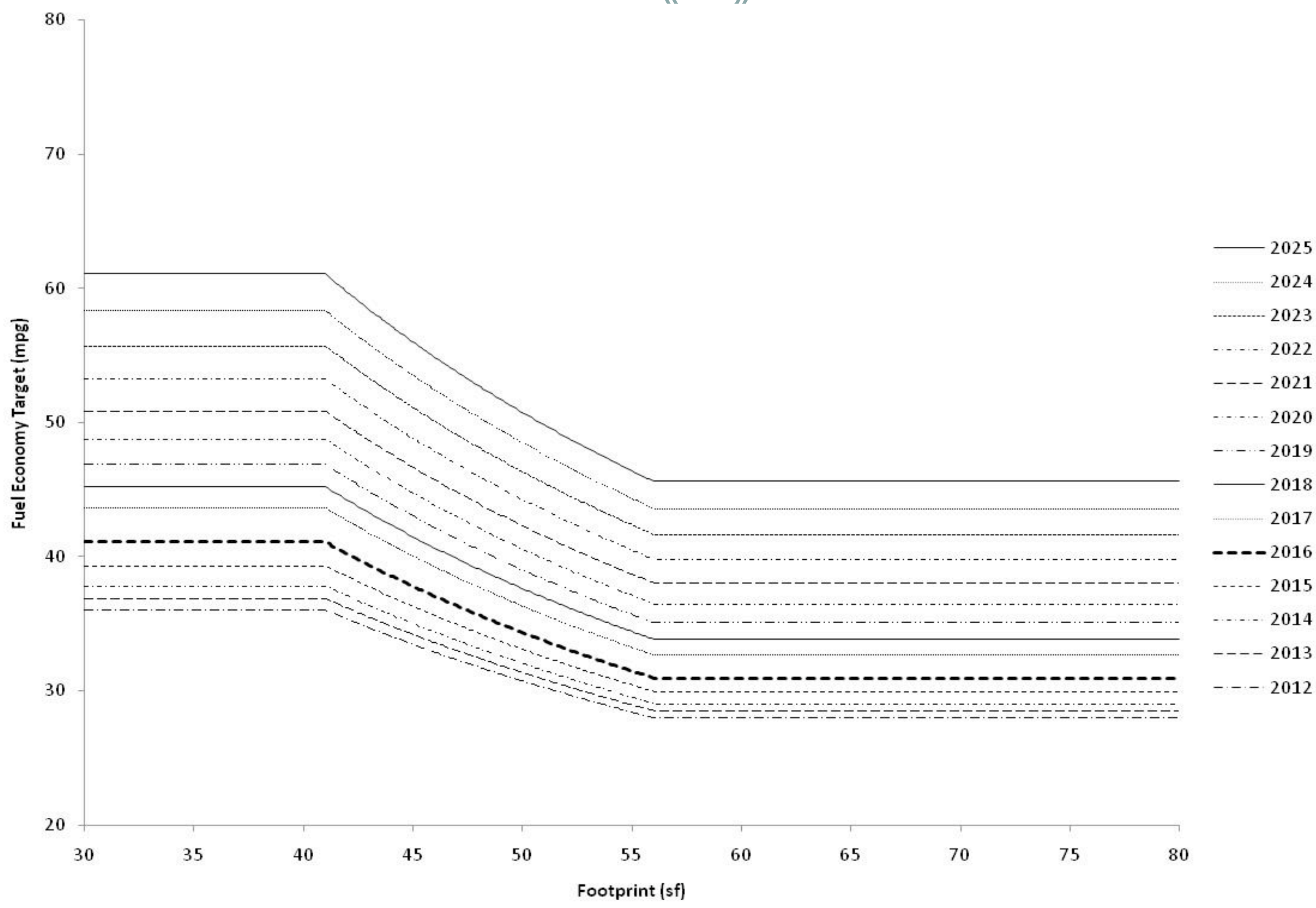


- OMEGA incrementally applies technology to vehicles in order to reduce emissions and determine manufacturer cost of compliance
  - "Technology" includes improvements to the engine, transmission, or any other change that reduces emissions from the vehicle
  - OMEGA inputs are informed by FEV work, Ricardo work, SAE papers and other literature.
- OMEGA is subject to a user's constraints (regulatory design, technology availability, feasibility of adoption)

