Technical Support Document

Corporate Average Fuel Economy Standards for Passenger Cars and Light Trucks for Model Years 2027 and Beyond and Fuel Efficiency Standards for Heavy-Duty Pickup Trucks and Vans for Model Years 2030 and Beyond

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U.S. Department of Transportation

National Highway Traffic Safety Administration

NHTSA

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Table of Acronyms and Abbreviations

Abbreviation	Term
AAA	American Automobile Association
AALA	American Automotive Labeling Act
ABS	Antilock Braking Systems
AC	Air Conditioning
ACAS	Automotive Collision Avoidance System
ACC	Advanced Clean Cars (including versions ACC I and ACC II)
ACT	Advanced Clean Trucks
ADAS	Advanced Driver Assistance Systems
ADEAC	Advanced Cylinder Deactivation
ADEACD	Advanced Cylinder Deactivation with Dual Overhead Camshaft
ADEACS	Advanced Cylinder Deactivation with Single Overhead Camshaft
ADSL	Advanced Diesel Engine
ADVENG	non-basic engine technologies
AEB	Automatic Emergency Braking
AEO	Annual Energy Outlook
AER	All-Electric Range
AERO	aerodynamic drag technology
AERO0	baseline level of aerodynamic improvement
AFV	Alternative Fuel Vehicle
AGM	Absorbed-Glass-Mat
AHSS	Advanced High Strength Steel
AIC	Akaike Information Criterion
AIS	Abbreviated Injury Scale
AKI	Anti-Knock Index
AL	Aluminum
AMPC	Advanced Manufacturing Production Tax Credit
AMTL	Advanced Mobility Technology Laboratory
ANL	Argonne National Laboratory
APA	Administrative Procedure Act
AT	Automatic Transmissions
AT	traditional automatic transmissions
AWD	All-Wheel Drive
BAC	Blood Alcohol Concentration
BAS	Brake Assistance Systems
BCG	Boston Consulting Group
BEA	Bureau of Economic Analysis

Abbreviation	Term
BEV	Battery Electric Vehicle
BISG	Belt Integrated Starter Generator
BLIS	Blind Spot Information System
BLS	Bureau of Labor Statistics
BMEP	Brake Mean Effective Pressure
BMW	BMW of North America, LLC
BNEF	Bloomberg New Energy Finance
BPT	Benefit-Per-Ton
BSA	Blind Spot Alert
BSD	Blind Spot Detection
BSFC	Brake-Specific Fuel Consumption
BTU	British Thermal Unit
BTW	Brake and Tire Wear
CAA	Clean Air Act
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CARS	Car Allowance Rebate System
CBI	Confidential Business Information
CD	Charge-Depleting
CDS	Crashworthiness Data System
CEGR	Cooled Exhaust Gas Recirculation
CFR	Code of Federal Regulations
CFRP	Carbon Fiber Reinforced Plastic
CH_4	Methane
CI	Compression Ignition
CIB	Crash Imminent Braking
CIR	Combined Injury Risk
CISG	Crank Integrated Starter Generator
CL	Cost Learning
CMB	Gross Combined
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CONFIG	engine cam configuration
CONV	Conventional Powertrain
COV	Coefficient of Variation
COVID-19	Coronavirus disease of 2019
CPI	Consumer Price Index

Abbreviation	Term
CPM	Cost Per Mile
CR	Compression Ratio
CRSS	Crash Report Sampling System
CUV	Crossover Utility Vehicle
CVC	Clean Vehicle Credit
CVT	Continuously Variable Transmission
CVTL	Continuously Variable Transmission with Level
CY	Calendar Year
CZMA	Coastal Zone Management Act
DBS	Dynamic Brake Support
DC	Direct Current
DCT	Dual Clutch Transmission
DD	Direct Drive Transmission
DEAC	Dynamic Cylinder Deactivation
DFS	Dynamic Fleet Share
DLR	Dynamic Road Load
DMC	Direct Manufacturing Costs
DOE	U.S. Department of Energy
DOHC	Dual Overhead Camshaft
DOI	Department of the Interior
DOT	U.S. Department of Transportation
DSLI	advanced diesel engine with improvements
DSLIAD	advanced diesel engine with improvements and advanced cylinder deactivation
E.O.	Executive Order
EC	Elemental Carbon
ECU	Engine Control Unit
EERE	Office of Energy Efficiency and Renewable Energy
EETT	Electrical and Electronics Technical Team
EF	Emission Factor
EFR	Engine Fiction Reduction
EGR	Exhaust Gas Recirculation
EIA	U.S. Energy Information Administration
EIS	Environmental Impact Statement
EISA	Energy Independence and Security Act of 2007
ELEC	electrification
EM	Electric Motor
EPA	U.S. Environmental Protection Agency
EPCA	Energy Policy and Conservation Act of 1975

Abbreviation	Term
EPS	Electric Power Steering
EREV	Extended Range Electric Vehicle
ESC	Electronic Stability Control
ETDS	Electric Traction Drive System
ETW	Equivalent Test Weight
EU	European Union
EV	Electric Vehicle
FARS	Fatal Accident Reporting System
FCA	Fiat Chrysler Automobiles
FCEV	Fuel Cell Electric Vehicle
FCIV	Fuel Consumption Improvement Value
FCV	Fuel Cell Vehicle
FCW	Forward Collision Warning
FE	Fuel Efficiency
FFV	Flexible Fuel Vehicle
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Standards
FP	Fuel Price
FR	Fatality Rate
FRIA	Final Regulatory Impact Analysis
FTP	Federal Test Procedure
GCVW	Gross Combined Weight
GCWR	Gross Combined Weight Rating
GDP	Gross Domestic Product
GES	General Estimates System
GHG	Greenhouse Gas
GM	General Motors
GMC	General Motor Company
gpm	gallons per mile
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
GVW	Gross Vehicle Weight
GVWR	Gross Vehicle Weight Rating
GWh	Gigawatt hours
GWU	George Washington University
HCR	High Compression Ratio
HCRD	Atkinson enabled engine with DEAC
HCRE	Atkinson enabled engine
HD	Heavy-Duty

Abbreviation	Term
HDPUV	Heavy-Duty Pickups and Vans
HEG	High Efficiency Gearbox
HEV	Hybrid Electric Vehicle
HFET	Highway Fuel Economy Test
HP	Horsepower
HSS	High Strength Steels
HTF	Highway Trust Fund
HVAC	Heating, Ventilation, and Air Conditioning
HWFET	Highway Fuel Economy Test
IACC	improved accessories
IACMI	Institute for Advanced Composites Manufacturing Innovation
IAV	Ingenieurgesellschaft Auto und Verkehr's engine models
IC	Internal Combustion
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
ICM	Indirect Cost Multiplier
iEGR	Internal Exhaust Gas Recirculation
IFR	Interim Final Rule
IIHS	Insurance Institute for Highway Safety
IMEP	Indicated Mean Effective Pressure
IPC	Imported Passenger Car
IRA	Inflation Reduction Act
IWG	Interagency Working Group
JLR	Jaguar Land Rover
KABCO	scale used to represent injury severity in crash reporting
LBNL	Lawrence Berkeley National Laboratory
LCA	Lane Change Alert
LD	Light-Duty
LDB	Low Drag Brakes
LDV	Light-Duty Vehicle
LDW	Lane Departure Warning
LEV	Low-Emission Vehicle
LFP	Lithium Iron Phosphate
LIB	Lithium-Ion Batteries
LIDAR	Light Detection and Ranging
LIVC	Late Intake Valve Closing
LKA	Lane Keep Assist
LT	Light Trucks

Abbreviation	Term
LTV	Light Trucks and Vans
MAIS	Maximum Abbreviated Injury Scale
MAX	maximum values
MCT	Multi-Cycle Test
MD	Medium-Duty
MDHD	Medium-Duty and Heavy-Duty
MDPC	Minimum Domestic Passenger Car
MDPCS	Minimum Domestic Passenger Car Standard
MDPV	Medium-Duty Passenger Vehicle
MIN	minimum values
MIT	Massachusetts Institute of Technology
MOU	Memorandum of Understanding
MOVES	Motor Vehicle Emission Simulator (including versions MOVES3 and MOVES4)
MPG	Miles Per Gallon
mph	Miles Per Hour
MR	Mass Reduction
MSRP	Manufacturer Suggested Retail Price
MY	Model Year
NA	Naturally Aspirated
NAAQS	National Ambient Air Quality Standards
NADA	National Automotive Dealers Association
NAICS	North American Industry Classification System
NAS	National Academy of Sciences
NASEM	National Academies of Sciences, Engineering, and Medicine
NASS	National Automotive Sampling System
NBER	National Bureau of Economic Research
NCA	Nickel Cobalt Aluminum
NCAP	New Car Assessment Program
NCSA	National Center for Statistics and Analysis
NEMS	National Energy Modeling System
NEPA	National Environmental Policy Act
NESCCAF	Northeast States Center for a Clean Air Future
NHTS	National Household Transportation Survey
NHTSA	National Highway Traffic Safety Administration
NMC	Nickel Manganese Cobalt
NO_X	Nitrogen Oxide
NPRM	Notice of Proposed Rulemaking
NRC	National Research Council

Abbreviation	Term
NREL	National Renewable Energy Laboratory
NRVMT	VMT excluding rebound miles
NTTAA	National Technology Transfer and Advancement Act
NVH	Noise-Vibration-Harshness
NVPP	National Vehicle Population Profile
NZEV	Near Zero-Emissions Vehicles
OC	Off-Cycle
OEM	Original Equipment Manufacturer
OHV	Overhead Valve
OMB	Office of Management and Budget
OPEC	Organization of the Petroleum Exporting Countries
ORNL	Oak Ridge National Laboratory
PADD	Petroleum Administration for Defense District
PAEB	Pedestrian Automatic Emergency Braking
PC	Passenger Car
PDO	Property Damage-Only
PEF	Petroleum Equivalency Factor
PFI	Port Fuel Injection
PHEV	Plug-in Hybrid Electric Vehicle
PIC	NHTSA's CAFE Public Information Center
PM	Particulate Matter
$PM_{2.5}$	Particulate matter 2.5 microns or less in diameter
PMY	Pre-Model Year
PRIA	Preliminary Regulatory Impact Analysis
PS	Power Split
PV	Passenger Vehicle
RADAR	Radio Detection and Ranging
RCD	Reverse Collision Detection
RDPI	Real Disposable Personal Income
RIA	Regulatory Impact Analysis
ROLL	tire rolling resistance
RPE	Retail Price Equivalent
RPM	Revolutions Per Minute
RRC	Rolling Resistance Coefficient
RWD	Rear-Wheel Drive
SAE	Society of Automotive Engineers
SAFE	Safer Affordable Fuel-Efficient
SAX	Secondary Axle Disconnect

Abbreviation	Term
SBREFA	Small Business Regulatory Enforcement Fairness Act
SC	Social Cost
SC-CO2	Social Cost of Carbon Dioxide
scf	standard cubic feet
SC-GHG	Social Cost of Greenhouse Gases
SCO	Synthetic Crude Oil
SGDI	Stoichiometric Gasoline Direct Injection
SGDID	Dual Over-Head Cam Engine and Gasoline Direct Injection
SGDIS	Single Over-Head Cam Engine and Gasoline Direct Injection
SHEV	Strong Hybrid Electric Vehicle
SHEVP	Power Split Strong Hybrid Electric Vehicle
SI	Spark Ignition
SIR	Societal Injury Risk
SKIP	refers to skip input in market data input file
SO_2	Sulfur Dioxide
SOC	State of Charge
SOHC	Single Overhead Camshaft
SO_X	Sulfur Oxide
SPR	U.S. Strategic Petroleum Reserve
SS12V	Stop-Start 12V Hybrid Electric Vehicle
S-SBR	Solution Styrene Butadiene Rubber
SUV	Sport Utility Vehicle
SwRI	Southwest Research Institute
TAR	Technical Assessment Report
TC	Turbocharged Aspiration
TCU	Transmission Control Unit
TPMS	Tire Pressure Monitoring System
TS&D	Fuel Transportation, Storage, and Distribution
TSD	Technical Support Document
TTW	Tank-to-Wheel
TURBO0	reference baseline turbocharged downsized technology
TURBO1	turbocharged downsized technology
TURBO2	advanced turbocharged downsized technology
TURBOAD	turbocharged engine with advanced cylinder deactivation
TURBOD	turbocharged engine with cylinder deactivation
TURBOE	turbocharged engine with cooled exhausted recirculation
TWh	Terawatt-hours
UDDS	Urban Dynamometer Driving Schedule

Abbreviation	Term
UE	Upstream Emissions
UMTRI	University of Michigan Transportation Research Institute
VCR	Variable Compression Ratio
VIN	Vehicle Identification Number
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compounds
VSL	Value of a Statistical Life
VTG	Variable Turbo Geometry Technology
VTGE	Variable Turbo Geometry (Electric)
VTO	DOE Vehicle Technologies Office
VTTS	Value of Travel Time Savings
VVL	Variable Valve Lift
VVT	Variable Valve Timing
VW	Volkswagen
VWA	Volkswagen Group of America
WF	Work Factor
WTP	Willingness to Pay
ZEV	Zero Emission Vehicle

1. What is NHTSA Analyzing, and Why?

CAFE Model Files Referenced in this Chapter

Below is a list of CAFE Model Files referenced in this chapter. See Chapter 2.1.9. "Where to Find the Internal NHTSA Files?" for a full list of files referenced in this document and their respective file locations.

- CAFE Model Documentation
- Market Data Input File

The National Highway Traffic Safety Administration (NHTSA) is establishing new Corporate Average Fuel Economy (CAFE) standards for passenger cars (PC) and light trucks (LT) produced for Model Years (MYs) 2027-2031, setting forth augural CAFE standards for passenger cars and light trucks produced for model year 2032, and establishing fuel efficiency standards for heavy-duty pickup trucks and vans (HDPUVs) for model (MYs) 2030-2035. NHTSA is required by statute to set new CAFE standards for passenger cars and light trucks for each model year, and NHTSA is permitted by statute to set new fuel efficiency standards for HDPUVs.[1] NHTSA is establishing standards that increase in stringency at 2 percent per year for passenger cars produced for model years 2027-2031 (and setting forth augural standards that would increase by another 2 percent for passenger cars produced in model year 2032), at 0 percent per year for light trucks produced in model years 2027-2028 and 2 percent per year for light trucks produced in model years 2029-2031 (and setting forth augural standards that would increase by another 2 percent for light trucks produced in model year 2032). For HDPUVs, NHTSA is establishing fuel efficiency standards that increase by 10 percent per year for model years 2030-2032, and at 8 percent per year for model years 2033-2035. The regulatory alternatives representing these final stringency increases are called "PC2LT002" for passenger cars and light trucks, and "HDPUV108" for HDPUVs. These standards are also referred to throughout the rulemaking documents as the "preferred alternative" or "final standards."

This Technical Support Document (TSD) describes the supporting technical analysis that informed agency decision-makers in determining the rates of stringency increase for the final and augural CAFE standards for passenger cars and light trucks for model years 2027-2032, and for the fuel efficiency standards for HDPUVs for model years 2030-2035. This document describes the technical details about the inputs used to create models and perform simulations, that together create the analysis results discussed in the Final Regulatory Impact Assessment (FRIA).

Chapter 1 of this TSD explains how NHTSA develops footprint-based curves for the regulatory alternatives that represent different levels of possible CAFE stringency, and work-factor-based curves for the regulatory alternatives that represent different levels of possible HDPUV stringency. Chapter 1 also presents the regulatory alternatives themselves, for passenger cars and light trucks, and for HDPUVs, and explains how the CAFE Model ("the model") uses inputs to conduct the analysis.

Chapter 2 describes the development of the inputs that the model uses, including the analysis fleet, the zero emissions vehicle (ZEV) Module, compliance credits, technology effectiveness values, technology adoption and availability, technology costs, and other inputs.

Chapter 3 describes the technology options within the model.

Chapter 4 describes consumer responses to manufacturer compliance strategies, including macroeconomic assumptions that affect and describe consumer behavior, changes in fleet composition (including new vehicle sales and retirement or scrappage of existing vehicles), changes in vehicle miles traveled (VMT), and changes in fuel consumption.

Chapter 5 describes how the model simulates the environmental effects of the different regulatory alternatives, including greenhouse gas emissions effects, criteria pollutant emissions effects, and how health effects flow from those changes.

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[1] 49 U.S.C. 32902.

Chapter 6 describes how the model simulates the economic effects of the different regulatory alternatives, in terms of costs and benefits that accrue to consumers and to society.

Chapter 7 describes how the model simulates the safety effects of the different regulatory alternatives.

1.1. Why Does NHTSA Conduct this Analysis?

When NHTSA develops new regulations, it generally presents an analysis that estimates the effects of such regulations, and the effects of other regulatory alternatives. These analyses derive from statutes such as the Administrative Procedure Act (APA) and National Environmental Policy Act (NEPA), from Executive Orders (such as E.O. 12866 and E.O. 13563), and from other administrative guidance (e.g., Office of Management and Budget Circular A-4). For CAFE standards, the Energy Policy and Conservation Act (EPCA) of 1975, as amended by the Energy Independence and Security Act (EISA) of 2007, contains a variety of provisions that require NHTSA to consider certain compliance elements in certain ways, and avoid considering other elements, in determining maximum feasible CAFE standards. No such restrictions exist for how NHTSA determines maximum feasible fuel efficiency standards for HDPUVs. Collectively, capturing all of these requirements and guidance elements analytically means NHTSA presents an analysis that spans a meaningful range of regulatory alternatives, quantifies a range of technological, economic, and environmental impacts, and does so in a manner that accounts for EPCA's express requirements for the CAFE program (e.g., that passenger cars and light trucks are regulated separately, and that the standard for each fleet must be set at the maximum feasible level in each model year) as well as EISA's requirements for the HDPUV program (e.g., that standards must have four years of lead time and three years of regulatory stability).

NHTSA's final rule is thus supported by, although not dictated by, extensive analysis of potential impacts of the regulatory alternatives under consideration. Together with the preamble to the final rule, this TSD, a FRIA, and a Final Environmental Impact Statement (EIS) provide an extensive and detailed enumeration of related methods, estimates, assumptions, and results. NHTSA's analysis has been constructed specifically to reflect various aspects of governing law applicable to CAFE and HDPUV standards. The analysis has been expanded and improved in response to comments received to the 2022 final rule and to the NPRM and based on additional work conducted over the last several months. Further improvements, which could not be incorporated in this final rule analysis due to timeline considerations and/or complexity, may be made in the future based on comments received and other additional work generally previewed in these rulemaking documents. The analysis for this final rule aided NHTSA in implementing its statutory obligations, including the weighing of various considerations, by reasonably informing decision-makers about the estimated effects of choosing different regulatory alternatives.

NHTSA's analysis makes use of a range of data (i.e., observations of things that have occurred), estimates (i.e., things that may occur in the future), and models (i.e., methods for making estimates). Two examples of *data* include (1) records of actual odometer readings used to estimate annual mileage accumulation at different vehicle ages and (2) CAFE compliance data used as the foundation for the "analysis fleet" containing, among other things, production volumes and fuel economy levels of specific configurations of specific vehicle models produced for sale in the United States. Two examples of *estimates* include (1) forecasts of future gross domestic product (GDP) used, with other estimates, to forecast future vehicle sales volumes and (2) the "retail price equivalent" (RPE) factor used to estimate the ultimate cost to consumers of a given fuel-saving technology, given accompanying estimates of the technology's "direct cost," as adjusted to account for estimated "cost learning effects" (i.e., the tendency that it will cost a manufacturer less to apply a technology as the manufacturer gains more experience doing so, and is, in itself, a third example of an estimate used).