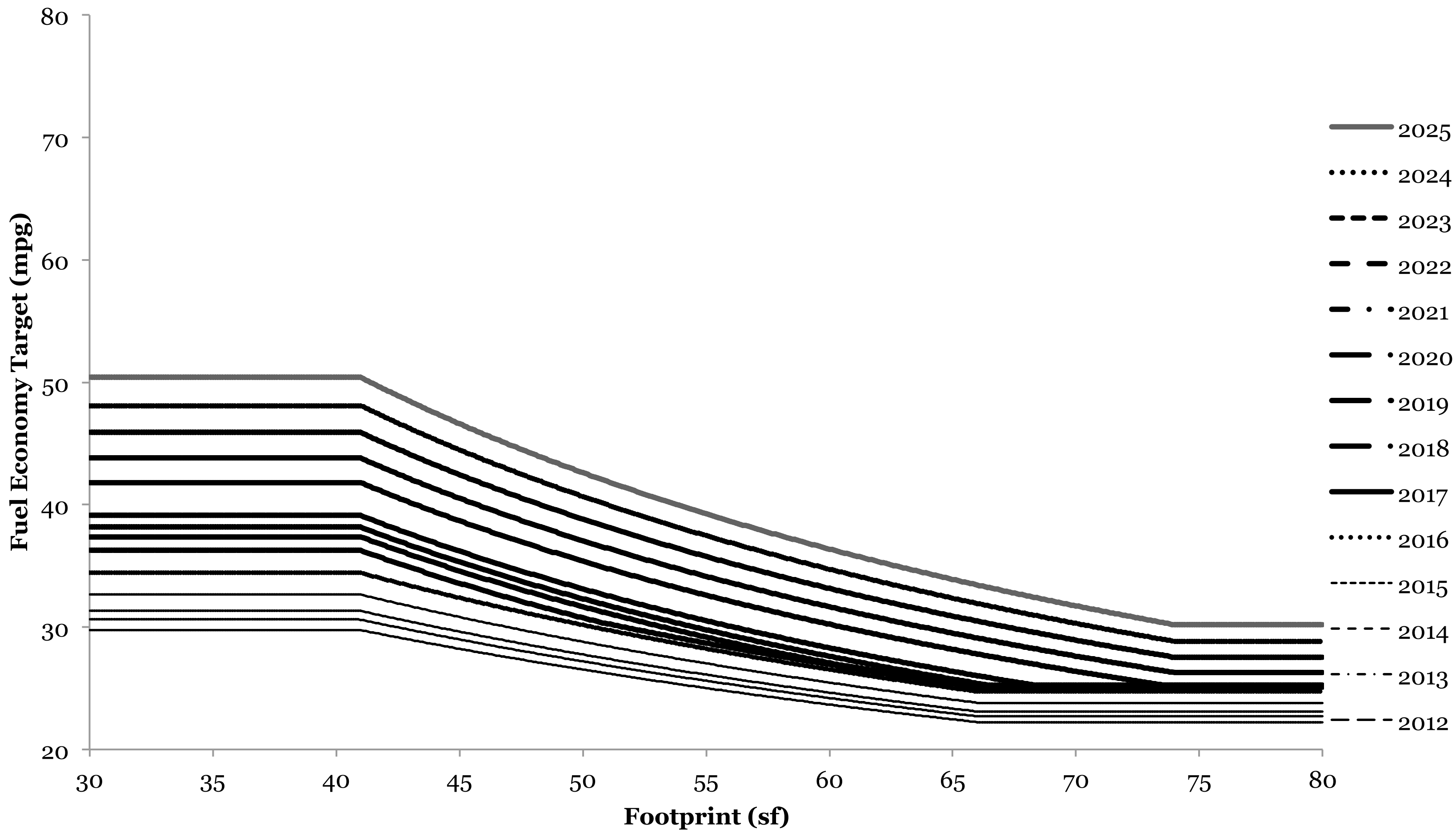
APPENDIX:

CAFE and CO2 Proposed Footprint Standard Curves

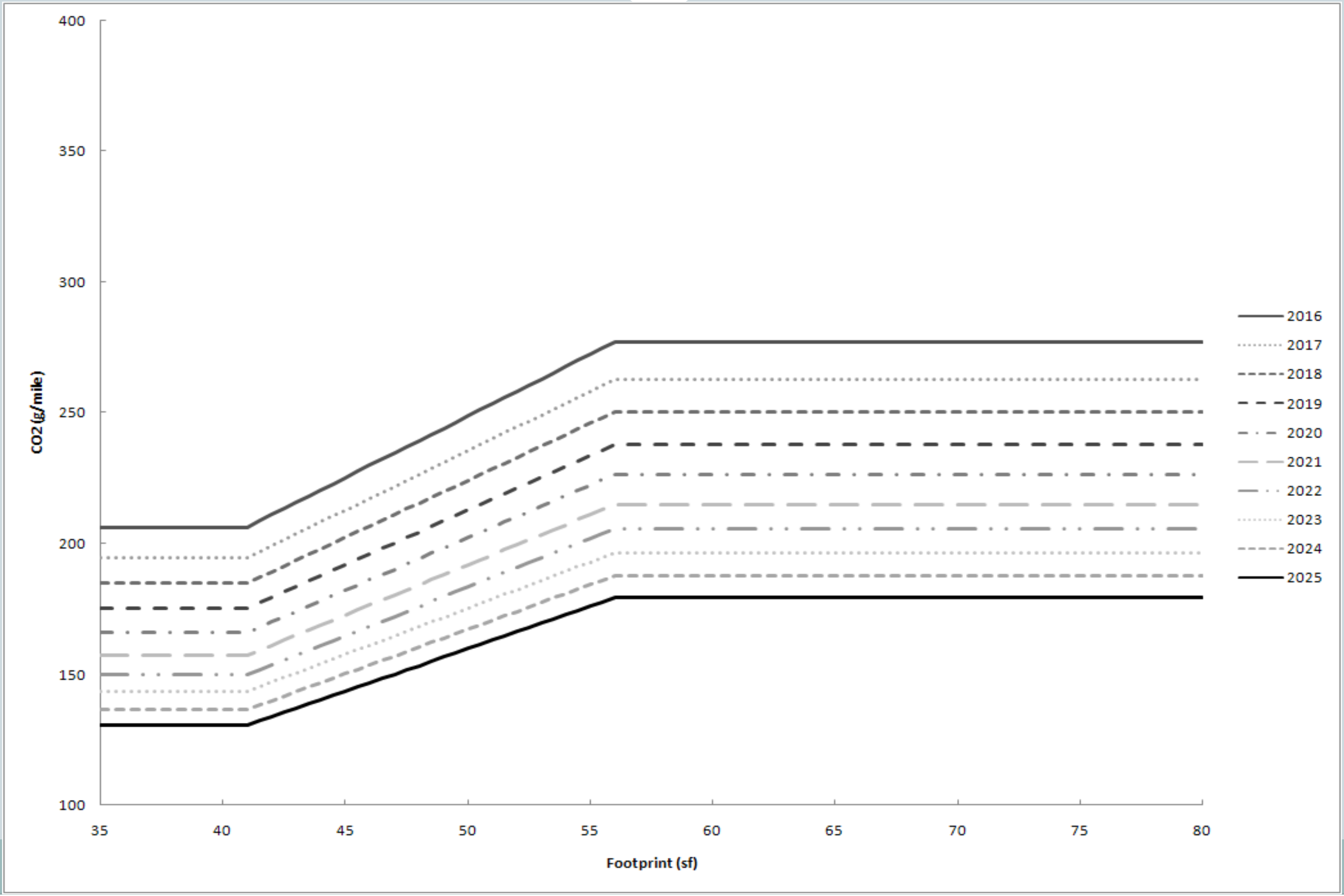
Proposed CAFE Target Curves for Passenger Cars