NHTSA uses the CAFE Compliance and Effects Modeling System (usually shortened to the "CAFE Model" or just "the model") to estimate manufacturers' potential responses to new CAFE, carbon dioxide (CO_2) and

HDPUV standards and to estimate various impacts of those responses.[2] U.S. Department of Transportation's (DOT's) Volpe National Transportation Systems Center (often simply referred to as the “Volpe Center”) develops, maintains, and applies the model for NHTSA. NHTSA has used the CAFE Model to perform analyses supporting every CAFE rulemaking since 2001. The 2016 rulemaking regarding HDPUV fuel efficiency standards, the last HDPUV rulemaking, also used the CAFE Model for analysis.

The basic design of the CAFE Model is as follows: the system first estimates how vehicle manufacturers might respond to a given regulatory scenario, and from that potential compliance solution, the system estimates what impact that response will have on fuel consumption, emissions, and economic externalities. In a highly summarized form, the following diagram shows the basic categories of CAFE Model procedures, and the sequential flow between different stages of the modeling. The diagram does not present specific model inputs or outputs or most specific procedures and model interactions. The CAFE Model Documentation accompanying this TSD presents these details.

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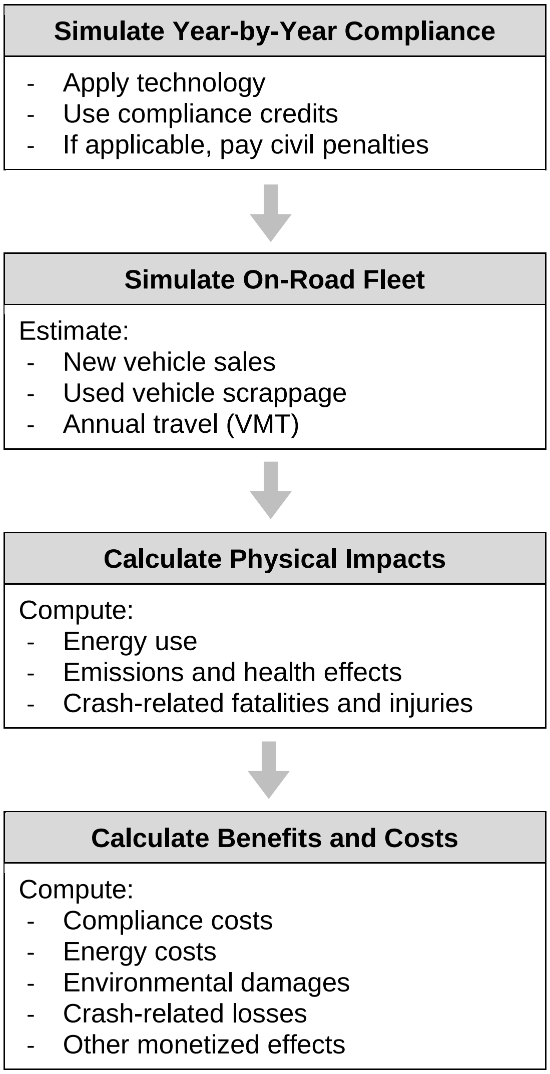
[2] The NHTSA analysis does provide estimates for all GHGs produced, however the CO_2 compliance curves are the only aspect of the GHG standards considered during compliance modeling. Compliance with CO_2 standards is modeled in the reference baseline fleet for existing EPA GHG standareds, in this analysis that is for years thru 2026, to simulate the reference baseline behavior of the modeled fleet. NHTSA recognizes EPA may publish new final GHG standards for MYs 2027 and beyond before this final rule is published, however, those standards were not included in the reference baseline analysis, as the agencies developed their respective standards for MYs 2027 and beyond jointly.

Figure 1-1: CAFE Model Procedures and Logical Flow



More specifically, the model may be characterized as an integrated system of models. For example, one model estimates manufacturers' responses, another estimates resultant changes in total vehicle sales, and still another estimates resultant changes in fleet turnover (i.e., scrappage). A regulatory scenario involves specification of the form, or shape, of the standards (e.g., linear attribute-based standards), scope of passenger car, light truck, and/or HDPUV regulatory classes, and stringency of the CAFE and/or fuel efficiency standards for each model year to be analyzed. Additionally, and importantly, the model does not *determine* the form or stringency of the standards. Instead, the model applies *inputs* specifying the form and stringency of standards to be analyzed and produces *outputs* showing the impacts on the manufacturers working to meet those standards. Those outputs then become the basis for comparing between different potential stringency levels.

Manufacturer compliance simulation and the ensuing effects estimation, collectively referred to as compliance modeling, encompass numerous subsidiary elements. Compliance simulation begins with a detailed user-provided[3] initial forecast of the vehicle models offered for sale during the simulation period. The compliance

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[3] Because the CAFE Model is publicly available, anyone can develop their own initial forecast (or other inputs) for the model to use. The DOT-developed Market Data Input File that contains the forecast used for this final rule is available on NHTSA's website at https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy.

simulation then attempts to bring each manufacturer into compliance with the applicable standards[4] defined by the regulatory scenario contained within an input file developed by the user.

Estimating impacts involves calculating resultant changes in new vehicle costs, estimating a variety of costs (e.g., for fuel) and effects (e.g., CO_2 emissions from fuel combustion) occurring as vehicles are driven over their lifetimes before eventually being scrapped, and estimating the monetary value of these effects. Estimating impacts also involves consideration of consumer responses – e.g., the impact of vehicle fuel economy, operating costs, and vehicle price on consumer demand for passenger cars, light trucks, and HDPUVs. Both basic analytical elements involve the application of many analytical inputs. Many of these inputs are developed *outside* the model and not *by* the model.

NHTSA also uses the U.S. Environmental Protection Agency's (EPA's) Motor Vehicle Emissions Simulator (MOVES) model to estimate "vehicle" or "downstream" emission factors for criteria pollutants,[5] and uses four DOE and DOE-sponsored models to develop inputs to the CAFE Model, including three developed and maintained by DOE's Argonne National Laboratory (ANL). The agency uses the DOE Energy Information Administration's (EIA's) National Energy Modeling System (NEMS) to estimate fuel prices,[6] uses Argonne's Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model to estimate emissions rates from fuel production and distribution processes,[7] and uses Argonne's Battery Manufacturing Cost Estimation (BatPaC) tool to estimate electric and hybrid vehicle battery costs.[8] DOT also sponsored DOE/Argonne to use Argonne's Autonomie full-vehicle modeling and simulation system to estimate the fuel economy impacts for over a million combinations of technologies and vehicle types.[9] We adapted the same tools, including updating initial inputs and data, for the HDPUV portions of the analysis.[10] Other chapters in this TSD and discussion in the accompanying FRIA describe details of the agency's use of these models. In addition, as discussed in the Final EIS accompanying this final rule, DOT relied on a range of climate models to describe impacts on climate, air quality, and public health. The Final EIS discusses and describes the use of these models.

The CAFE Model, therefore, serves as a "hub" that connects and holds together a wide range of inputs, processes, and other models that all inform DOT's analysis, and that, in turn, provides model results underlying the Final EIS accompanying this final rule. Though not exhaustive, the diagram on the following page shows most of the important connections between different elements of DOT's analysis.

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[4] With appropriate inputs, the model can also be used to estimate impacts of manufacturers' potential responses to new CO_2 standards and to California's ZEV program.

[5] See http://www.epa.gov/moves. This final rule uses version MOVES4, available at https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves.

[6] See https://www.eia.gov/outlooks/aeo/info_nems_archive.php. This final rule uses fuel prices estimated using the AEO 2023 version of NEMS. See https://www.eia.gov/outlooks/aeo/.

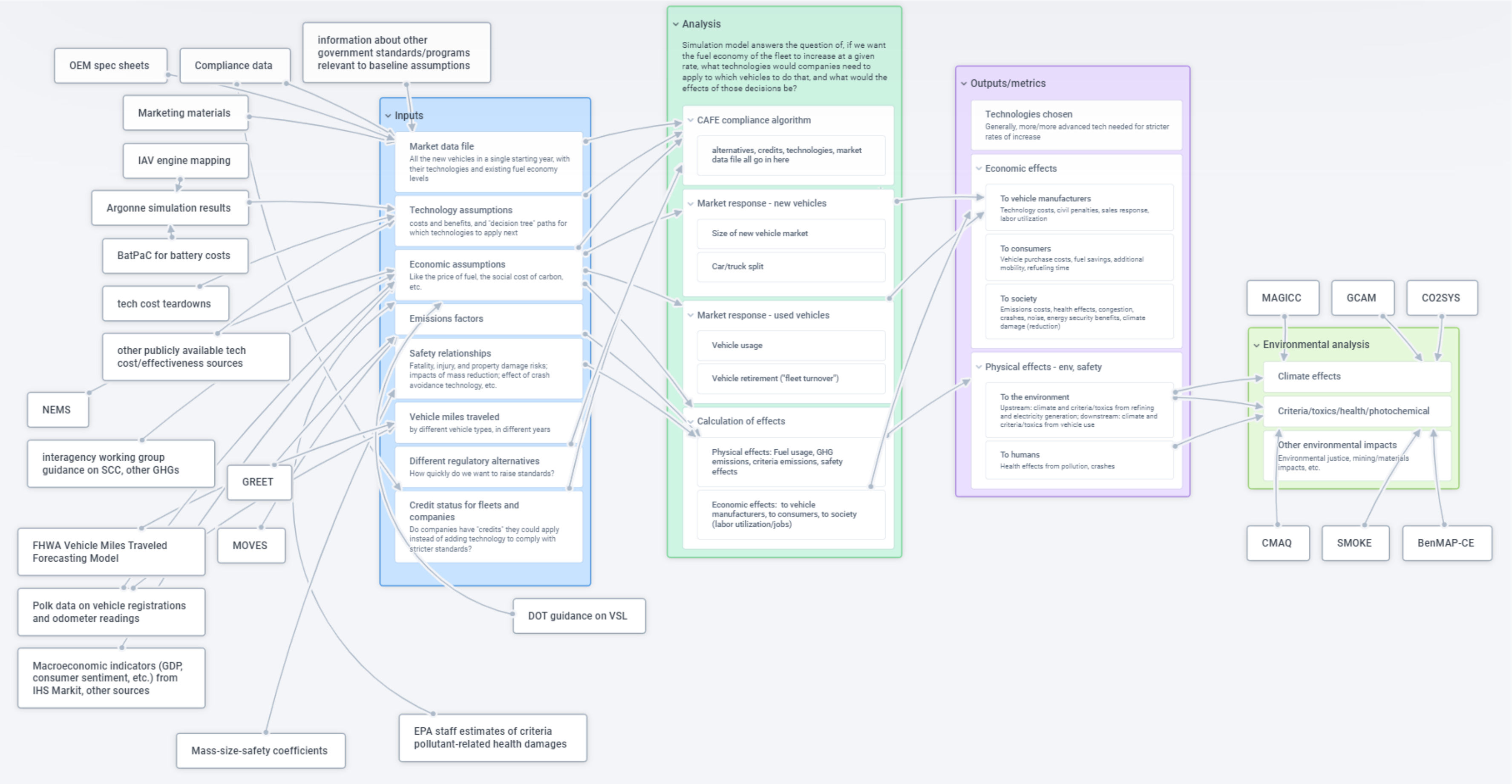
[7] Information regarding GREET is available at https://greet.es.anl.gov/. This final rule uses the 2022 version of GREET.

[8] Argonne National Laboratory. BatPaC: Battery Manufacturing Cost Estimation Available at: https://www.anl.gov/tcp/batpac-battery-manufacturing-cost-estimation. (Accessed: Feb 7, 2023).

[9] As part of the Argonne simulation effort, individual technology combinations simulated in Autonomie were paired with Argonne's BatPaC model to estimate the battery cost associated with each technology combination based on characteristics of the simulated vehicle and its level of electrification. Information regarding Argonne's BatPaC model is available at https://www.anl.gov/cse/batpac-model-software. In addition, the impact of engine technologies on fuel consumption, torque, and other metrics was characteritzed using GT-POWER simulation modeling in combination with other engine modeling that was that was conducted by IAV Automotive Engineering, Inc. (IAV) and South West Research Institute (SWRI). The engine characterization "maps" resulting from this analysis were used as inputs for the Autonomie full-vehicle simulation modeling. Information regarding GT-POWER is available at https://www.gtisoft.com/gt-power/.

[10] Specific details on the input modifiications to support the HDPUV analysis are discussed under their associated chapters.

Figure 1-2: Key Elements of DOT's Analysis, from 2022 TSD



To prepare for the analysis that supported the notice for this rule, DOT has continued its ongoing effort to refine and expand the CAFE Model. Since the 2022 final rule, DOT has made the following changes to the CAFE Model and inputs, including:

- Update analysis fleet from MY2020 to MY2022
- Addition of the HDPUV fleet and supporting analyses, added to account for manufacturers' responses to applicable fuel efficiency and CO_2 standards, including:
    - New HDPUV-specific technologies, costs, and fuel efficiency improvement assumptions.
    - New HDPUV technology classes (Pickup2b, Van2b, Pickup3, and Van3).
    - New HDPUV engine technology classes (ranging from 4C1B to 10C2B for Dual Overhead Camshaft (DOHC), Single Overhead Cam (SOHC), and OHV variants).
    - New HDPUV vehicle styles (WorkTruck, WorkVan, FleetSUV) beyond those previously included (Chassis Cab, Cutaway) and the removal of one prior vehicle style (Large Pickup).
    - Revised HDPUV-related compliance calculations of fuel efficiency standards and ratings, calculated and reported in mpg space and gallons/100-mile space. And HDPUV fuel consumption credits calculated and reported in gallons, based on the useful life value assumption.
    - New target function and coefficients applicable to the HDPUV CO_2 standards.
    - Allowing use of credits (via carry-forward) to offset shortfalls to the manufacturers' HDPUV fuel efficiency and CO_2 ratings during standard setting years.
    - Allowing unrestricted application of plug-in hybrid electric vehicle (PHEVs), battery electric vehicles (BEVs), and fuel cell vehicles (FCEVs) to the HDPUV fleet during standard setting years, as is allowed by the governing statute.
    - Accounting for additional HDPUV-specific categories of downstream health related impacts and emission damage costs attributed to criteria air pollutants (SO_X, NO_X, and $PM_{2.5}$).
    - Revising the sales and scrappage models to account for the HDPUV fleet.
    - Incorporating the accounting for the ZEV mandates applicable in California and the Section 177 states for the HDPUV fleet.
- Inclusion of updated assumptions for light-duty vehicle technologies, costs, and fuel efficiency improvement and removing obsolete technologies: engine friction reduction (EFR), advanced diesel engine with improvements and advanced cylinder deactivation (DSLIAD), manual transmissions, AT6L2, electric power steering (EPS), improved accessories (IACC), Low Drag Brakes (LDB), secondary axle disconnect (SAX), and some variants of engines and P2 hybrid pairings.
- Allowing direct user input of additional parameters, including:
    - Petroleum equivalency factor (PEF).
    - Share of total refueling events to consider when calculating benefits attributed to the refueling time cost.
    - Whether application of PHEV, BEV, or FCEV technologies is permitted during the standard setting model years. This is not applicable to the HDPUV fleet or to vehicles designated as ZEV candidates. For the current analysis of the CAFE light-duty fleet, NHTSA allowed application of PHEVs while disallowing application of BEVs and FCEVs during the standard setting years.[11]
- Updating calculation of implicit opportunity cost to exclude a portion of vehicle sales assumed to be used for commercial applications. For the central analysis, NHTSA did not implement this added feature of the model, but produced multiple sensitivity analyses that varied this parameter for the HDPUV fleet.
- Procedures added for estimating and reporting:
    - the commercial operator implicit opportunity cost, using the same assumptions of commercial use vs consumer use, as above.
    - vehicular $PM_{2.5}$ emissions attributed to brake and tire wear (BTW).
- Allowing the use of credits (via transfers and carry-forward) to offset shortfalls to the manufacturers' CO_2 ratings during standard setting years.

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[11] See CAFE Model Documentation for a discussion of 'Standard Setting' limitations on the model.

- Inclusion of expanded accounting of Federal incentives as outlined in the Inflation Reduction Act (IRA); propagating this change within relevant modules and including these incentives in the "effective cost" metric used when simulating manufacturers' potential application of fuel-saving technologies.
- Expanding the accounting for manufacturer responses to the ZEV mandates applicable in California and the Section 177 states for the light-duty fleet (and manufacturer commitments to deploy electric vehicles consistent with the targets of the Advanced Clean Cars II program), differentiating between credits earned prior to model year 2026 and starting in model year 2026. Revising the model allows the simulation of compliance with much higher ZEV targets set by the states.
- Incorporating new procedures and methodologies for technology inheriting between platforms, engines, and transmissions and their respective vehicle "users."
- Expanding procedures for estimating new vehicles sales and the shares of passenger car and light truck fleets during future model years in the reference baseline and action alternative scenarios:
    - Incorporating revisions to allow direct specification of coefficients for estimating the nominal forecast of sales under the reference baseline scenario.
    - Including an option to use a user-defined annual forecast of light-duty and HDPUV sales and a user-defined annual forecast of the portion of the light-duty fleet that will be passenger cars in the reference baseline scenario.
    - Including a user-selectable option for propagating reference baseline computed car shares to all action alternatives or allowing the car shares for each alternative to be adjusted based on the differences in regulatory costs, vehicle and battery tax credits, and fuel savings occurring between alternatives and between car and truck fleets.
- Inclusion of new coefficients for the VMT model used when evaluating the light-duty fleet only.
- Updated input parameters for the safety model.
- Updating and expanding model reporting capabilities:
    - reporting of additional metrics such as vehicle and battery tax credits.
    - options to split vehicle and diagnostic reports by scenario.

In response to feedback, interagency meetings, comments from stakeholders, as well as continued development, DOT has made additional changes to the CAFE Model for the final rule. Since the 2023 NPRM, DOT has made the following changes to the CAFE Model and inputs, including:

- Updated battery costs for electrified technologies.
- Updated ZEV State shares, credit values and projected ZEV requirements.
- Reclassified Rivian and Ford vehicles from HDPUV to light-duty based official cert data submission.
- Allow the user to directly input air conditioning (AC) efficiency, AC leakage and off cycle credit limits for each model year, separately for conventional vehicles and electric vehicles.
- All references to '2b3' regulatory class have been changed to 'HDPUV'.
- The model will no longer apply road load-improving technology to electric vehicles as part of the standard setting constraints.
- The model will no longer apply road load-improving technology to electric vehicles to achieve compliance with GHG rules.
- Updating and expanding model reporting capabilities:
    - Outputs now show battery costs, non-battery tech costs, and AC/OC costs split, as well as "total" tech costs.
    - Added Minimum Domestic Passenger Car (MDPC) output for domestic passenger cars.
    - Expand reporting of AC and off-cycle credits in the compliance report to split columns into "CAFE" and "CO_2" values.
- Updated IRA Tax credit implementation:
    - The IRA tax credit is now applied in model year 2023 instead of model year 2024 and ends in model year 2032 instead of model year 2033.

- Model now has a toggle to zero out A/C and O/C costs rather than show cost savings when these are removed.
- Updated input factors for economic models.
- Updated input factors for the safety models.
- Updated emission modeling.
    - Updated upstream factors.
    - Set N_2O emissions to a global count, consistent with other GHG.

These changes reflect DOT’s long-standing commitment to ongoing refinement of its approach to estimating the potential impacts of new CAFE and HDPUV standards, and, since the early 2000s, refining the CAFE Model to make such estimates, as shown in Table 1-1.