Proposed CAFE Target Curves for Light Trucks



Proposed CO2 Target Curves for Passenger Cars



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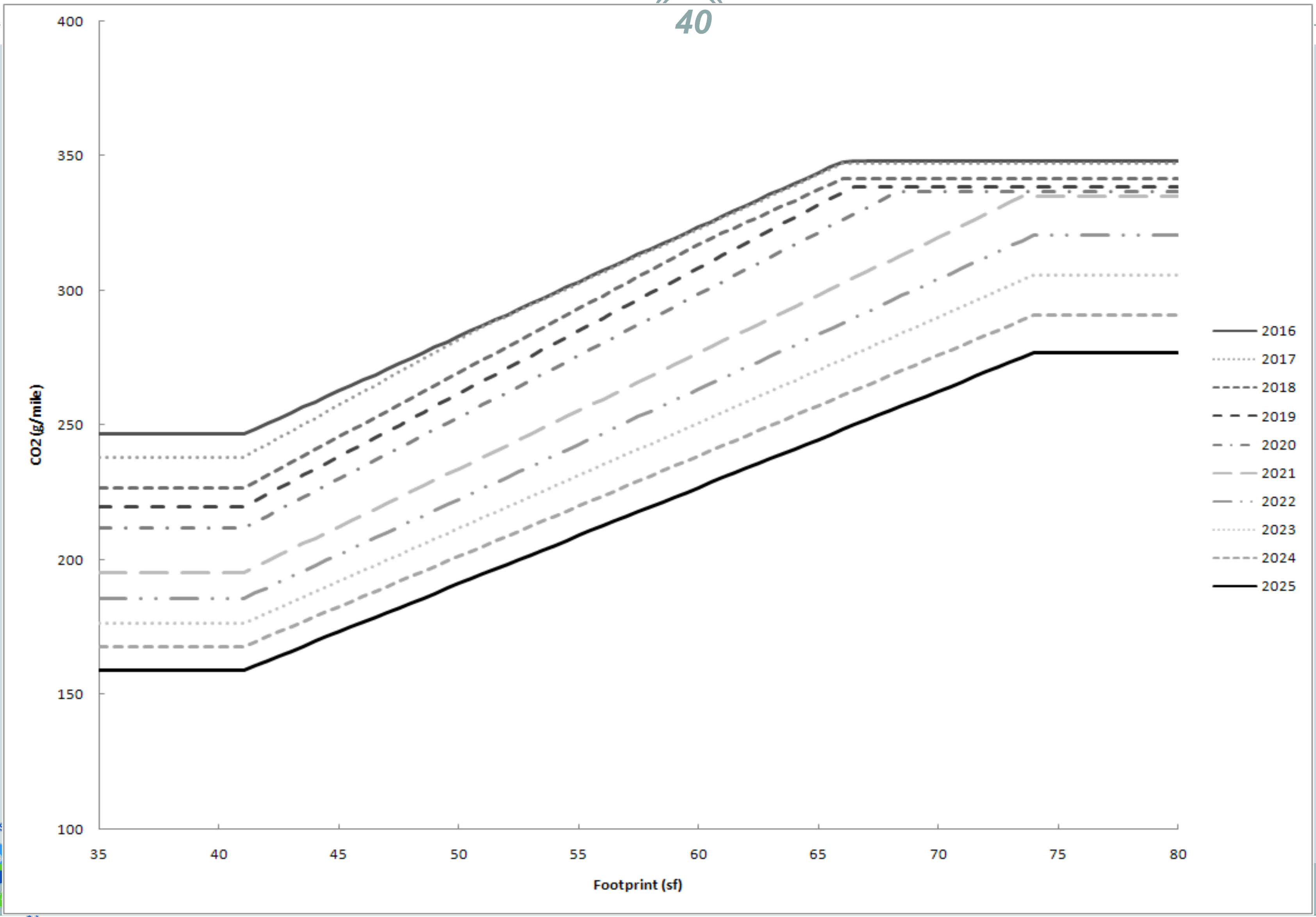

Resources

- Proposed 2017~2025 MY GHG Regulation
  - http://www.gpo.gov/fdsys/pkg/FR-2011-12-01/pdf/2011-30358.pdf
- Joint (EPA and NHTSA) Draft Technical Support Document
  - http://epa.gov/otaq/climate/documents/420d11901.pdf
- Supporting Documents
  - http://www.epa.gov/otaq/climate/publications.htm#vehicletechnologies
    - Ricardo Computer Simulation of Light-duty Technologies
    - Ricardo Response Surface Model Tool
    - Cost analyses