Table 1-1: CAFE Model and Inputs Refinement Milestones

2001-2002	• Inception and early development • Application to all manufacturers
2003	• Accounting for redesign cadence
2004-2006	• Integration of compliance, effects, and benefit-cost methods • Accounting for shared engines and transmissions • Representation of attribute-based LT standards • Application of social cost of carbon • Maximization of estimated net benefits • Probabilistic uncertainty analysis (Monte Carlo method)
2007-2009	• Attribute-based PC standards • "Synergy" factors to adjust MPG estimates for technology pairings
2010	• Flex Fuel Vehicle credits • Accounting for manufacturers' multiyear product planning
2011-2012	• Initial use of full vehicle simulations • Accounting for BEV and PHEV charging • Applying technology-specific estimates of changes in consumer value • New methods to estimate: ○ generation and use of CAFE credits ○ potential for market-driven fuel economy increases ○ changes in highway fatalities due to changes in vehicle mass
2013-2016	• Wide application of full vehicle simulation • Accounting for shared vehicle platforms • Attribute-based standards for heavy-duty (class 2b and 3) pickups and vans
2017-2020	• Simulation of compliance with attribute-based CO_2 standards[12] • Refinements to compliance credit calculations • New modules to estimate: ○ impacts on new vehicle sales and used vehicle retirement ○ changes in annual mileage accumulation (VMT) ○ employment effects ○ health effects of criteria pollutant emissions

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[12] This capability is used in the calcuation of reference baseline fleet behavior.

2021	• Inclusion of 400- and 500-mile BEVs and HCR engines with cylinder deactivation • Accounting for CAFE and CO_2 standards jointly[13] (expanding existing capability to estimate separately) • Incorporating: ○ ZEV mandates applicable in California and the "Section 177" states ○ California "Framework" agreement with specific OEMs • Estimating impacts and monetized damages of highway vehicle crashes that do not result in fatalities
2022-2023	• Addition of HDPUV, and required updates across entire model • Update technologies considered in the analysis ○ Addition of HCRE, HCRD and updated Diesel technology models ○ Removal of EFR, DSLIAD, manual transmissions, AT6L2, EPS, IACC, LDB, SAX, and some P2 combinations. • User control of additional input parameters • Updated ZEV Mandate modeling approach • Expanded accounting for Federal Incentives, such as the IRA • Expanded procedures for estimating new vehicle sales and fleet shares • VMT coefficient updates • Additional output values and options
2023-2024	• Expanded Off-Cycle and A/C efficiency capability in the model to allow adoption by ICE vehicles and electrified vehicles independently, and apply independent limits • Expanded ZEV framework to allow adoption on per model year basis and pooling of credits • Updated modeling of application of road load technologies to ZEVs during standard setting years and when considered for GHG compliance • Added capability to model HDPUV fuel agnostic standards • Changed 2b3 references to HDPUV throughout all the inputs • Added additional output values and options

Because the CAFE Model simulates a wide range of actual constraints and practices related to automotive engineering, planning, and production, such as common vehicle platforms, sharing of engines among different vehicle models, and timing of major vehicle redesigns, the analysis produced by the CAFE Model provides a transparent and realistic basis to show pathways manufacturers could follow over time in applying new technologies, which helps better assess impacts of potential future standards. Considering the technological heterogeneity of manufacturers' current product offerings, and the wide range of ways in which the many fuel-economy- and efficiency-improving technologies included in the analysis can be combined, the CAFE Model has been designed to use inputs that provide an estimate of the fuel economy or efficiency achieved for many tens of thousands of different potential combinations of fuel-saving technologies. Across the range of technology classes encompassed by the analysis fleet, this analysis involves more than a million such estimates. While the CAFE Model requires no specific approach to developing these inputs, the National Academy of Sciences (NAS) has recommended, and stakeholders have commented, that full-vehicle simulation provides the best balance between realism and practicality. DOE/Argonne has spent several years developing, applying, and expanding means to use distributed computing to exercise its Autonomie full-vehicle modeling and simulation tool over the scale necessary for realistic analysis of CAFE and HDPUV standards. This scalability and related flexibility (in terms of expanding the set of technologies to be simulated) makes Autonomie well-suited for developing inputs to the CAFE Model.

In addition, DOE/Argonne's Autonomie also has a long history of development and widespread application by a wide range of users in government, academia, and industry. Many of these users apply Autonomie to inform funding and design decisions. These real-world exercises have contributed significantly to aspects of

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[13] *Id.*

Autonomie important to producing realistic estimates of fuel economy and efficiency levels, such as estimation and consideration of performance, utility, and drivability metrics (e.g., towing capability, shift busyness, frequency of engine on/off transitions.) This steadily-increasing realism has, in turn, steadily increased confidence in the appropriateness of using Autonomie to make significant investment decisions. Notably, DOE uses Autonomie for analysis supporting budget priorities and plans for programs managed by its Vehicle Technologies Office (VTO).

Like any model, both Autonomie and the CAFE Model benefit from ongoing refinement. Nevertheless, NHTSA is confident that the combination of models in the most recent iteration produces a realistic characterization of the potential impacts of potential new standards. The majority of stakeholders that have supported the agency's reliance on the DOE/Argonne Autonomie tool and CAFE Model have noted not only technical reasons to use these models, but also other reasons such as efficiency, transparency, and ease with which outside parties can utilize models and replicate the agency's analysis.

This analysis exercises the CAFE Model in a manner that explicitly accounts for the fact that vehicle manufacturers face the combination of CAFE and/or HDPUV standards, existing EPA greenhouse gas (GHG) standards, and state ZEV mandates applicable during the (NHTSA) rulemaking time frame. Additionally, vehicle manufacturers have committed to deploy additional electric vehicles consistent with state programs that have been adopted but not granted a waiver of Clean Air Act preemption. These regulations have important interactions affecting strategies a manufacturer could use to comply with each of the above, and NHTSA believes, as discussed at more length in the preamble, that it is important for agency decision-makers to be as informed as possible about the effects of the regulatory landscape in which future CAFE compliance would be occurring.

As explained, the analysis is designed to reflect several statutory and regulatory requirements applicable to CAFE and HDPUV standard setting. The Energy Policy and Conservation Act of 1975 (EPCA) contains several requirements governing the scope and nature of CAFE standard setting. Among these, some have been in place since EPCA was first signed into law in 1975, and some were added in 2007, when Congress passed EISA and amended EPCA. The authority for HDPUV standards that came with EISA included considerably fewer such requirements. The Clean Air Act (CAA), as discussed elsewhere, provides EPA with very broad authority under Section 202(a), and does not contain EPCA/EISA's prescriptions. In some cases, in the interest of harmonization, NHTSA has created some additional flexibilities by regulation not expressly included or prohibited by EPCA/EISA in order to harmonize better with some of EPA's programmatic decisions. EPCA/EISA requirements regarding the technical characteristics of CAFE and HDPUV standards and the analysis thereof include, but are not limited to, the following, and the analysis reflects these requirements as summarized:

Corporate Average Standards: 49 U.S.C. 32902 requires that standards apply to the average fuel economy (which, for HDPUVs, is fuel efficiency) levels achieved by each corporation's fleets of vehicles produced for sale in the United States.[14] EPA has adopted a similar approach under Section 202(a) of the CAA in the interest of harmonization. The CAFE Model calculates the CAFE fuel economy, HDPUV fuel efficiency, and CO_2 levels of each manufacturer's fleets based on estimated production volumes and characteristics, including fuel economy/efficiency levels, of distinct vehicle models that could be produced for sale in the United States.[15]

Separate Standards for Passenger Cars, Light Trucks, and HDPUVs: 49 U.S.C. 32902 requires the Secretary of Transportation (the Secretary) to set CAFE standards separately for passenger cars and light trucks, and also to set separate standards for HDPUVs. EPA has adopted a similar approach under Section 202(a) of the CAA. The CAFE Model accounts separately for passenger cars, light trucks, and HDPUVs, including differentiated standards and compliance.

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[14] This differs from safety standards and traditional emissions standards, which apply separately to each vehicle. For example, every vehicle produced for sale in the United States must, on its own, meet all applicable Federal motor vehicle safety standards (FMVSS), but no vehicle produced for sale must, on its own, meet Federal fuel economy or efficiency standards. Rather, each manufacturer is required to produce a mix of vehicles that, taken together, achieve an average fuel economy or efficiency level no less than the applicable minimum level.

[15] The NHTSA analysis does provide estimates for all GHGs produced, however the CO_2 compliance curves are the only aspect of the GHG standards considered during compliance modeling.

Attribute-Based Standards: 49 U.S.C. 32902 requires the Secretary to define CAFE (passenger car and light truck) standards as mathematical functions expressed in terms of one or more attributes related to fuel economy. This means that for a given manufacturer's fleet of vehicles produced for sale in the United States in a given regulatory class and model year, the applicable minimum CAFE requirement (i.e., the numerical value of the requirement) is computed based on the applicable mathematical function, and the mix and attributes of vehicles in the manufacturer's fleet. While this requirement is not express for HDPUVs, NHTSA also sets attribute-based standards for that category of vehicles. EPA has also adopted attribute-based standards under its broad CAA Section 202(a) authority in its current GHG standards. The CAFE Model accounts for such functions and vehicle attributes explicitly.

Separately Defined Standards for Each Model Year: 49 U.S.C. 32902 requires the Secretary to set CAFE standards (separately for passenger cars and light trucks[16]) and fuel efficiency standards for HDPUVs at the maximum feasible levels in each model year. While passenger car and light truck standards must be set separately for each model year, HDPUV standards must be set in 3-year tranches, although they may vary within a tranche. CAA Section 202(a) allows EPA to establish CO_2 standards separately for each model year, and EPA has chosen to do this in the previous vehicle CO_2 standard-setting rules. The CAFE Model represents each model year explicitly, and accounts for the production relationships between model years.[17]

Separate Compliance for Domestic and Imported Passenger Car Fleets: 49 U.S.C. 32904 requires the EPA Administrator to determine CAFE compliance separately for each manufacturer's fleets of domestic passenger cars and imported passenger cars,[18] which manufacturers must consider as they decide how to improve the fuel economy of their passenger car fleets, if they build both domestic and imported passenger cars. EPA does not have a similar requirement for CO_2 standard compliance. The CAFE Model accounts explicitly for this requirement when simulating manufacturers' potential responses to CAFE standards, and the model combines any given manufacturer's domestic and imported cars into a single fleet instead when simulating that manufacturer's potential response to CO_2 standards.

Minimum CAFE Standards for Domestic Passenger Car Fleets: 49 U.S.C. 32902 requires that domestic passenger car fleets also meet a minimum CAFE standard, which is calculated as 92 percent of the industry-wide average level required under the applicable attribute-based CAFE standard, as projected by the Secretary at the time the standard is promulgated. EPA's GHG program does not contain a similar requirement. The CAFE Model accounts explicitly for this requirement for CAFE standards and sets this requirement aside for CO_2 standards.

Civil Penalties for Noncompliance: 49 U.S.C. 32912 (and implementing regulations) prescribes a rate (in dollars per tenth of a mpg) at which the Secretary is to levy civil penalties if a manufacturer fails to comply with a CAFE standard for a given fleet in a given model year, after considering available credits. While NHTSA does not consider credit availability in determining maximum feasible standards, some manufacturers have historically demonstrated a willingness to pay civil penalties rather than achieving full numerical compliance across all fleets.[19] The CAFE Model calculates civil penalties for CAFE shortfalls and provides means to estimate that a manufacturer might stop adding fuel-saving technologies once continuing to do so would be effectively more "expensive" (after accounting for fuel prices and buyers' willingness to pay for fuel economy) than paying civil penalties. This capability can be implemented or not at the user's choice. In contrast, the CAA does not authorize the EPA Administrator to allow manufacturers to sell noncompliant fleets and pay civil penalties; manufacturers who have chosen to pay civil penalties for CAFE compliance instead have tended to employ EPA's more-extensive programmatic flexibilities to meet EPA's CO_2 emissions standards. Thus, the CAFE Model does not allow civil penalty payment as an option for CO_2 standards.[20] For

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[16] 49 U.S.C. chapter 329 uses the term "non-passenger automobiles," while NHTSA uses the term "LTs" in its CAFE regulations. The terms' meanings are identical.

[17] For example, a new engine first applied to a given vehicle model/configuration in MY 2030 will most likely be retained in MY 2031 of that same vehicle model/configuraiton, in order to reflect the fact that manufacturers do not apply brand-new engines to a given vehicle model every single year. The CAFE Model is designed to account for this reality, while still respecting applicable statutory constraints.

[18] A passenger car is considered domestic or import based on the definitions provided in 49 U.S.C. 32904.

[19] NHTSA does not assume willingness to pay civil penalties for manufacturers who have commented publicly that they will not pay civil penalties in the rulemaking time frame.

[20] Compliance with CO_2 standards are includinced in our model as part of the overall regulatory landscape considered for setting maximum feasible CAFE and HDPUV Standards.

NHTSA's HDPUV standards, the model also does not allow civil penalty payment because manufacturers have not exercised this option in the real world.

Dual-Fueled and Dedicated Alternative Fuel Vehicles: For purposes of calculating CAFE levels used to determine passenger car and light truck fleet compliance, 49 U.S.C. 32905 and 32906 specify methods for calculating the fuel economy levels of vehicles operating on alternative fuels to gasoline or diesel fuels.[21] The CAFE Model can account for these requirements explicitly for each relevant vehicle model. However, 49 U.S.C. 32902 also prohibits consideration of the fuel economy of dedicated Alternative Fuel Vehicle (AFV) models (or the non-gasoline calculated fuel economy of dual-fueled AFVs) when NHTSA determines what levels of passenger car and light truck CAFE standards are maximum feasible for the model years at issue in a rulemaking. The CAFE model therefore has an option to be run in a manner that excludes the additional application of dedicated AFV technologies in model years for which maximum feasible standards are under consideration, and to limit the consideration of dual-fueled AFVs' fuel economy to only their gasoline or diesel operation. We run the model with this limitation when performing the analysis that informs the standard ultimately chosen. The CAFE Model can also be run without this analytical constraint, and we do run it this way to ensure that the environmental impacts of this action are considered pursuant to NEPA. In evaluating the potential fuel efficiency standards for HDPUVs, per regulation, the CAFE Model considers only the gasoline or diesel fuel as counting toward the fuel use. As a result, vehicles that run completely on alternative fuels, such as fully electric vehicles (EVs), currently receive a 0 g/100 mile value for purposes of compliance in the HDPUV fleet. CAA Section 202(a) does not similarly require EPA to avoid consideration of dedicated AFVs when setting CO_2 standards, or to limit consideration of dual-fueled AFVs. The CAFE model thus accounts for dual-fueled and dedicated AFVs when simulating manufacturers' potential responses to CO_2 standards.

Creation and Use of Compliance Credits: 49 U.S.C. 32903 provides that manufacturers may earn CAFE "credits" by achieving a CAFE level beyond that required of a given fleet in a given model year and specifies how these credits may be used to offset the amount by which a different fleet falls short of its corresponding requirement. These provisions allow credits to be "carried forward" and "carried back" between model years, transferred between regulated classes (domestic passenger cars, imported passenger cars, and light trucks), and traded between manufacturers. However, credit use is also subject to specific statutory limits. For example, CAFE compliance credits can be carried forward a maximum of five model years and carried back a maximum of three model years. Also, EPCA/EISA caps the amount of credit that can be transferred between a manufacturer's fleets and prohibits manufacturers from applying traded or transferred credits to offset a failure to achieve the minimum standard for domestic PCs. No such statutory restrictions exist for HDPUVs, which may also earn credits as set forth in 49 CFR 535.7, and which implements certain restrictions like credit lifespan and prohibiting transfers. The CAFE Model explicitly simulates manufacturers' potential use of credits carried forward from prior model years or transferred from other fleets.[22]

49 U.S.C. 32902 prohibits consideration of manufacturers' potential application of CAFE compliance credits when setting maximum feasible CAFE standards for passenger cars and light trucks, although there is no

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[21] In some cases (like for "flex-fuel vehicles" that are capable of running on E85), the statute provides no further direction after MY 2020, and NHTSA and EPA have developed regulatory provisions to address the gap.

[22] The CAFE Model does not explicitly simulate the potential that manufacturers would carry CAFE or HDPUV credits back (i.e., borrow) from future MYs, or acquire and use CAFE or HDPUV compliance credits from other manufacturers. At the same time, because EPA has currently elected not to limit credit trading or transferring (at least between PCs and LTs), the CAFE Model can be exercised in a manner that simulates unlimited (a.k.a. "perfect") CO_2 compliance credit trading throughout the industry (or, potentially, within discrete trading "blocs"). NHTSA believes that there is significant uncertainty in how manufacturers may choose to employ these particular flexibilities in the future: for example, while it is reasonably foreseeable that a manufacturer who over-complies in one year may "coast" through several subsequent years relying on that prior improvement rather than continuing to make technology improvements year after year, it is harder to assume with confidence that manufacturers will rely on future technology investments to offset prior-year shortfalls, or whether/how manufacturers will trade credits with market competitors rather than making their own technology investments. Historically, carry-back and trading have been much less utilized than carry-forward, for a variety of reasons including higher risk and preference not to 'pay competitors to make fuel economy improvements we should be making' (to paraphrase one manufacturer), although NHTSA recognizes that carry-back and trading are used more frequently when standards increase more rapidly in stringency. Given the uncertainty just discussed, and given also the fact that the agency has yet to resolve some of the analytical challenges associated with simulating use of some of these flexibilities, the agency considers borrowing and trading to involve sufficient risk that it is prudent to support this final rule with analysis that sets aside the potential that manufacturers could come to depend widely on borrowing and trading. While compliance costs in real life may be somewhat different from what is modeled today as a result of this analytical decision, that is broadly true no matter what, given constraints on consideration of credit availability in determining maximum feasible standards, and the agency does not believe that the difference would be so great that it would change the policy outcome. Furthermore, a manufacturer employing a trading strategy would presumably do so because it represents a lower-cost compliance option. Thus, the estimates derived from this modeling approach are likely to be conservative in this respect, with real-world compliance costs possibly being lower.

such prohibition for setting HDPUV standards. The CAFE Model can be operated in a manner that excludes the application of CAFE credits for a given model year under consideration for standard setting, and we run the model with this restriction when performing our standard-setting analysis for the CAFE standards for passenger cars and light trucks. CAA 202(a) does not preclude the EPA Administrator from adopting analogous provisions. With some exceptions, EPA's reference baseline regulations limit the "life" of compliance credits from most model years to 5 years, and limit borrowing to 3 years, but do not limit transfers (between a manufacturer's fleets) or trades (between manufacturers) of compliance credits. The CAFE Model accounts for the absence of limits on transfers of CO_2 standards. Insofar as the CAFE Model can be exercised in a manner that simulates trading of CO_2 compliance credits, such simulations treat trading as unlimited.[23]

Statutory Basis for Stringency: 49 U.S.C. 32902 requires the Secretary to set CAFE standards for passenger cars and light trucks at the maximum feasible levels, considering technological feasibility, economic practicability, the need of the U.S. to conserve energy, and the impact of other motor vehicle standards of the Government on fuel economy. HDPUV standards must also be maximum feasible, considering appropriateness, cost-effectiveness, and technological feasibility. EPCA/EISA authorizes the Secretary to interpret these factors, and as the Department's interpretation has evolved, NHTSA has continued to expand and refine its qualitative and quantitative analysis to account for these statutory factors. For example, the Autonomie simulations reflect the agency's judgment that it would not be economically practicable, appropriate, or cost-effective for a manufacturer to "split" an engine shared among many vehicle model/configurations into myriad versions each optimized to a single vehicle model/configuration.

National Environmental Policy Act: In addition, the agency is issuing an EIS that documents the estimated impacts of regulatory alternatives under consideration. The EIS accompanying this final rule documents changes in emission inventories as estimated using the CAFE Model, but also documents corresponding estimates – based on the application of other models documented in the EIS – of impacts on the global climate, on tropospheric air quality, and on human health.

Other Aspects of Compliance, including ZEV Mandates: Beyond these statutory requirements applicable to DOT and/or EPA are several specific factors also considered.

The CAFE Model can simulate manufacturers' compliance with ZEV mandates applicable in California and Section 177 states. Additionally, the model can simulate manufacturer commitments to deploy electric vehicles consistent with state programs that have been adopted but not granted a waiver of Clean Air Act preemption. This approach involves identifying specific vehicle model/configurations that could be replaced with PHEVs or BEVs, and immediately making these changes in each model year, before beginning to consider the potential that other technologies could be applied toward compliance with CAFE or CO_2 standards.

Several technical characteristics of CAFE and/or CO_2 regulations are also relevant to the construction of this analysis. For example, through certain model years, EPA has defined procedures for calculating average CO_2 levels, and has revised procedures for calculating CAFE levels, to reflect manufacturers' application of "OC" technologies that increase fuel economy. Similar procedures are available for HDPUV compliance. Although too little information is available to account for these provisions explicitly in the same way that the agency has accounted for other technologies, the CAFE Model does include and makes use of inputs reflecting the agency's expectations regarding the extent to which manufacturers may earn such credits, along with estimates of corresponding costs. Similarly, the CAFE Model includes and makes use of inputs regarding credits EPA has elected to allow manufacturers to earn toward CO_2 levels (not CAFE) based on the use of AC refrigerants with lower global warming potential, or on the application of technologies to reduce refrigerant leakage. In addition, EPA has elected to provide that through certain model years, manufacturers may apply "multipliers" to plug-in hybrid EVs, BEVs, fuel cell vehicles, and hydrogen vehicles, such that when calculating a fleet's average CO_2 levels (not CAFE), the manufacturer may, for example, "count" each EV twice.[24] The CAFE Model accounts for these multipliers, based on current regulatory provisions or on

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[23] To avoid making judgments about possible future trading activity, when exercising the model in this way, the agency combines all manufacturers into a single entity, so that the most cost-effective choices are made for the fleet as a whole. Compliance with CO_2 standards are included in our model as part of the overall regulatory landscape considered for setting maximum feasible CAFE and HDPUV standards.

[24] The EPA incentives are considered in reference baseline calculations simulating fleet behavior up to standard setting years (2022-2026).

alternative approaches. Although these are examples of regulatory provisions that arise from the exercise of discretion rather than specific statutory mandate, they can materially impact outcomes.

Besides the updates to the model described above, any analysis of regulatory actions that will be implemented several years in the future, and whose benefits and costs accrue over decades, requires many assumptions. Over such time horizons, many, if not most, of the relevant assumptions in such an analysis are inevitably uncertain. It is natural that each successive CAFE and HDPUV analysis should update assumptions to reflect better the current state of the world and the best current estimates of future conditions.

As discussed in the list provided above, assumptions have been updated since the 2022 final rule, and the 2023 NPRM, for this final rule. While NHTSA would have made these updates as a matter of course, we note that the ongoing recovery from the global Coronavirus disease of 2019 (COVID-19) pandemic, the war in Ukraine and the economic consequences of both of those events have been profoundly disruptive, including ways directly material to major analytical inputs such as fuel prices, GDP, vehicle production and sales, and highway travel. For this analysis, NHTSA continues to use a model year 2022 reference for passenger cars and light trucks and an updated HDPUV analysis fleet (the last HDPUV analysis fleet was built in 2016). NHTSA has also updated estimates of manufacturers' compliance credit banks, updated fuel price projections to reflect the U.S. Energy Information Administration's (EIA's) 2023 Annual Energy Outlook (AEO), updated projections of GDP and related macroeconomic measures, updated projections of future highway travel, and updated estimates and assumptions used to compute social costs (SCs) and benefits related to vehicle use and fuel consumption. (e.g., costs related to traffic safety). These and other updated analytical inputs are discussed in detail in the remainder of this TSD.

1.2. What Is NHTSA Analyzing?

1.2.1. Attribute-Based Standards

Passenger car, light truck, and HDPUV standards are all attribute-based. As in the CAFE and CO_2 rulemakings in 2010, 2012, 2020, and 2022, NHTSA is setting CAFE standards defined by a mathematical function of vehicle footprint, which has an observable correlation with fuel economy. For our purposes, a vehicle's footprint is defined, per 49 CFR 523.2, as the vehicle's track width multiplied by the vehicle's wheelbase and rounded to the nearest 1/10 foot squared. EPCA, as amended by EISA, expressly requires that CAFE standards for passenger cars and light trucks be based on one or more vehicle attributes related to fuel economy and be expressed in the form of a mathematical function.[25] Thus, the final standards, and regulatory alternatives, take the form of fuel economy targets expressed as functions of vehicle footprint,[26] that are separate for passenger cars and light trucks. Chapter 1.2.3 below discusses NHTSA's continued reliance on footprint as the relevant attribute for passenger cars and light trucks in this final rule.

Under the footprint-based standards, the function defines a fuel economy performance target for each unique footprint combination within a passenger car or light truck model type. Using the functions, each manufacturer will have a CAFE average standard for each year that is almost certainly unique to each of its fleets,[27] based upon the footprints and production volumes of the vehicle models produced by that manufacturer. A manufacturer will have separate footprint-based standards for passenger cars and for light trucks, consistent with 49 U.S.C. 32902(b)'s direction that NHTSA must set separate standards for passenger cars and for light trucks. The functions are mostly sloped, so that generally, larger vehicles (i.e., vehicles with larger footprints) will be subject to lower mpg targets than smaller vehicles. This is because, typically, smaller vehicles are more capable of achieving higher levels of fuel economy, mostly because they tend not to have to work as hard (and therefore to require as much energy) to perform their driving task. Although a manufacturer's fleet average standards could be estimated throughout the model year based on the projected production volume of its vehicle fleet (and are estimated as part of EPA's certification process), the standards with which the manufacturer must comply are determined by its final model year production figures. A manufacturer's calculation of its fleet average standards, as well as its fleets' average performance at the end

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[25] 49 U.S.C. 32902(a)(3)(A).

[26] The product of vehicle wheelbase and average track width per 49 CFR 523.2.

[27] EPCA/EISA requires NHTSA and EPA to separate passenger cars into domestic and import passenger car fleets for CAFE compliance purposes (49 U.S.C. 32904(b)), whereas EPA combines all passenger cars into one fleet for CO_2 standards compliance.

of the model year, will thus be based on the production-weighted average target and performance of each model in its fleet.[28]

For passenger cars, consistent with prior rulemakings, NHTSA is defining final fuel economy targets as shown in Equation 1-1.

Equation 1-1: Passenger Car Fuel Economy Footprint Target Curve

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

Where:

$TARGET_{FE}$ is the fuel economy target (in mpg) applicable to a specific vehicle model type with a unique footprint combination,

a is a minimum fuel economy target (in mpg),

b is a maximum fuel economy target (in mpg),

c is the slope (in gallons per mile per square foot, or gpm per square foot), of a line relating fuel consumption (the inverse of fuel economy) to footprint, and

d is an intercept (in gpm) of the same line.

Here, *MIN* and *MAX* are functions that take the minimum and maximum values, respectively, of the set of included values. For example, *MIN*[40, 35] = 35 and *MAX*(40, 25) = 40, such that *MIN*[*MAX*(40, 25), 35] = 35.

The resultant functional form is reflected in Chapter 1.4 below in graphs displaying the passenger car target function in each model year for each regulatory alternative.

For light trucks, also consistent with prior rulemakings, NHTSA is defining fuel economy targets as shown in Equation 1-2.

Equation 1-2: Light Truck Fuel Economy Footprint Target Curve

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

Where:

$TARGET_{FE}$ is the fuel economy target (in mpg) applicable to a specific vehicle model type with a unique footprint combination,

a, *b*, *c*, and *d* are as for passenger cars, but taking values specific to light trucks,

e is a second minimum fuel economy target (in mpg),

f is a second maximum fuel economy target (in mpg),

g is the slope (in gpm per square foot) of a second line relating fuel consumption (the inverse of fuel economy) to footprint), and

h is an intercept (in gpm) of the same second line.

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[28] As discussed in prior rulemakings, a manufacturer may have some vehicle models that exceed their target and some that are below their target. Compliance with a fleet average standard is determined by comparing the fleet average standard (based on the production-weighted average of the target levels for each model) with fleet average performance (based on the production-weighted average of the performance of each model).

As for the passenger car target function, the resultant functional form for light trucks is reflected in Chapter 1.4 below in graphs displaying the light truck target function in each model year for each regulatory alternative. Although the general model of the target function equation is the same for both passenger cars and light trucks, and each model year, the parameters of the function equation differ for cars and trucks.

For HDPUVs, NHTSA has previously set attribute-based standards, but used a work-based metric as the attribute rather than the footprint attribute used for passenger car and light truck standards. Work-based measures such as payload and towing capability are key among the parameters that characterize differences in the design of these vehicles, as well as differences in how the vehicles will be used. Buyers consider these utility-based attributes when purchasing a HDPUV. Since NHTSA has been regulating HDPUVs, these standards have been based on a “work factor” attribute that combines the vehicle’s payload and towing capabilities, with an added adjustment for 4-wheel drive vehicles.

Similar to the standards for passenger cars and light trucks, NHTSA (and EPA) have historically set HDPUV standards such that each manufacturer’s fleet average standard is based on production volume-weighting of target standards for all vehicles, that in turn are based on each vehicle’s work factor. These target standards are taken from a set of mathematical functions or curves. There is a target standard curve for compression ignition engine (CI) based HDPUVs and a target standard curve for spark ignition engine (SI) based HDPUVs. While NHTSA is not required by statute to set HDPUV standards that are attribute-based and that are described by a mathematical function, NHTSA continues to believe that doing so continues to be reasonable for this segment of vehicles, consistent with prior HDPUV standard-setting rulemakings. NHTSA is continuing to use the work-based attribute and to increase stringency gradually (which for HDPUVs means that standards appear to *decline*, as compared to passenger car and light truck standards where increasing stringency means that standards appear to *increase*), as discussed further below. NHTSA is defining HDPUV fuel efficiency targets as shown in Equation 1-3:

Equation 1-3: HDPUV Fuel Efficiency Work Factor Target Curve

$$\textit{Sub configuration Target Standard (gallons per 100 miles)} = [c \times (WF)] + d$$

Where:

c is the slope of the gasoline, CNG, Strong Hybrid, and PHEV work factor target curve in gal/100mile per WF

For diesel engines, BEVs, and FCVs, c will be replaced with e

d is the gasoline CNG, Strong Hybrid, and PHEV minimum fuel consumption work factor target curve value in gal/100mile

For diesel engines, BEVs, and FCVs, d will be replaced with f

$$WF = \text{Work Factor} = [0.75 \times (\text{Payload Capacity} + Xwd)] + [0.25 \times \text{Towing Capacity}]$$

Where:

Xwd = 4wd adjustment = 500 lbs. if the vehicle group is equipped with 4wd and all-wheel drive (AWD), otherwise equals 0 lbs. for 2wd

Payload Capacity = GVWR (lbs.) – Curb Weight (lbs.) (for each vehicle group)

Towing Capacity = GCWR (lbs.) – GVWR (lbs.) (for each vehicle group)

To clarify, as has been the case since NHTSA began establishing attribute-based standards, no individual vehicle is required to meet the specific applicable fuel economy or fuel efficiency target, because compliance with CAFE and HDPUV standards is determined, per statute in the case of CAFE standards, based on corporate average performance. In this respect, CAFE and HDPUV standards are unlike, for example, Federal Motor Vehicle Safety Standards (FMVSS) and certain vehicle criteria pollutant emissions standards, where each vehicle must meet the requirements. Instead, CAFE and HDPUV standards apply to the average fuel economy or efficiency levels achieved by manufacturers' entire fleets of vehicles produced for sale in the United States. Safety standards apply on a vehicle-by-vehicle basis, such that every single vehicle produced for sale in the United States must, on its own, comply with applicable minimum FMVSS. When first mandating CAFE standards in the 1970s, Congress specified a more flexible averaging-based approach that allows some vehicles to "under-comply" (i.e., fall short of the overall flat standard, or fall short of their target under attribute-based standards) while others "over-comply" as long as a manufacturer's overall fleet is in compliance.

For passenger cars and light trucks, the required CAFE level applicable to a given fleet in a given model year is determined by calculating the production-weighted harmonic average of fuel economy targets applicable to specific vehicle model configurations in the fleet, as shown in Equation 1-4.

Equation 1-4: Calculation for Required CAFE Level

$$CAFE_{required} = \frac{\sum_i PRODUCTION_i}{\sum_i \frac{PRODUCTION_i}{TARGET_{FE,\, i}}}$$

Where:

$CAFE_{required}$ is the CAFE level that the fleet is required to achieve,

i refers to specific vehicle model/configurations in the fleet,

$PRODUCTION_i$ is the number of model configuration i produced for sale in the United States, and

$TARGET_{FE,\, i}$ is the fuel economy target (as defined above) for model configuration i.

For HDPUVs, the required fuel efficiency level applicable in a given model year is similarly determined by calculating the production-weighted average of subconfiguration targets applicable to specific vehicle model configurations in the fleet, as shown in Equation 1-5.[29]

Equation 1-5: Calculation for Required HDPUV Level

$$\text{Fleet Average Standard} = \frac{\sum [Subconfiguration\ Target\ Standard_i \times Volume_i]}{\sum [Volume_i]}$$

Where:

$Subconfiguration\ Target\ Standard_i$ = fuel consumption standard for each group of vehicles with the same payload, towing capacity, and drive configuration (gallons per 100 miles), and

$Volume_i$ = production volume of each unique subconfiguration of a model type based upon payload, towing capacity, and drive configuration.

Chapter 1.2.2 describes the advantage of attribute-based standards, generally. Chapter 1.2.3 explains the specific decision to continue to use footprint, for passenger cars and light trucks, and work factor, for HDPUVs, as the attribute(s) over which to vary stringency. Chapter 1.2.4 discusses the mathematical functions for CAFE standards, and Chapter 1.2.5 discusses the mathematical functions for HDPUV standards.

1.2.2. Why Attribute-Based Standards, and What Are the Benefits?

As explained above, Congress expressly requires the passenger car and light truck CAFE standards to be attribute-based, and NHTSA continues to believe that it is reasonable to set attribute-based standards for

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[29] 49 CFR 535.5(a)(2).

HDPUVs as well, given the many characteristics they share with light trucks (both in terms of technologies used and how they are manufactured). Under attribute-based standards, every vehicle model has a fuel economy or fuel efficiency target, the levels of which depend on the level of that vehicle's determining attribute. As discussed further below, in this final rule, NHTSA is retaining vehicle footprint as the attribute for passenger car and light truck CAFE standards, and to retain work factor as the attribute for model years 2030-2035 HDPUV standards. Again, the manufacturer's fleet average CAFE or HDPUV performance is calculated by the harmonic production-weighted average of those targets, as shown above in Equation 1-4 and Equation 1-5. This means that no vehicle is required to meet its target; instead, manufacturers are free to balance improvements however they deem best within (and in some cases, given credit transfers, at least partially across) their fleets.

While Congress expressly requires CAFE standards for passenger cars and light trucks to be specified as a mathematical function dependent on one or more attributes related to fuel economy, Congress has provided NHTSA the authority to select *which* attributes and mathematical functions, and Congress has also provided NHTSA broad authority in choosing how to regulate HDPUVs. Before Congress amended EPCA to require that CAFE standards be attribute-based and defined by a mathematical function, CAFE standards were instead specified as single mpg values (e.g., 27.5 mpg for passenger cars, 20.7 mpg for light trucks). Because these single-mpg standards were wholly independent of fleet composition, these requirements posed a significantly greater technical challenge for manufacturers producing more larger vehicles for the U.S. market than for manufacturers focused more on smaller vehicles, because smaller vehicles generally achieve greater fuel economy levels. Therefore, because the standards are fleet-average standards, these single-mpg standards presented an inherent incentive to shift production toward smaller vehicles rather than increasing the application of fuel-saving technologies across entire fleets, meaning that fuel economy benefits would be primarily available to purchasers of smaller vehicles, rather than broadly available to consumers with a more diverse range of vehicle preferences.

In setting attribute-based standards, NHTSA has sought to reflect the trade-off – i.e., the relationship – between the attribute and fuel economy/efficiency, consistent with the overarching purpose of EPCA/EISA to conserve energy. If the shape of the standards captures these trade-offs, every manufacturer is more likely to continue adding fuel-efficient technology across the distribution of the attribute within their fleet, instead of potentially changing the attribute – and other correlated attributes, including fuel economy/efficiency – as part of their compliance strategy. The shape of the standards is discussed in more detail in Chapter 1.4.

1.2.3. Attributes for Passenger Car, Light Truck, and HDPUV Standards

1.2.3.1. Footprint as the Attribute for Passenger Car and Light Truck CAFE Standards

49 U.S.C. 32902(b)(3)(A) states that the attribute used to set CAFE standards must be a "vehicle attribute related to fuel economy." While there are many vehicle attributes related to fuel economy, NHTSA has chosen to use vehicle footprint as the relevant attribute since model year 2011, the first year of CAFE standards set under EISA, and NHTSA is continuing this approach for the standards in this final rule.[30,31] Footprint has an observable correlation to fuel economy. There are several policy and technical reasons why NHTSA believes that footprint remains the most appropriate attribute on which to base CAFE standards for the vehicles covered by this rulemaking, even though some other vehicle attributes (notably, curb weight) are better correlated to fuel economy, and even though the 2021 NAS Report suggested adding another attribute.

First, the 2002 NAS Report described at length and quantified the potential safety problem with average fuel economy standards that specify a single numerical requirement for the entire industry,[32] identifying that smaller and lighter vehicles incentivized by those standards could be less safe for their occupants. Since that report, and because prior litigation has concerned the possible safety effects associated with CAFE standards, NHTSA has sought to set CAFE standards with an eye toward these possible effects. Because

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[30] We note that EPA has also set its CO_2 standards for light-duty vehicles using footprint as the attribute since model year 2012.

[31] A vehicle's footprint is defined as the vehicle's track width multiplied by the vehicle's wheelbase and rounded to the nearest 1/10 squared foot, per 49 CFR 523.2.

[32] Transportation Research Board and National Research Council. 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. *The National Academies Press*: Washington, D.C. pp. 5, 12. Available at: https://nap.nationalacademies.org/catalog/10172/effectiveness-and-impact-of-corporate-average-fuel-economy-cafe-standards. (Accessed: Feb 7, 2024) (hereafter, "2002 NAS Report").

vehicle size is correlated with vehicle safety at least for the occupants of the vehicles, and because CAFE standards can affect vehicle size when manufacturers are considering how to improve the fuel economy of their vehicles, NHTSA believes it is important to choose an attribute correlated with vehicle size (mass or some dimensional measure).

As discussed in NHTSA's model year 2011 CAFE final rule, when first electing to adopt footprint-based standards for both passenger cars and light trucks, NHTSA carefully considered other alternatives, including vehicle mass and "shadow" (overall width multiplied by overall length). Vehicle mass is strongly correlated with fuel economy: on a per-mile basis, a vehicle with more mass takes more energy to move than a vehicle with less mass. Mass and crush space are both important safety considerations, and mass *disparity,* in particular, can affect crash outcomes for all parties. Mass is also quite easy to manipulate artificially (i.e., changing the attribute(s) to achieve a more favorable target). Without much difficulty, a manufacturer could add enough mass to a vehicle to decrease its applicable fuel economy target by a significant amount – even infotainment systems add weight through components, wiring, etc. Mass-based standards can also discourage manufacturers from applying mass-efficient materials and designs, because their standards would become more stringent as mass is reduced. A mass-based attribute would provide the wrong incentive given that EPCA's objective is energy conservation.

In comparison, footprint is also correlated with fuel economy but not as strongly as mass. Footprint has a positive correlation with frontal surface area, and front surface area has a negative correlation with aerodynamic drag, and therefore with fuel economy. However, the relationship is less deterministic than mass. Footprint is also less directly associated with vehicle occupant safety, as discussed in Chapter 7. As compared to mass, NHTSA continues to believe that footprint is much less susceptible to gaming, because while there is some potential to adjust track width, wheelbase is more difficult and expensive to change, at least outside a planned vehicle redesign – it cannot easily be adjusted year to year, unlike mass. Among other things, changes in footprint can affect vehicle dynamics, for example, requiring reevaluation of compliance with certain FMVSS and safety system performance. This is not to say that a footprint-based standard eliminates manipulation, or that a footprint-based system eliminates the possibility that manufacturers will change vehicles in ways that compromise safety.

Based on the data present in the EPA Trends report,[33] see Table 1-2 below, we see that vehicle footprints, within vehicle types, have been stable on a sales weighted basis since model year 2012, with the sedan/wagon category seeing the largest increase of footprint at a 3.4% increase, or about a 2 square foot increase. A 1.5 square foot increase would equate to about a 2-inch increase in the track width of a model year 2022 Toyota Corolla.[34] Furthermore, despite the slight increases in footprint, many vehicle categories show a reduction in vehicle mass, on a sales-weighted average, including a 164 lbs. decrease in weight for pickups. However, when the sales-weighted average for both of these characteristics, footprint and weight, are taken in aggregate, an overall 5.4% increase in footprint and 325 lbs. increase in weight is seen over the time period.

The disconnect between *vehicle-class* level characteristics and the *aggregate* fleet characteristics is directly traceable to the change in fleet share. The increase in sales-weighted average footprint, as well as weight, is directly caused by the nearly 28.4% reduction in fleet share for the smaller footprint sedans/wagons, in exchange for the 29.5% increase in fleet shares for larger-footprint truck sport utility vehicles (SUVs) and pickups.

Table 1-2: EPA Trends Report Data for 2012 and 2022 Fleet Share, Footprint and Weight Comparison

	Fleet Share (%)			**Footprint (ft^2)**			**Weight (lbs.)**		
	2012	**2022**	**Delta**	**2012**	**2022**	**%Delta**	**2012**	**2022**	**Lbs. Delta**
All	100%	100%	0.00%	49	52	5.4%	3979	4303	325

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[33] 2023 EPA Trends Report.

[34] The model year 2022 Corolla has a wheelbase of about 106 inches, adding 2 inches to the track width would add approximatly 212 square inches or 1.47 square feet to the footprint of the vehicle. See the Baseline Fleet Input File for data on the 2022 Corolla wheelbase.

Sedan/ Wagon	55.0%	26.5%	-28.4%	45	47	3.4%	3452	3597	145
Minivan/Van	4.9%	2.9%	-2.0%	55	56	2.1%	4442	4559	117
Car SUV	9.4%	10.4%	1.0%	47	48	1.6%	3915	3890	-25
Truck SUV	20.6%	43.8%	23.2%	50	50	0.9%	4640	4488	-151
Pickup	10.1%	16.4%	6.3%	64	65	0.5%	5335	5171	-164

Reviewing these trends shows us that the aggregate increase in footprint size is primarily driven by fleet share changes and not large increases in vehicle class footprint sizes. This evidence leads us to conclude the use of footprint as an attribute for passenger car and light truck CAFE standards does not lead to manufacturers significantly altering the size of their vehicles, within vehicle classes. This also supports our decision not to adjust the footprint functions, discussed below. The major shift in vehicle fleet share in this analysis is not considered a result of the use of the footprint attribute or of the shape of the standards curves but is likely a function of the difference in stringency between the passenger car and light truck fleets and will be considered when setting stringencies.

The question has also arisen periodically of whether NHTSA should instead consider multi-attribute standards for CAFE, such as those that also depend on mass, torque, power, towing capability, and/or off-road capability. To date, every time NHTSA has considered options for which attribute(s) to select, the agency has concluded that a properly-designed footprint-based approach provides the best means of achieving the basic policy goals[35] involved in applying an attribute-based standard. At the same time, footprint-based standards can be structured in a way that furthers the energy and environmental policy goals of EPCA/EISA by not creating inappropriate incentives to increase vehicle size in ways that could increase fuel consumption.

In the 2021 NAS Report, the committee recommended that if Congress does not act to remove the prohibition at 49 U.S.C. 32902(h) on considering the fuel economy of dedicated AFVs (like BEVs) in determining maximum feasible CAFE standards, then the Secretary (or agency) should consider accounting for the fuel economy benefits of ZEVs by "setting the standard as a function of a second attribute in addition to footprint – for example, the expected market share of ZEVs in the total U.S. fleet of new light-duty vehicles – such that the standards increase as the share of ZEVs in the total U.S. fleet increases."[36] While NHTSA considered this recommendation carefully and sought comment on an approach to implementing it, NHTSA ultimately agreed with many commenters that including electrification as an attribute on which to base fuel economy standards may be inconsistent with our current legal authority.

1.2.3.2. Work Factor as the Attribute for HDPUV Standards

NHTSA and EPA originally considered Gross Vehicle Weight Rating (GVWR) and Gross Combined Weight Rating (GCWR) as possible attributes for setting fuel efficiency standards for the HDPUV fleet. However, concerns over gaming the mass of the vehicles exist, similar to concerns expressed for using mass or weight as the attribute for passenger cars and light trucks. Additionally, under GVWR- or GCWR-based standards, allowing worse fuel efficiency from vehicles with higher curb weight would tend to penalize light-weighted vehicles with comparable payload capabilities by making them meet more stringent standards than they would have had to meet without the weight reduction. The agencies concluded that using payload and towing capacities as the work-based attributes would avoid the gaming risk and also avoid penalizing light-weighting. These attributes were combined into a "work factor," with an additional fixed adjustment for four-wheel drive vehicles to account for the fact that 4wd, critical to enabling many off-road heavy-duty work applications, adds roughly 500 lbs. to the vehicle weight.

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[35] Increasing the likelihood of improved fuel economy across the entire fleet of vehicles; by reducing disparities between manufacturers' compliance burdens; and by reducing incentives for manufacturers to respond to standards by reducing vehicle size in ways that could compromise occupant safety.

[36] National Academies of Sciences, Engineering, and Medicine. 2021. Assessment of Technologies for Improving Fuel Economy of Light-Duty Vehicles – 2025-2035. *The National Academies Press*: Washington, D.C. p. 5. Available at: https://www.nationalacademies.org/our-work/assessment-of-technologies-for-improving-fuel-economy-of-light-duty-vehicles-phase-3. (Accessed Feb. 7, 2024) (hereinafter, "2021 NAS Report"). Summary Recommendation 5, p. 368.

Towing does not directly factor into test weight, as nothing is towed during the test. Thus, only the higher curb weight caused by heavier truck components would affect measured test results. However, towing capacity can still be a significant factor because heavy-duty pickup truck towing capacities can be quite large, with a correspondingly large effect on design, and thus on possible fuel efficiency levels.

NHTSA and EPA also noted that, from a HDPUV purchaser perspective, payload and towing capability typically play a greater role than physical dimensions (as footprint represents) in influencing purchaser decisions on which heavy-duty vehicle to buy.

NHTSA continues to believe that “work factor” remains a reasonable attribute on which to base HDPUV fuel efficiency standards. Such standards are meant to be relatively consistent from a stringency perspective. Vehicles across the entire range of the HDPUV segment have their respective fuel consumption target values, and therefore all HDPUVs will be affected by the standard. With an attribute-based standards approach, there should be no significant effect on the relative distribution of vehicles with differing capabilities in the fleet, which means that buyers should still be able to purchase the vehicle that meets their needs.

1.2.4. Choosing the Mathematical Function to Specify Footprint-Based Standards for Passenger Cars and Light Trucks

In requiring NHTSA to “prescribe by regulation separate average fuel economy standards for passenger and non-passenger automobiles based on 1 or more vehicle attributes related to fuel economy and express each standard in the form of a mathematical function,” EPCA/EISA provides discretion regarding not only the selection of the attribute(s), but also regarding the nature of the function. Having decided to establish passenger car and light truck standards that continue to be based on vehicle footprint as the attribute “related to fuel economy,” NHTSA still must choose the mathematical functions to represent the relationship between footprint and fuel economy.

The relationship between fuel economy and footprint, though directionally clear (i.e., fuel economy tends to decrease with increasing footprint), is theoretically vague, and quantitatively uncertain – not so precise as to necessarily yield only a single possible curve. The decision of how to specify this mathematical function therefore reflects some amount of judgment. The function can be specified with a view toward achieving different levels of energy conservation (which may include both energy security and environmental goals), encouraging different levels of application of fuel-saving technologies, avoiding any adverse effects on overall highway safety, reducing disparities of distributing compliance burdens (and thus fuel economy improvements) more equally across manufacturers, and preserving consumer choice amongst different types and sizes of vehicles, among other aims. The following are among the specific technical concerns and resultant policy tradeoffs that NHTSA has previously considered in selecting the details of specific past and future curve shapes:

- Steeper footprint-based standards may create incentives to upsize vehicles, potentially oversupplying vehicles of certain footprints beyond what the market would demand, and thus increasing the possibility that fleetwide (or total) fuel savings benefits will be forfeited artificially.
- Flatter standards (curves) increase the risk that standards cannot be met by larger vehicles without significant cost, making them unaffordable or removing them from certain markets, reducing the supply of options for consumers who may need the utility of a larger vehicle.
- Given the same industry-wide average required fuel economy standard, flatter standards tend to place greater compliance burdens on full-line manufacturers, although this is not necessarily true if the vehicles are ZEVs.
- If cutpoints (i.e., locations of rapid change in slope, as with piecewise-linear functions) are adopted, given the same industry-wide average required fuel economy, moving small-vehicle cutpoints to the left (i.e., up, in terms of fuel economy) discourages the introduction of small vehicles, and reduces the incentive to downsize small vehicles.
- If cutpoints are adopted, given the same industry-wide average required fuel economy, moving large-vehicle cutpoints to the right (i.e., down, in terms of fuel economy) encourages the introduction of larger vehicles – especially large pickups – and extends the size range over which downsizing is discouraged in ways that could compromise overall highway safety.

NHTSA is retaining the same curve shapes for passenger car and light truck standards in in this final rule that NHTSA has used over the past several rulemakings – that is, at this time NHTSA is not changing the shape of the existing footprint curves. The history of how the existing footprint curves were developed, and the agency's exploration of alternative approaches, is well documented in Chapter 1 of the 2022 TSD,[37] and we refer readers there who wish to review that history. NHTSA carefully considered the existing curve shapes in light of ongoing trends in the fleet,[38] and determined, as in the 2022 TSD, that changing our approach to standard *stringency* made more sense for CAFE standards than changing the *curve shapes* at this point. As explained in the 2022 TSD and discussed in Chapter 3 of the 2023 EPA Trends Report, for the most part, vehicle manufacturers have continued over the past several years to reduce their offerings of smaller footprint vehicles, such as sedans and wagons, and increase their sales of larger footprint vehicles such as light truck crossovers and sport utility vehicles (SUVs).

That said, NHTSA is aware that EPA recently issued a final rule changing the shapes of its CO_2 standards curves for passenger cars and light-duty trucks, as compared to its prior set of standards.[39] EPA explained that it chose to make the slopes of both curves, especially the car curves, flatter than those of prior rulemakings, stating that, "When emissions reducing technology is applied, such as advanced ICE, or HEV or PHEV or BEV electrification technologies, the relationship between increased footprint and tailpipe emissions is reduced. From a physics perspective, a positive footprint slope for ICE vehicles makes sense because as a vehicle's size increases, its mass, road loads, and required power (and corresponding vehicle-based CO_2 emissions) will increase accordingly [and its fuel economy will correspondingly decrease accordingly]. Moreover, as the emissions control technology becomes increasingly more effective, the relationship between tailpipe emissions and footprint decreases proportionally; in the limiting case of vehicles with 0 g/mile tailpipe emissions such as BEVs, there is no relationship at all between tailpipe emissions and footprint."[40]

Since the Supreme Court's decision in Massachusetts v. EPA, NHTSA and EPA have employed equivalent footprint-based target curves for passenger cars and light trucks. Now, NHTSA cannot reasonably promulgate target curves that are flatter like EPA's new curves based on EPA's rationale, for two main reasons. First, EPA altered their curves based on considering the effects of BEVs in the fleet. Given that the target curves *are* the CAFE standards, and 49 U.S.C. 32902(h) prohibits consideration of BEVs in determining maximum feasible CAFE standards, NHTSA does not believe that the law permits us to base target curve shapes on BEV penetration rates, even if NHTSA recognizes that BEV penetration rates are continuing to increase. Second, even if NHTSA did consider BEVs in developing target curve shapes, NHTSA could not consider them the same way as EPA does. BEV compliance values in the CAFE program are determined, per statute, using DOE's Petroleum Equivalency Factor, and the calculated equivalent fuel economies appear to still vary with vehicle footprint so that, in general, larger vehicles have lower calculated equivalent fuel economies. They are not the fuel-economy-equivalent of 0 g/mi, which would be infinite fuel economy. NHTSA therefore cannot adopt EPA's rationale that curve slopes should become flatter in response to increasing numbers of BEVs because our statutory requirements differ from EPA's.

EPA also proposed that the "truck curve [for CO_2 standards] be based on the car curve (to represent the base utility across all vehicles for carrying people and their light cargo), but with the additional allowance of increased utility that distinguishes these vehicles used for more work-like activity."[41] To account for tow rating, "EPA proposes a simple offset for the truck curve, compared to the car curve, that increases with footprint," and "The offsets for AWD and utility were then scaled as a function of the nominal fleet-wide BEV penetrations anticipated to be achieved under the final stringency levels."[42] EPA additionally proposed to gradually reduce the upper (larger footprint) cutpoint for trucks, in response to concern that the existing cutpoint might create a compliance incentive to upsize.[43]

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[37] U.S. Department of Transportation. 2022. Technical Support Document: Final Rulemaking for Model Years 2024-2026 Light-Duty Vehicle Corporate Average Fuel Economy Standards. Final report. National Highway Traffic Safety Administration. Washington D.C. Available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/2022-04/Final-TSD_CAFE-MY-2024-2026.pdf. (Accessed: Feb 7, 2024).

[38] See trends discussion in Chapter 1.2.3.1.

[39] 89 FR 27842 (April 18, 2024)

[40] 89 FR 27842, 27904 (April 18, 2024)

[41] *Id*. at 29235.

[42] *Id*.

[43] *Id*. at 29236.

Again, NHTSA does not interpret 49 U.S.C. 32902(h) as permitting the agency to base target curves on anticipated BEV penetrations; that said, NHTSA is also aware of the need for the light truck curve to reflect the work performed by those “more work-like” vehicles, which must be balanced against the risk of encouraging upsizing. To address this in the CAFE program, NHTSA is retaining the existing light truck curve, which was originally designed to reflect those work needs.

For these reasons, NHTSA cannot justify making similarly-shaped curves for passenger cars and light trucks under our current authority, and the agency did not consider adopting such curves in this final rule. NHTSA may nonetheless explore reasonable and appropriate changes to the existing curve shapes in a future action.

1.2.5. Choosing the Mathematical Function to Specify Work-Factor-Based Standards for HDPUVs

As discussed, NHTSA is not statutorily required to set attribute-based standards defined by a mathematical function for HDPUVs, but previously concluded that doing so was reasonable and appropriate given the similarities of the HDPUV fleet to the light truck fleet, and NHTSA continues to believe that is the case. NHTSA previously chose to set HDPUV standards based on a “work factor” attribute, which combines elements of both payload and towing capabilities. These attributes, like footprint for passenger cars and light trucks, relate to fuel consumption in a way that is directionally clear – more payload and/or more towing equals more fuel consumed, all else equal – but also like footprint, there are many different possible curves that could theoretically represent that relationship. As in the Phase 2 rule, NHTSA is retaining the approach to curve fitting set forth in the Phase 1 rule.[44] The basic work factor equation is shown in Chapter 1.2.3, and NHTSA is retaining separate target curves for gasoline-fueled (and any other Otto-cycle) vehicles and diesel-fueled (and any other Diesel-cycle) vehicles. The targets will be used to determine the production-weighted average standards that apply to the combined diesel and gasoline fleet of HDPUVs produced by a manufacturer in each model year. The targets were based on a set of vehicle, engine, and transmission technologies (TRANS) assessed by NHTSA and EPA to be feasible and appropriate for HDPUVs in the 2014-2018 timeframe, and while it is certainly appropriate for the stringency of the standards to increase over time, there does not appear to be a reason to re-evaluate the shape of the target curves themselves. As discussed further in Chapter 2.2, HDPUVs have significantly longer redesign schedules as compared to passenger cars and light trucks, and technology changes tend to percolate through the HDPUV fleet relatively more slowly, which makes it less likely that the shape of the target curves would need to change in response. For example, with the exception of a few low-volume BEVs in this segment,[45] there are no other electrified technologies in the current baseline fleet.[46]

The NHTSA fuel consumption target curves and the EPA GHG target curve have considerable overlap during common years. In the Phase 2 rule, NHTSA target curves were established using the direct relationship between fuel consumption and CO_2 using conversion factors of 8,887 g CO_2/gallon for gasoline, and 10,180 g CO_2/gallon for diesel. We maintained the same approach for this rule, but due to statutory lead time constraints, NHTSA’s year over year stringency increases delayed in comparison to what EPA established for its recently-promulgated CO_2 target curves. NHTSA’s HDPUV standards aim to trail the EPA stringencies in the early years and ‘catch up’ to the EPA standards by model year 2035.

1.3. What Does the CAFE Model Need to Conduct This Analysis?

To conduct the analysis described above, the CAFE Model needs a variety of inputs. At a high level, the model needs the following: regulatory alternatives (see Chapter 1.4), an analysis fleet (see Chapter 2.2), information to simulate compliance with the State ZEV programs (see Chapter 5.1), technology effectiveness values (see Chapter 2.3 and Chapter 3), technology cost information (see Chapter 3), economic assumptions (see Chapter 4 for macroeconomic assumptions and Chapters 5, 6, and 7 for all others), and estimates about

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[44] *See* 76 FR 57162-64 (Sep. 15, 2011) for a complete discussion.

[45] Ford Lightning Platinum, and Extended Range

[46] Electrified technologies in this context means micro-hybrids, mild hybrids, strong hybrids, battery electric and plug-in hybrids as well as fuel cell vehicles.

environmental (see Chapter 5) and safety (see Chapter 7) effects. Chapter 2 discusses the required inputs in more detail.

1.4. What Are the Regulatory Alternatives Under Consideration in This Final Rule?

Agencies typically consider regulatory alternatives in rulemaking analyses as a way of evaluating the comparative effects of different potential ways of accomplishing their desired goal, which in this case is the statutory mandate to set maximum feasible standards. NEPA requires agencies to compare the potential environmental impacts of their regulatory actions to those of a reasonable range of alternatives.[47] E.O. 12866 and E.O. 13563, as well as Office of Management and Budget (OMB) Circular A-4, also encourage agencies to evaluate regulatory alternatives in their rulemaking analyses.

Alternatives analysis begins with a "No-Action" Alternative, typically described as what would occur in the absence of any regulatory action by the agency – in other words, the reference baseline. OMB Circular A-4 states that "the choice of an appropriate reference baseline may require consideration of a wide range of potential factors, including:

- evolution of the markets;
- changes in regulations promulgated by the agency or other government entities;
- other external factors affecting expected benefits and costs;
- the degree of compliance by regulated entities with other regulations; and
- the scale and number of entities or individuals that will be subject to, or experience the benefits or costs of, the regulation."[48]

For passenger cars and light trucks, this final rule includes a No-Action Alternative and five "action alternatives;" for HDPUVs, the final rule includes a No-Action Alternative and four action alternatives. The final standards may, in places, be referred to as the "Preferred Alternative(s)," which is NEPA parlance, but NHTSA intends "final standards" and "Preferred Alternative(s)" to be used interchangeably for purposes of this document.

Regulations regarding implementation of NEPA require agencies to "evaluate reasonable alternatives to the final action and the alternatives in comparative form" based on the affected environment and environmental consequences.[49] This does not amount to a requirement that agencies evaluate the widest conceivable spectrum of alternatives. Rather, the range(s) of alternatives must be reasonable and consistent with the purpose and need of the action(s).

The different regulatory alternatives for passenger cars and light trucks are defined in terms of percent-changes in CAFE stringency from year to year. Readers should recognize that those year-over-year changes in stringency are *not* measured in terms of mile per gallon differences (as in, 1 percent more stringent than 30 miles per gallon (MPG) in one year equals 30.3 MPG in the following year), but rather in terms of shifts in the *footprint functions* that form the basis for the *actual* CAFE standards (as in, on a gallon per mile basis, the CAFE standards change by a given percentage from one model year to the next).

In a departure from recent CAFE rulemaking trends, for this final rule we have applied individual, different rates of increase to the passenger car and the light truck fleets in different model years. Rather than have both fleets increase their respective standards at the same rate, passenger car standards will increase at a steady rate year over year, while light truck standards will not increase for few years before beginning to rise again at the passenger car rate. Several action alternatives evaluated for this final rule have a passenger car fleet rates-of-increase of fuel economy that are different from the rates-of-increase of fuel economy for the light truck fleet, while one action alternative has the same rate of increase for passenger cars and light trucks

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[47] 40 CFR 1502.14.
[48] See Office of Management and Budget. 2023. Circular A-4. General Issues, 4. Developing an Analytic Baseline. Available at: https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf. (Accessed: Apr. 4, 2024).
[49] 40 CFR 1502.14.

for all model years. NHTSA has discretion, by law, to set CAFE standards that increase at different rates for cars and trucks, because NHTSA must set maximum feasible CAFE standards separately for cars and trucks.

For HDPUVs, the different regulatory alternatives are also defined in terms of percent-increases in stringency from year to year, but in terms of fuel consumption reductions rather than fuel economy increases, so that increasing stringency appears to result in standards going *down* (representing a direct reduction in fuel consumed) over time rather than *up*. Also, unlike for the passenger car and light truck standards, because HDPUV standards are in fuel consumption space, year-over-year percent changes do actually represent gallon/mile differences across the work-factor range. Under each action alternative, the stringency changes are the same, or a slightly different percentage in the case of the preferred alternative, rates in each model year in the rulemaking time frame. One action alternative is less stringent than the Preferred Alternative for HDPUVs, and two action alternatives are more stringent.[50]

Table 1-3: Regulatory Alternatives Under Consideration for MYs 2027-2031 Passenger Cars and Light Trucks

Name of Alternative	Passenger Car Stringency Increases, Year-Over-Year	Light Truck Stringency Increases, Year-Over-Year
No-Action Alternative	n/a	n/a
Alternative PC1LT3	1%	3%
Alternative PC2LT002 (Preferred Alternative)	2%	0% MYs 2027-28 2% MYs 2029-32
Alternative PC2LT4 (Preferred Alternative)	2%	4%
Alternative PC3LT5	3%	5%
Alternative PC6LT8	6%	8%

Table 1-4: Regulatory Alternatives Under Consideration for MYs 2030-2035 HDPUVs

Name of Alternative	HDPUV Stringency Increases, Year-Over-Year
No-Action Alternative	n/a
Alternative HDPUV4	4%
Alternative HDPUV108 (Preferred Alternative)	10% MYs 2030-32 8% MYs 2033-35
Alternative HDPUV10	10%
Alternative HDPUV14	14%

A variety of factors will be at play simultaneously as manufacturers seek to comply with the eventual standards that NHTSA promulgates. NHTSA, EPA, and CARB will all likely be regulating simultaneously; manufacturers will be responding to those regulations as well as to anticipated shifts in market demand during the rulemaking time frame (both due to cost/price changes for different types of vehicles over time, fuel price changes, and the recently-passed tax credits for BEVs and PHEVs). Many costs and benefits that will accrue as a result of manufacturer actions during the rulemaking time frame will be occurring for reasons other than CAFE standards, and NHTSA believes it is important to try to reflect as many of those factors as possible in order to present a more accurate picture of the effects of different potential CAFE and HDPUV standards to decision-makers and to the public.

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[50] The PC, LT, and HDPUV target curve function coefficients are defined above in Equations 1-1, 1-2, and 1-3, respectively. See Chapter 1.2.1 for a complete discussion about the footprint and work factor curve functions and how they are calculated.

The following sections define each regulatory alternative, including the No-Action Alternative, for each program, and explain their derivation.

1.4.1. Reference baseline/No-Action Alternative

As with the 2022 final rule, our No-Action Alternative is nuanced. In this analysis, the No-Action alternative assumes:

- The existing (through model year 2026) national CAFE and GHG standards are met, and that the CAFE and GHG standards for model year 2026 finalized in 2022 continue in perpetuity.[51]
- Manufacturers who committed to the California Framework Agreements met their contractual obligations for model year 2022.
- The HDPUV model year 2027 standards finalized in the NHTSA/EPA Phase 2 program continue in perpetuity.
- Manufacturers will take action to comply with and assume implementation of the ZEV/Advanced Clean Cars I(ACC I)/Advanced Clean Trucks (ACT) programs that California and other states intend to implement through 2035.
- Manufacturers will voluntarily deploy electric vehicles consistent with ACC II program, regardless of whether it becomes legally binding.[52]
- Manufacturers will make production decisions in response to estimated market demand for fuel economy or fuel efficiency, considering estimated fuel prices, estimated product development cadence, the estimated availability, applicability, cost, and effectiveness of fuel-saving technologies, and available tax credits.
- This No-Action Alternative also includes NHTSA's estimates of ways that manufacturers could take advantage of recently passed tax credits for battery-based vehicle technologies[53]

NHTSA continues to believe that to properly estimate fuel economies/efficiencies (and achieved CO_2 emissions) in the No-Action Alternative, it is necessary to simulate all of these legal requirements and other influences affecting automakers and vehicle design simultaneously. Consequently, the CAFE Model evaluates each requirement in each model year, for each manufacturer/fleet. Differences among fleets and compliance provisions often create over-compliance in one program, even if a manufacturer is able to exactly comply (or under-comply) in the other program. This is similar to how manufacturers approach the question of concurrent compliance in the real world – when faced with multiple regulatory programs, the most cost-effective path may be to focus efforts on meeting one or two sets of requirements, even if that results in "more effort" than would be necessary for another set of requirements, in order to ensure that all regulatory obligations are met. We elaborate on those model capabilities below. Generally speaking, the model treats each manufacturer as applying the following logic when making technology decisions, both for simulating passenger car and light truck compliance, and HDPUV compliance, with a given regulatory alternative:

1. What do I need to carry over from last year?
2. What should I apply more widely in order to continue sharing (of, e.g., engines) across different vehicle models?
3. What new BEVs do I need to build in order to satisfy the various state ZEV programs and voluntary deployment of electric vehicles consistent with ACC II?
4. What further technology, if any, could I apply that would enable buyers to recoup additional costs within 30 months after buying new vehicles for both light-duty and HDPUV?
5. What additional technology, if any, should I apply to respond to potential new CAFE and CO_2 standards for passenger cars and light trucks, or HDPUV standards?

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[51] NHTSA recognizes EPA may publish their 27+ standards before this final rule is published, however, EPA's 27+ standards were not included in the reference baseline analysis, as the agencies developed their respective 27+ standards jointly.

[52] California, Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Jersey, New Mexico, New York, Oregon, Rhode Island, Vermont, Virginia, and Washington have all adopted some combination of the ACC and/or ACT standards.

[53] The AMPC and CVC provide tax credits for light-duty and HDPUV PHEVs, BEVS, and FCEVs. Chapter 2.2 below discusses, in detail, how NHTSA has modeled these tax credits.

Additionally, within the context of 4 and 5, the CAFE Model may consider, as appropriate, the applicability of recently-passed tax credits for battery-based vehicle technologies, such as PHEVs, which improve the attractiveness of those technologies to consumers and thus the model's likelihood of choosing them as part of a compliance solution. The CAFE Model simulates all of these simultaneously. As mentioned above, this means that when manufacturers make production decisions in response to actions or influences other than CAFE or HDPUV standards, those costs and benefits are not attributable to possible future CAFE or HDPUV standards. One consequence, in turn, is that the effects of the final rule appear less cost-beneficial than they would otherwise, but NHTSA believes this is appropriate in order to give the decision-maker the clearest possible understanding of the effects of the decision being made, as opposed to the effects of the many things discussed above, that will be occurring simultaneously and would have happened otherwise.

Existing NHTSA standards during the rulemaking time frame are modeled as follows:

To account for the existing model year 2026 passenger car and light truck standards, the No-Action Alternative includes the following coefficients defining those standards, which (for purposes of this analysis) are assumed to persist without change in subsequent model years:

Table 1-5: Passenger Car CAFE Target Function Coefficients for No-Action Alternative[54]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	66.95	66.95	66.95	66.95	66.95	66.95
b (mpg)	50.09	50.09	50.09	50.09	50.09	50.09
c (gpm per s.f.)	0.00033512	0.00033512	0.00033512	0.00033512	0.00033512	0.00033512
d (gpm)	0.00119613	0.00119613	0.00119613	0.00119613	0.00119613	0.00119613

Table 1-6: Light Truck CAFE Target Function Coefficients for No-Action Alternative[55]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	53.73	53.73	53.73	53.73	53.73	53.73
b (mpg)	32.30	32.30	32.30	32.30	32.30	32.30
c (gpm per s.f.)	0.00037418	0.00037418	0.00037418	0.00037418	0.00037418	0.00037418
d (gpm)	0.00327158	0.00327158	0.00327158	0.00327158	0.00327158	0.00327158

These coefficients are used to create the following graphic below, where the x-axis represents vehicle footprint and the y-axis represents fuel economy, showing that in "CAFE space," targets are higher in fuel economy for smaller footprint vehicles and lower for larger footprint vehicles:

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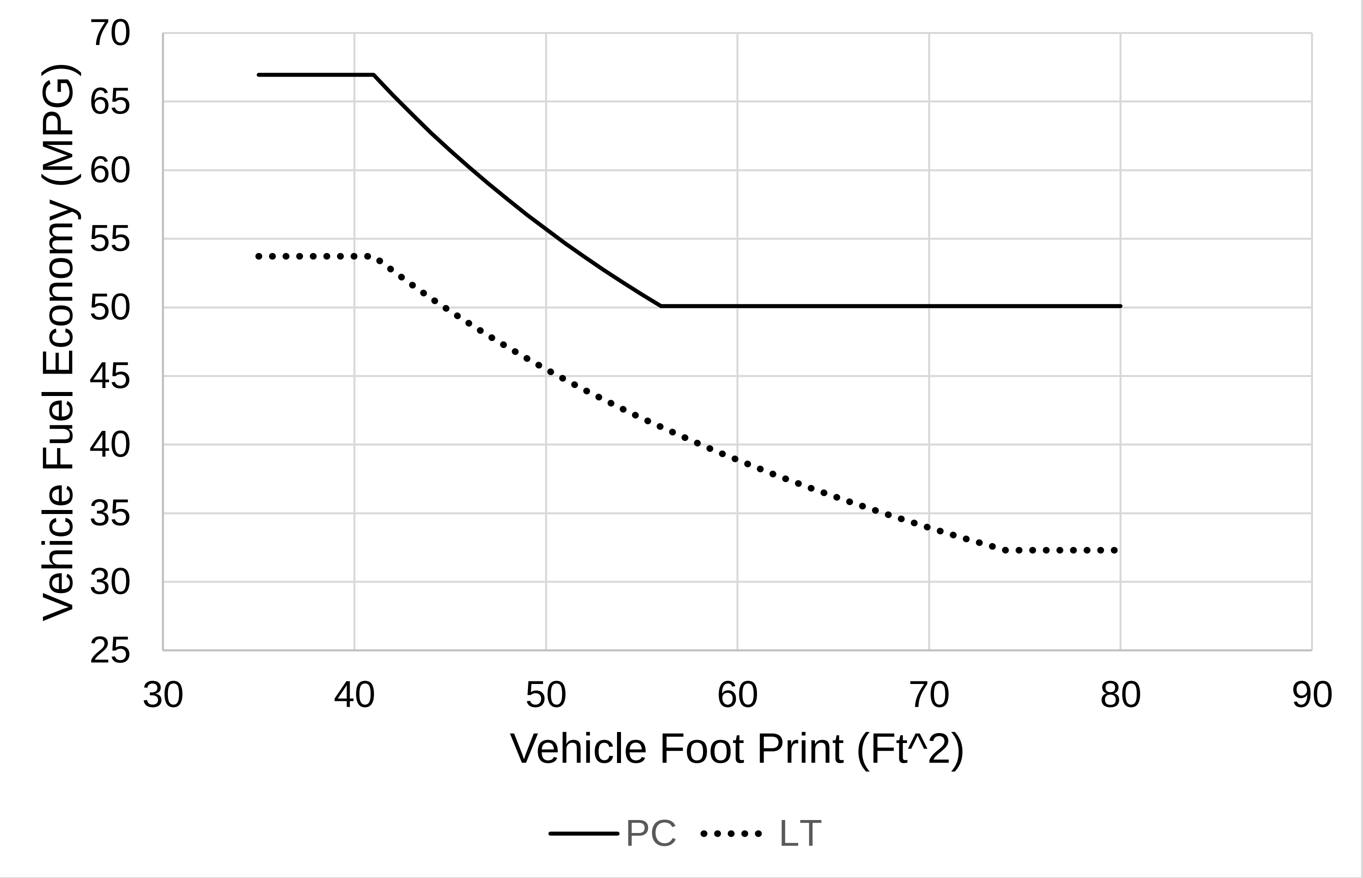
[54] The Function Coefficients 'a','b','c', and 'd' are defined in Equation 1-1 of Chapter 1.2.1.

[55] The Function Coefficients 'a','b','c', and 'd' are defined in Equation 1-1 of Chapter 1.2.1.

Figure 1-3: No-Action Alternative, Passenger Car and Light Truck Fuel Economy, Target Curves



Note: There is no model year associated with the No-Action Alternative in this figure because the same curve would apply in all relevant MYs.

Additionally, EPCA, as amended by EISA, requires that any manufacturer's domestically-manufactured passenger car fleet must meet the greater of either 27.5 mpg on average, or 92 percent of the average fuel economy projected by the Secretary for the combined domestic and non-domestic passenger automobile fleets manufactured for sale in the United States by all manufacturers in the model year. NHTSA retains the 1.9 percent offset to the minimum domestic passenger car standard (MDPCS), first used in the 2020 final rule, to account for recent projection errors as part of estimating the total passenger car fleet fuel economy.[56] The projection shall be published in the Federal Register when the standard for that model year is promulgated in accordance with 49 U.S.C. 32902(b).[57,58] For purposes of the No-Action Alternative, the MDPCS is as it was established in the 2022 final rule for model year 2026, as shown in Table 1-7 below:

Table 1-7: No-Action Alternative – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
53.5	53.5	53.5	53.5	53.5	53.5

To account for the existing HDPUV standards finalized in the Phase 2 rule, the No-Action Alternative for HDPUVs includes the following coefficients defining those standards, which (for purposes of this analysis) are assumed to persist without change in subsequent model years. The four-wheel drive coefficient is maintained

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[56] Preamble Section V.A.2 (titled "Separate Standards for Passenger Cars, Light Trucks, and Heavy-Duty Pickups and Vans, and Minimum Standards for Domestic Passenger Cars") discusses the basis for the offset.

[57] 49 U.S.C. 32902(b)(4).

[58] The offset will be applied to the final regulation numbers, but was not used in this analysis. The values for the MDPCS for the final action alternatives are nonadjusted values.

at 500 (coefficient ‘a’) and the weighting multiplier coefficient is maintained at 0.75 (coefficient ‘b’). The CI and SI coefficients are in the tables below:

Table 1-8: HDPUV CI Vehicle Fuel Efficiency Target Function Coefficients for No-Action Alternative[59]

	2030	2031	2032	2033	2034	2035
e (gal/100 miles per WF)	0.00034180	0.00034180	0.00034180	0.00034180	0.00034180	0.00034180
f (gal/100 miles per WF)	2.633	2.633	2.633	2.633	2.633	2.633

Table 1-9: HDPUV SI Vehicle Fuel Efficiency Target Function Coefficients for No-Action Alternatives[60]

	2030	2031	2032	2033	2034	2035
c (gal/100 miles per WF)	0.00041520	0.00041520	0.00041520	0.00041520	0.00041520	0.00041520
d (gal/100 miles per WF)	3.196	3.196	3.196	3.196	3.196	3.196

These equations are represented graphically below:

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[59] In the CAFE Model, these are Linear work-factor-based function where coefficients e and f are for diesels, BEVs and FCEVs. See Equation 1-3 in Chapter 1.2.1.

[60] In the CAFE Model, these are Linear work-factor-based function where coefficients c and d are for gasoline, CNG, strong hybrid vehicles and PHEVs. See Equation 1-3 in Chapter 1.2.1.

Figure 1-4: No-Action Alternative, HDPUV – CI Vehicles, Target Curves

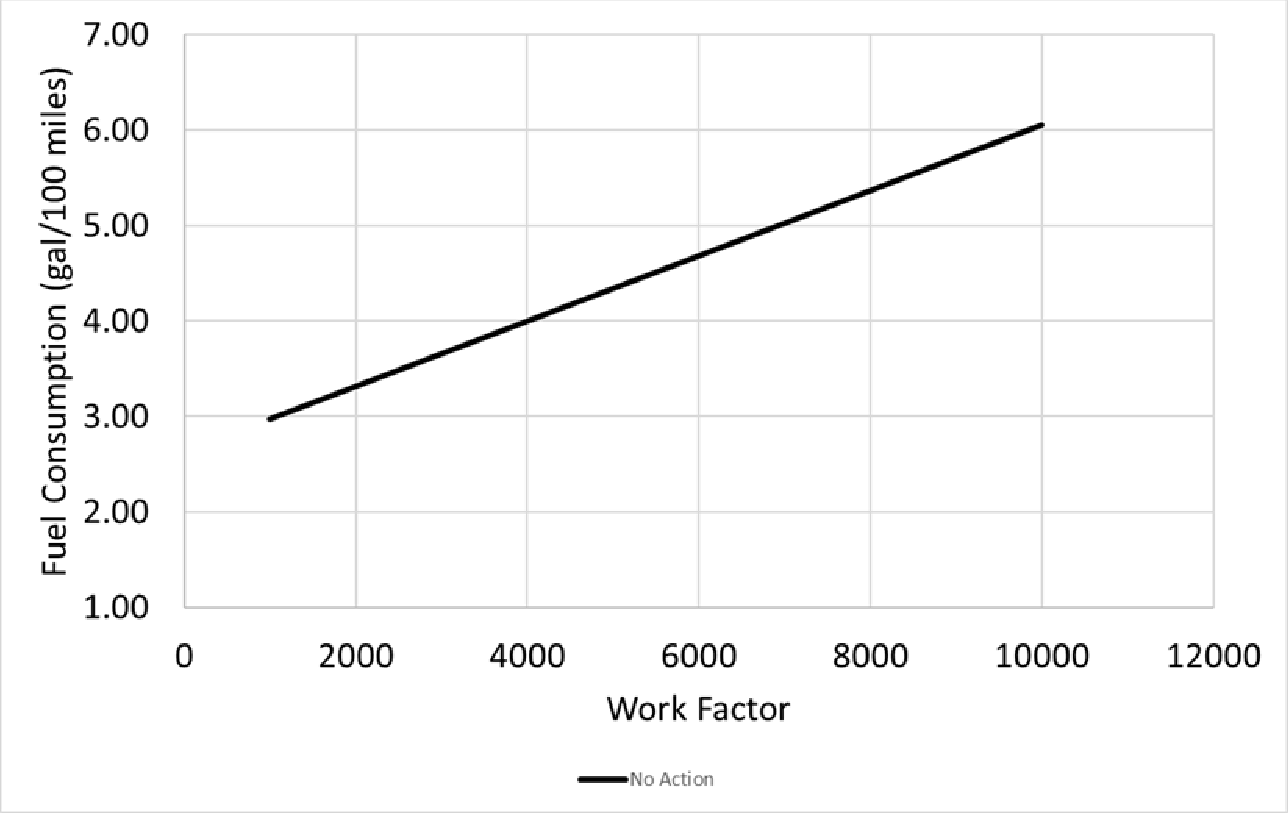
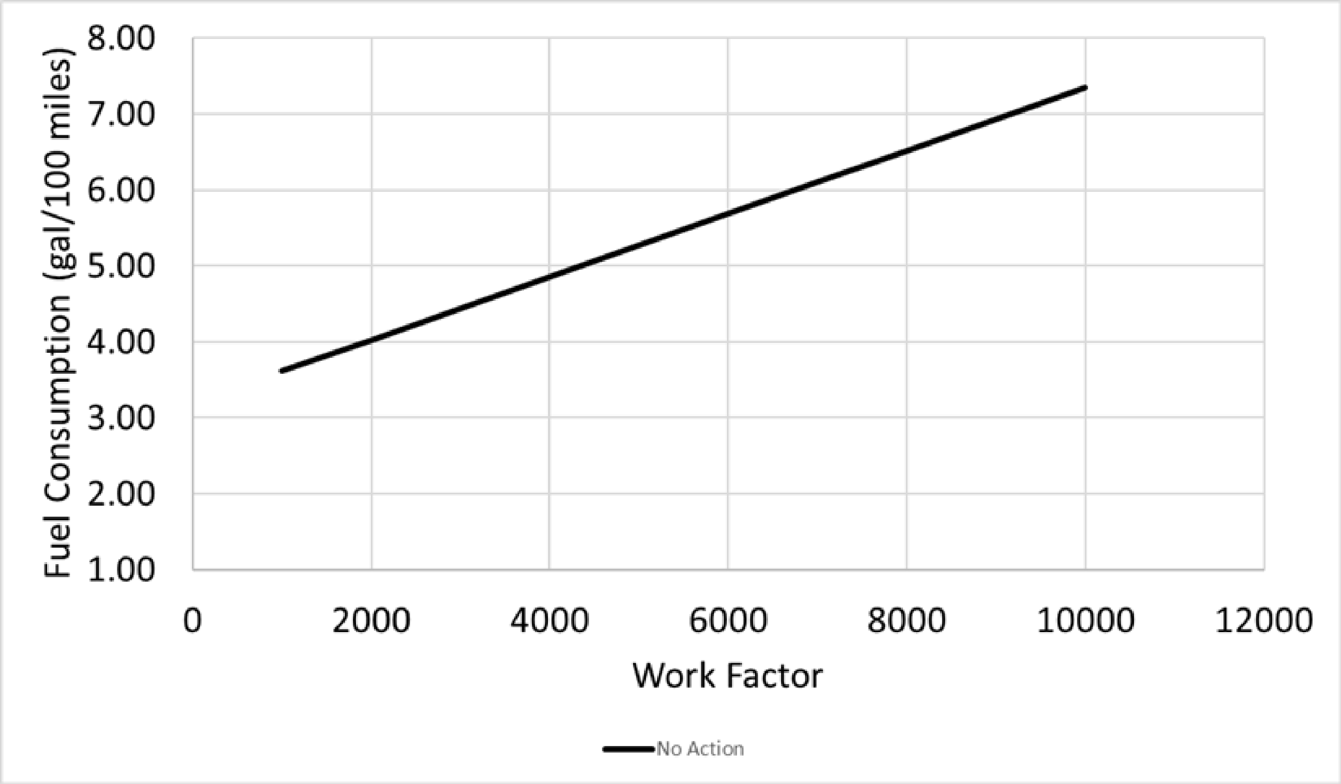


Figure 1-5: No-Action Alternative, HDPUV – SI Vehicles, Target Curves



As the reference baseline scenario, the No-Action Alternative also includes the following other actions that NHTSA believes will occur in the absence of further regulatory action by NHTSA:

To account for the existing national GHG emissions standards, the No-Action Alternative for passenger cars and light trucks includes the following coefficients defining the GHG standards set by EPA in 2022 for model year 2026, which (for purposes of this analysis) are assumed to persist without change in subsequent MYs:

Table 1-10: Passenger Car CO_2 Target Function Coefficients for No-Action Alternative

	2027	2028	2029	2030	2031	2032
a (g/mi)	114.3	114.3	114.3	114.3	114.3	114.3
b (g/mi)	160.9	160.9	160.9	160.9	160.9	160.9
c (g/mi per s.f.)	3.11	3.11	3.11	3.11	3.11	3.11
d (g/mi)	-13.10	-13.10	-13.10	-13.10	-13.10	-13.10
e (s.f.)	41.0	41.0	41.0	41.0	41.0	41.0
f (s.f.)	56.0	56.0	56.0	56.0	56.0	56.0

Table 1-11: Light Truck CO_2 Target Function Coefficients for No-Action Alternative

	2027	2028	2029	2030	2031	2032
a (g/mi)	141.8	141.8	141.8	141.8	141.8	141.8
b (g/mi)	254.4	254.4	254.4	254.4	254.4	254.4
c (g/mi per s.f.)	3.41	3.41	3.41	3.41	3.41	3.41
d (g/mi)	1.90	1.90	1.90	1.90	1.90	1.90
e (s.f.)	41.0	41.0	41.0	41.0	41.0	41.0
f (s.f.)	74.0	74.0	74.0	74.0	74.0	74.0

Coefficients *a*, *b*, *c*, *d*, *e*, and *f* define the existing model year 2026 federal CO_2 standards for passenger cars and light trucks, respectively, in Table 1-10 and Table 1-11 above. Analogous to coefficients defining CAFE standards, coefficients *a* and *b* specify minimum and maximum CO_2 targets in each model year. Coefficients *c* and *d* specify the slope and intercept of the linear portion of the CO_2 target function, and coefficients *e* and *f* bound the region within which CO_2 targets are defined by this linear form.

To account for the 2016 NHTSA/EPA Phase 2 national CO_2 emission standards, the No-Action Alternative for HDPUVs include the following coefficients defining the WF based standards set by EPA for the model year 2027 and beyond. The four-wheel drive coefficient is maintained at 500 (coefficient 'a') and the weighting multiplier coefficient is maintained at 0.75 (coefficient 'b'). The CI and SI coefficients are in the tables below:

Table 1-12: HDPUV CI Vehicle CO_2 Target Function Coefficients for No-Action Alternative

	2027 and Later
e	0.0348
f	268

Table 1-13: HDPUV SI CO_2 Vehicle Target Function Coefficients for No-Action Alternative

	2027 and Later
c	0.0369
d	284

Coefficients c, d, e, and f define the existing model year 2027 and beyond CO_2 standards from the Phase 2 final rule for HDPUVs, in Table 1-12 and Table 1-13 above. The coefficients define a linear work-factor based function with c and d representing gasoline, CNG vehicles, strong hybrid electric vehicles (SHEVs), and PHEVs and e and f representing diesels, BEVS and fuel cell electric vehicles (FCEV)s. For this rule, this is identical to the NHTSA's fuel efficiency standards No-Action Alternative.

The No-Action Alternative also includes NHTSA's estimates of ways that each manufacturer could introduce new PHEVs and BEVs in response to state ZEV programs.[61] Vehicle manufacturers told NHTSA, in CBI conversations regarding planned vehicle product and technology investments, that they are complying with and plan to comply in the future with ZEV programs. These conversations were later confirmed by manufacturers' public announcements, which are discussed in more detail in preamble Section IV. Therefore, NHTSA has included in the main provisions of the ACC and ACT programs in the CAFE Models' analysis of compliance pathways. Incorporating these programs into the model includes converting vehicles that have been identified as potential ZEV candidates into BEVs so that a manufacturer's fleet meets the calculated ZEV credit requirements. The CAFE Model brings manufacturers into compliance with ACC and ACT and their deployment commitments consistent with ACC II's targets first in the reference baseline, then solves for the technology compliance pathway used to meet increasing ZEV standards described by the state programs. The two programs have different requirements per model year, so they are modeled separately in the CAFE analysis. Chapter 2 below discusses, in detail, how NHTSA developed these estimates.

The No-Action Alternative also includes NHTSA's estimates of ways that manufacturers could take advantage of recently-passed tax credits for battery-based vehicle technologies. NHTSA explicitly models portions of three provisions of the IRA when simulating the behavior of manufacturers and consumers. The first is the Advanced Manufacturing Production Tax Credit (AMPC). The AMPC also includes a credit for the production of applicable critical minerals. This provision of the IRA provides a $35 per kWh tax credit for manufacturers of battery cells and an additional $10 per kWh for manufacturers of battery modules (all applicable to manufacture in the United States).[62] These credits, with the exception of the critical minerals credit, phase out from 2030 to 2032. The agency also jointly modeled the Clean Vehicle Credit (CVC),[63] which provides up to $7,500 toward the purchase of clean vehicles.[64] The AMPC and CVC provide tax credits for light-duty and HDPUV PHEVs, BEVS, and FCEVs. Chapter 2.2 below discusses, in detail, how NHTSA has modeled these tax credits.

The No-Action Alternative for the passenger car, light truck and HDPUV fleets also includes NHTSA's assumption, for purposes of compliance simulations, that manufacturers will add fuel economy- or fuel efficiency-improving technology voluntarily, if the value of future undiscounted fuel savings fully offsets the cost of the technology within 30 months. This assumption is often called the "30-month payback" assumption, and NHTSA has used it for many years and in many CAFE rulemakings.[65] It is used to represent consumer demand for fuel economy. It can be a source of apparent "over-compliance" in the No-Action Alternative, especially when technology is estimated to be extremely cost-effective, as occurs later in the analysis time frame when learning has significant effects on some technology costs.

NHTSA has determined that manufacturers do improve fuel economy even in the absence of new standards, for several reasons. First, overcompliance is not uncommon in the historical data, both in the absence of new standards, and with new standards – NHTSA's analysis in the 2022 TSD included CAFE compliance data

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[61] NHTSA interprets EPCA/EISA as allowing consideration of BEVs and PHEVs built in response to state ZEV programs as part of the analytical reference baseline because (1) 49 U.S.C. 32902(h) clearly applies to the "maximum feasible" determination, which is a determination *between* regulatory alternatives, and the reference baseline is simply the backdrop against which that determination is made, and (2) NHTSA continues to believe that it is arbitrary to interpret 32902(h) as requiring NHTSA to pretend that BEVs and PHEVs clearly built for non-CAFE-compliance reasons do not exist, because doing so would be unrealistic and would bias NHTSA's analytical results by inaccurately attributing costs and benefits to future potential CAFE standards that will not accrue as a result of those standards in real life.

[62] 26 U.S.C. 45X. If a manufacturer produces a battery module without battery cells, they are eligible to claim up to $45 per kWh for the battery module. The provision includes other provisions related to vehicles such as a credit equal to 10 percent of the manufacturing cost of electrode active materials, and another 10 percent for the manufacturing cost of critical minerals. We are not modeling these credits directly because of how we estimate battery costs and to avoid the potential to double count the tax credits if they are included into other analyses that feed into our inputs.

[63] 26 U.S.C. 30D.

[64] There are vehicle price and consumer income limitations on the CVC as well. Congressional Research Service. 2022. Tax Provisions in the Inflation Reduction Act of 2022 (H.R. 5376). Available at: https://crsreports.congress.gov/product/pdf/R/R47202/6. (Accessed: Feb. 7, 2024).

[65] Even though NHTSA uses the 30-month payback assumption to assess how much technology manufacturers would add voluntarily in the absence of new standards, the benefit-cost analysis accounts for the full lifetime fuel savings that would accrue to vehicles affected by the final standards.

showing that from 2004-2017, while not all manufacturers consistently over-complied, a number did. Of the manufacturers who did over-comply, some did so by 20 percent or more, in some fleets, over multiple model years.[66] Ordinary market forces can produce significant increases in fuel economy, either because of consumer demand or because of technological advances.

Second, manufacturers have consistently told NHTSA that they do make fuel economy improvements where the cost can be fully recovered by consumers in the first 2-3 years of ownership. The 2015 NAS report discussed this assumption explicitly, stating: "There is also empirical evidence supporting loss aversion as a possible cause of the energy paradox. Greene (2011) showed that if consumers accurately perceived the upfront cost of fuel economy improvements and the uncertainty of fuel economy estimates, the future price of fuel, and other factors affecting the present value of fuel savings, the loss-averse consumers among them would appear to act as if they had very high discount rates or required payback periods of about 3 years."[67] Furthermore, the 2020 NAS heavy-duty report states: "The committee has heard from manufacturers and purchasers that they look for 1.5- to 2-year paybacks or, in other cases, for a payback period that is half the expected ownership period of the first owner of the vehicle."[68] Naturally, there are heterogenous preferences for vehicle attributes in the marketplace, – at the same time that we are observing record sales of electrified vehicles, we are also seeing sustained demand for pickup trucks with higher payloads and towing capacity and hence lower fuel economy. This analysis, like all the CAFE analyses preceding it, uses an average value to represent these preferences for the CAFE fleet and the HDPUV fleet. The analysis balances the risks of estimating too low of a payback period, which would preclude most technologies from consideration regardless of potential cost reductions due to learning, against the risk of allowing too high of a payback period, which would allow an unrealistic cost increase from technology addition in the reference baseline fleet.

Third, as in previous CAFE analyses, our fuel price projections assume sustained increases in real fuel prices over the course of the rule (and beyond). As readers are certainly aware, fuel prices have changed over time – sometimes quickly, sometimes slowly, but generally over time upward:

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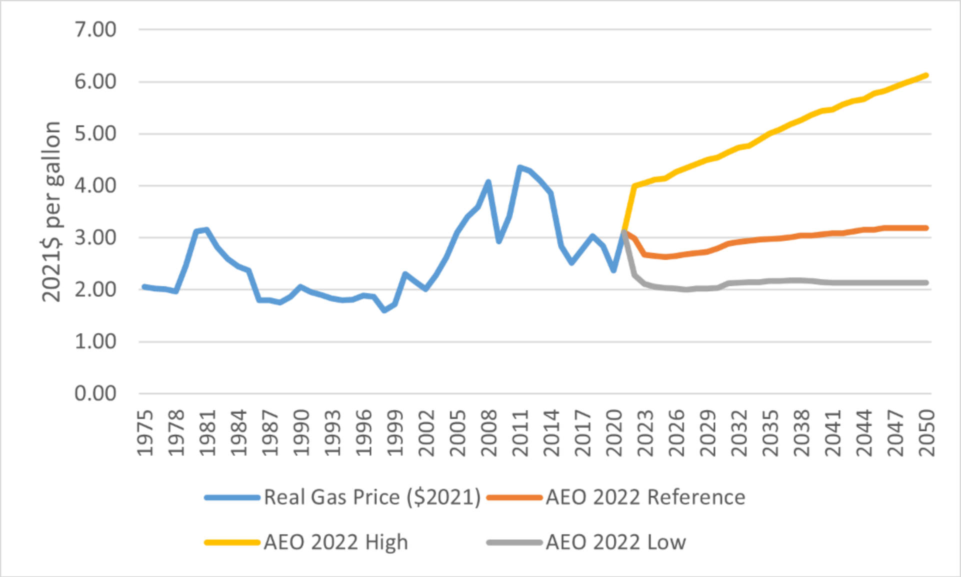
[66] See 2022 TSD, at 68.

[67] National Research Council. 2015. Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles. Washington, D.C: *The National Academies Press.* p. 31. Available at: https://nap.nationalacademies.org/catalog/21744/cost-effectiveness-and-deployment-of-fuel-economy-technologies-for-light-duty-vehicles. (Accessed: Feb. 7, 2024). (hereinafter, "2015 NAS report").

[68] National Academies of Sciences, Engineering, and Medicine. 2020. Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report. Washington, D.C: *The National Academies Press*. p. 296. Available at: https://nap.nationalacademies.org/catalog/25542/reducing-fuel-consumption-and-greenhouse-gas-emissions-of-medium-and-heavy-duty-vehicles-phase-two. (Accessed: Feb 7, 2024).

Figure 1-6: Real Fuel Prices Over Time



In the 1990s, when fuel prices were historically low (as shown above), manufacturers did not tend to improve their fuel economy, likely because there simply was very little consumer demand for improved fuel economy and CAFE standards remained flat. In subsequent decades, when fuel prices were higher, many of them have exceeded their standards in multiple fleets, and for multiple years. Our current fuel price projections look more like the last two decades, where prices have been more volatile, but also closer to $3/gallon on average. In recent years, when fuel prices have generally declined on average and CAFE standards have continued to increase, fewer manufacturers have exceeded their standards. However, our compliance data show that at least some manufacturers do improve their fuel economy if fuel prices are high enough, even if they are not able to respond perfectly to fluctuations precisely when they happen. This highlights the importance of fuel price assumptions both in the analysis and in the real world on the future of fuel economy improvements.

1.4.2. Alternative Baseline/No-Action Alternative

In addition to the reference baseline for the passenger car and light truck fleet analysis, NHTSA considered an alternative baseline analysis. This alternative baseline analysis for the passenger car and light truck fleets was performed to provide a greater level of insight into the possibilities of a changing baseline landscape. The Alternative Baseline analysis is not meant to be a replacement for the reference analysis, but a secondary review of the NHTSA analysis with all of the assumptions from the reference baseline held (see Paragraph 1.4.1 above), except for the assumption of compliance with CARB ZEV policies. The alternative baseline does not assume manufacturers will consider or preemptively react to any of the California light duty ZEV policies either during any of the model years simulated in the analysis, regardless of whether it becomes a legally binding program.

1.4.3. Action Alternatives for Passenger Cars, Light Trucks, and HDPUVs

In addition to the No-Action Alternatives, NHTSA has considered five “action” alternatives for passenger cars and light trucks and four action alternatives for HDPUVs, each of which is more stringent than the No-Action Alternative during the rulemaking time frame. These action alternatives are specified below and demonstrate different possible approaches to balancing the statutory factors applicable for passenger cars, light trucks, and HDPUVs. Section VI of the final rule preamble discusses in more detail how the different alternatives reflect different possible balancing approaches.

1.4.3.1. Alternative PC1LT3

Alternative PC1LT3 would increase CAFE stringency by 1 percent per year, year over year for model years 2027-2032 passenger cars, and by 3 percent per year, year over year for model years 2027-2032 light trucks.

Table 1-14: Passenger Car CAFE Target Function Coefficients for Alternative PC1LT3[69]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	67.63	68.31	69.00	69.70	70.40	71.11
b (mpg)	50.60	51.11	51.63	52.15	52.68	53.21
c (gpm per s.f.)	0.00033176	0.00032845	0.00032516	0.00032191	0.00031869	0.00031550
d (gpm)	0.00118417	0.00117232	0.00116060	0.00114900	0.00113751	0.00112613

Table 1-15: Light Truck CAFE Target Function Coefficients for Alternative PC1LT3[70]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	55.39	57.10	58.87	60.69	62.56	64.50
b (mpg)	33.30	34.33	35.39	36.48	37.61	38.78
c (gpm per s.f.)	0.00036296	0.00035207	0.00034151	0.00033126	0.00032132	0.00031168
d (gpm)	0.00317343	0.00307823	0.00298588	0.00289630	0.00280941	0.00272513

These equations are represented graphically below:

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[69] The Function Coefficients ‘a’,’b’,’c’, and ‘d’ are defined in Equation 1-1 of Chapter 1.2.1.

[70] The Function Coefficients ‘a’,’b’,’c’, and ‘d’ are defined in Equation 1-1 of Chapter 1.2.1.

Figure 1-7: Alternative PC1LT3, Passenger Car Fuel Economy, Target Curves

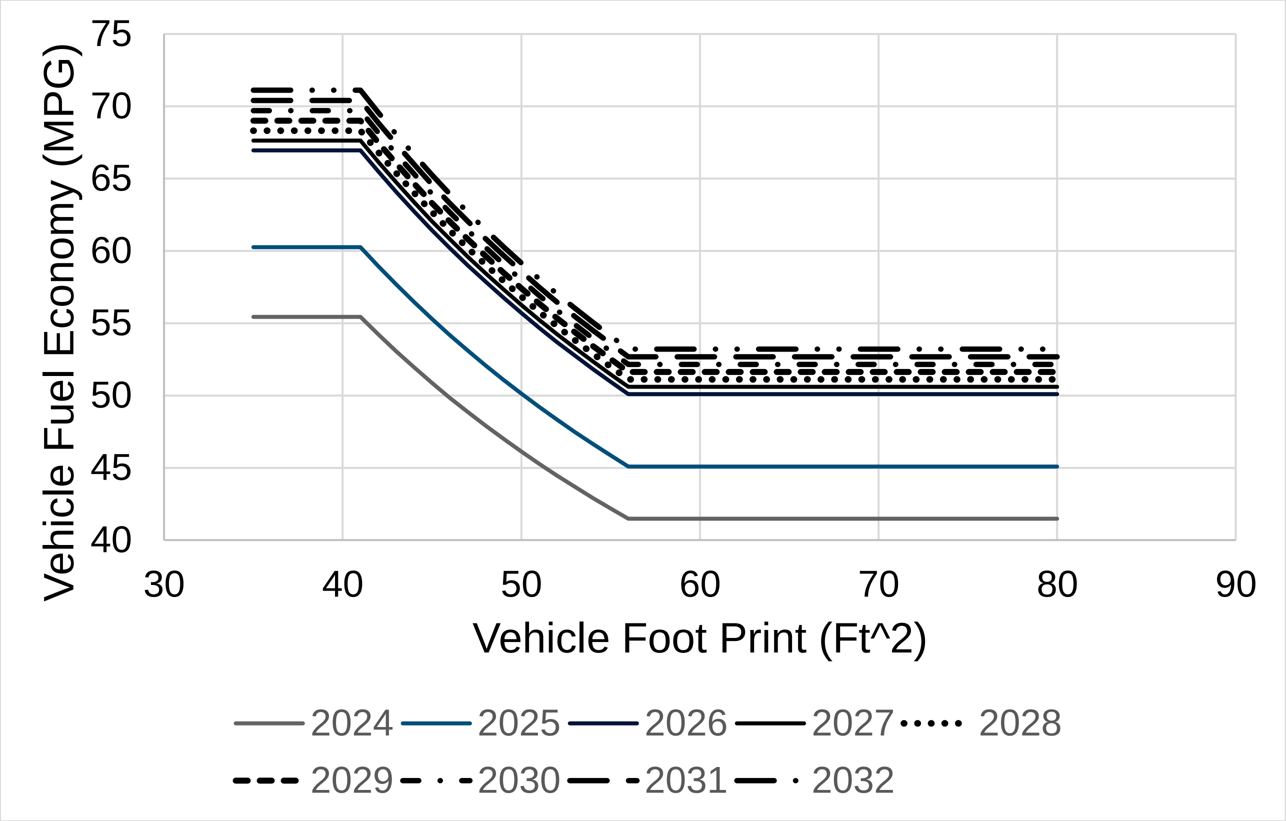
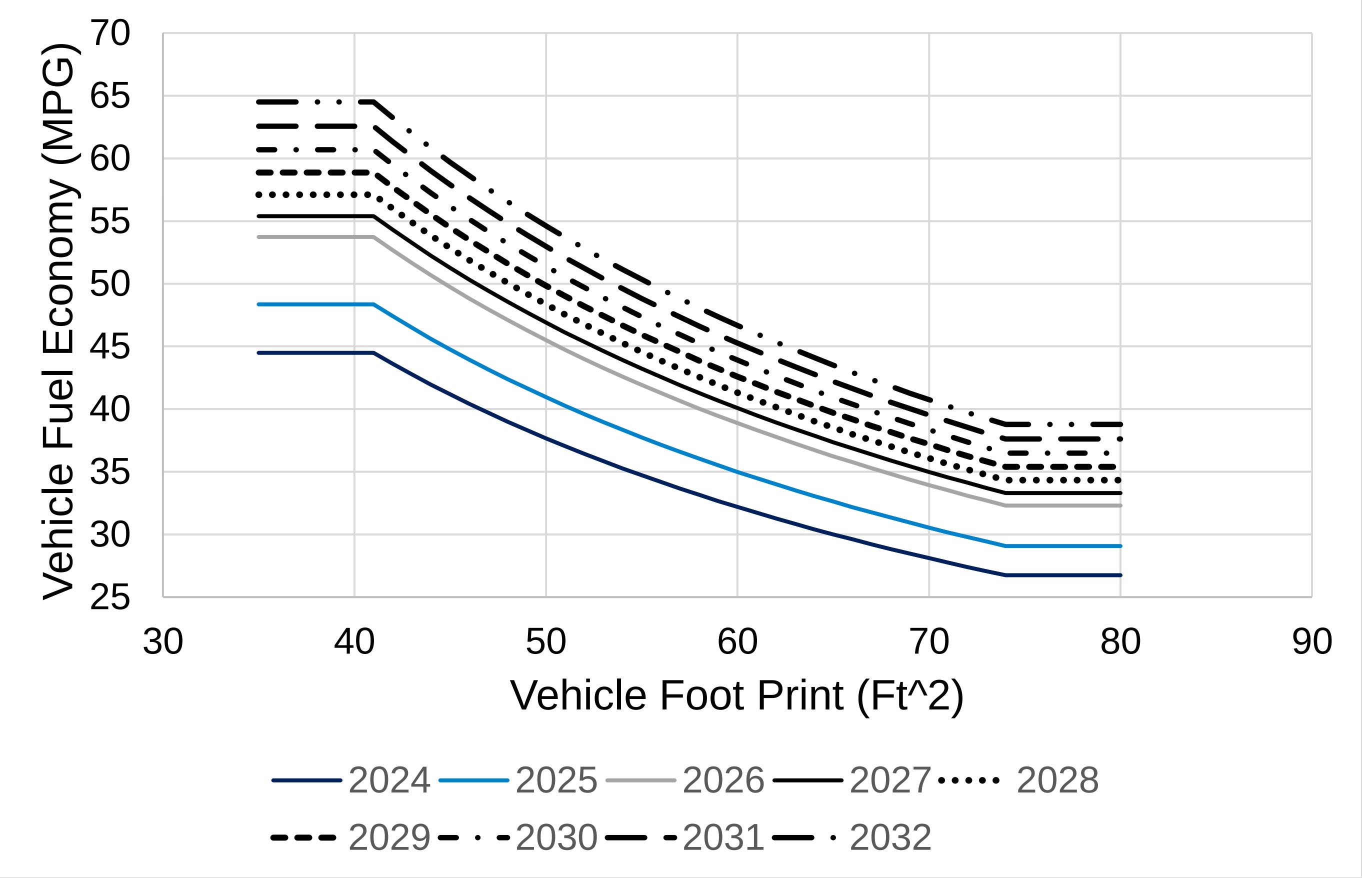


Figure 1-8: Alternative PC1LT3, Light Truck Fuel Economy, Target Curves



Under this alternative, the MDPCS is as follows:

Table 1-16: Alternative PC1LT3 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
54.6	55.2	55.7	56.3	56.9	57.4

1.4.3.2. Alternative PC2LT002 – Preferred Alternative

Alternative PC2LT002 would increase CAFE stringency by 2 percent per year, year over year for model years 2027-2032 passenger cars, and by 0 percent per year, year over year for model years 2027-2028 light trucks and then 2 percent per year, year over year for model years 2029-2032 light trucks.

Table 1-17: Passenger Car CAFE Target Function Coefficients for Alternative PC2LT002

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	68.32	69.71	71.14	72.59	74.07	75.58
b (mpg)	51.12	52.16	53.22	54.31	55.42	56.55
c (gpm per s.f.)	0.00032841	0.00032184	0.00031541	0.00030910	0.00030292	0.00029686
d (gpm)	0.00117220	0.00114876	0.00112579	0.00110327	0.00108120	0.00105958

Table 1-18: Light Truck CAFE Target Function Coefficients for Alternative PC2LT002

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	53.73	53.73	54.82	55.94	57.08	58.25
b (mpg)	32.30	32.30	32.96	33.63	34.32	35.02
c (gpm per s.f.)	0.00037418	0.00037418	0.00036670	0.00035936	0.00035218	0.00034513
d (gpm)	0.00327158	0.00327158	0.00320615	0.00314202	0.00307918	0.00301760

Table 1-19: Alternative PC2LT002 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
55.2	56.3	57.5	58.6	59.8	61.1

Figure 1-9: Alternative PC2LT002, Passenger Car Fuel Economy, Target Curves

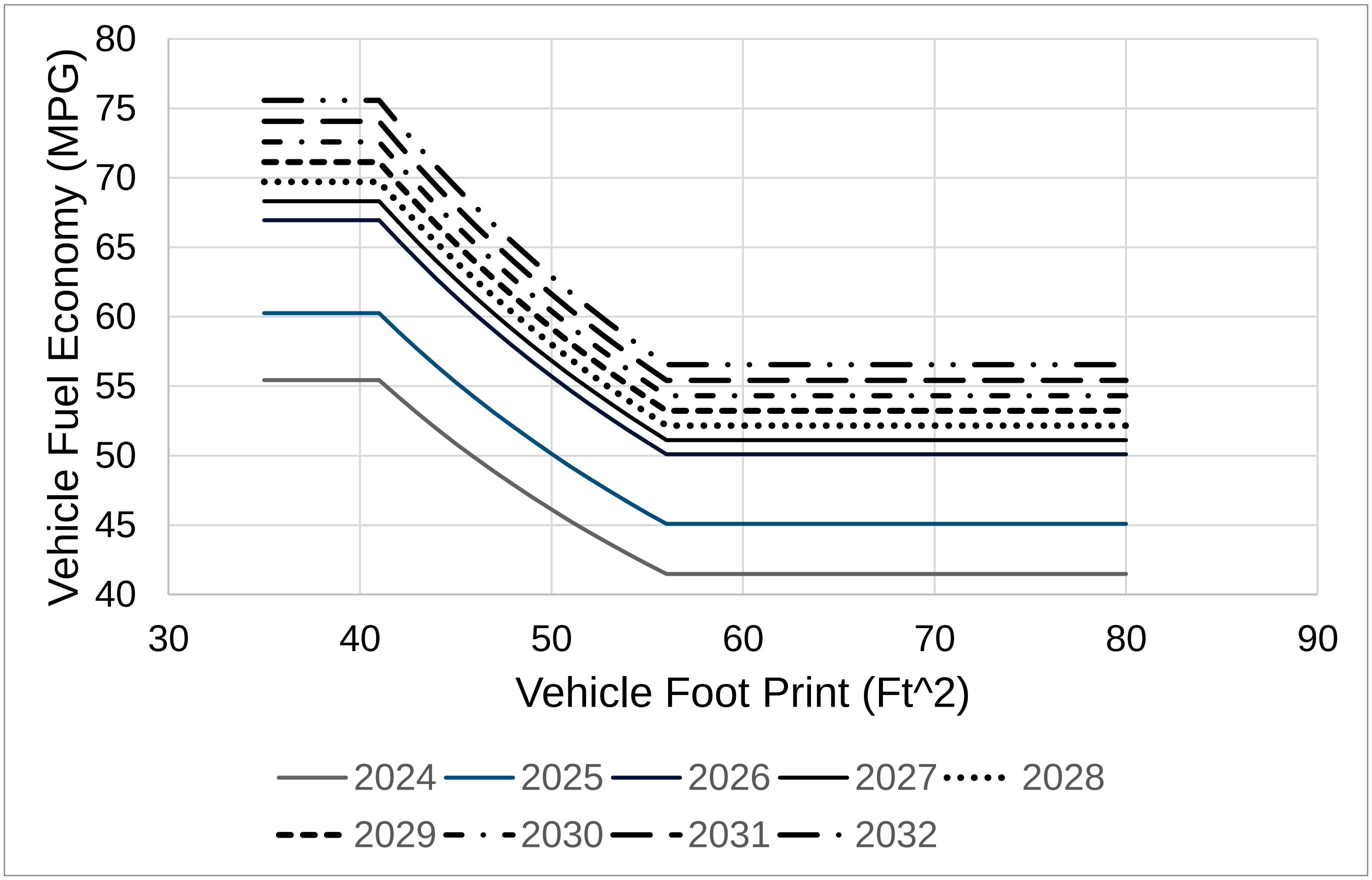
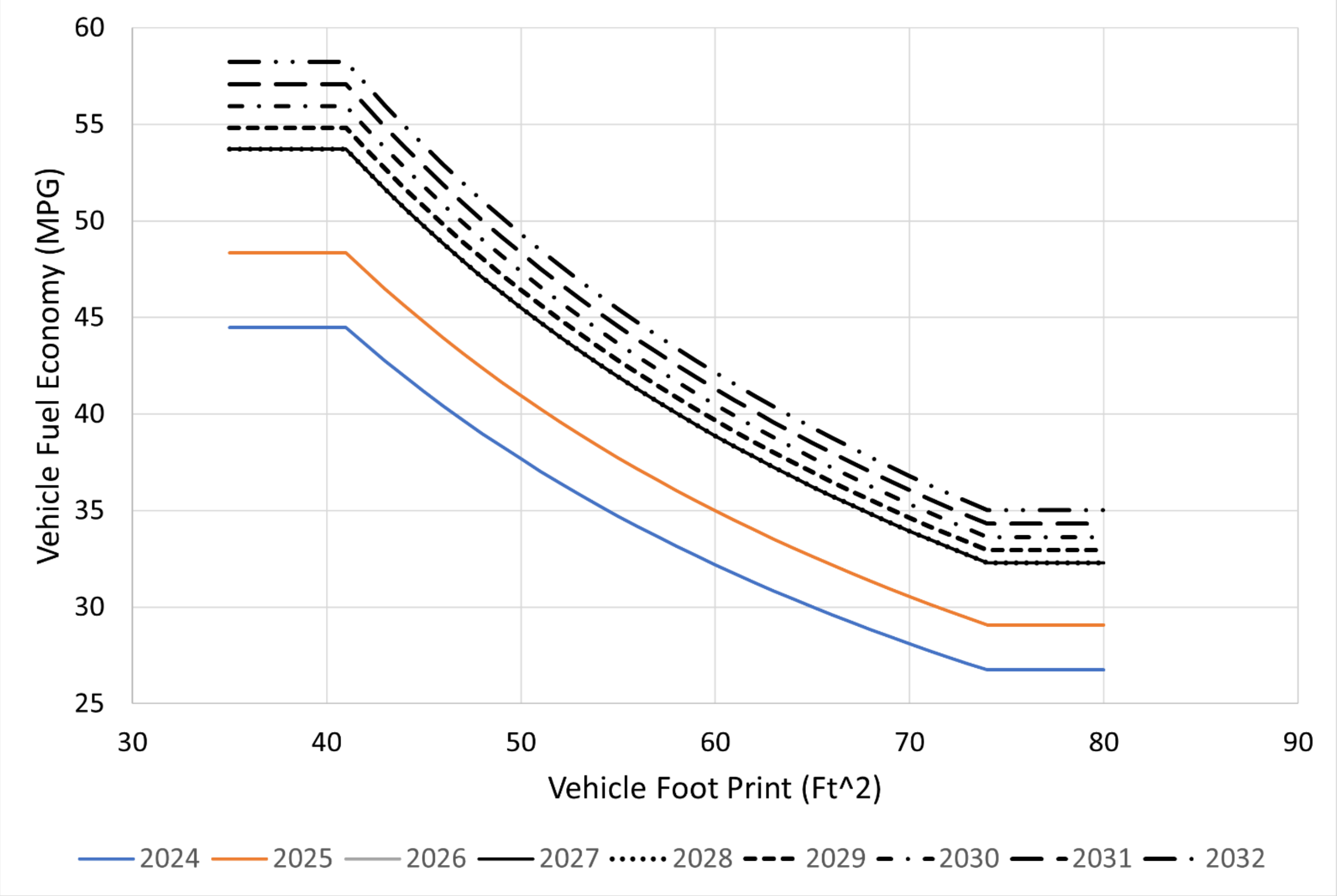


Figure 1-10: Alternative PC2LT002, Light Truck Fuel Economy, Target Curves[71]



1.4.3.3. Alternative PC2LT4

Alternative PC2LT4 would increase CAFE stringency by 2 percent per year, year over year for model years 2027-2032 passenger cars, and by 4 percent per year, year over year for model years 2027-2032 light trucks.

Table 1-20: Passenger Car CAFE Target Function Coefficients for Alternative PC2LT4[72]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	68.32	69.71	71.14	72.59	74.07	75.58
b (mpg)	51.12	52.16	53.22	54.31	55.42	56.55
c (gpm per s.f.)	0.00032841	0.00032184	0.00031541	0.00030910	0.00030292	0.00029686
d (gpm)	0.00117220	0.00114876	0.00112579	0.00110327	0.00108120	0.00105958

Table 1-21: Light Truck CAFE Target Function Coefficients for Alternative PC2LT4[73]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	55.96	58.30	60.73	63.26	65.89	68.64

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[71] This figure has MYs 2026,2027, and 2028 standards overlaid

[72] The Function Coefficients ‘a’,’b’,’c’, and ‘d’ are defined in Equation 1-1 of Chapter 1.2.1.

[73] The Function Coefficients ‘a’,’b’,’c’, and ‘d’ are defined in Equation 1-1 of Chapter 1.2.1.

b (mpg)	33.64	35.05	36.51	38.03	39.61	41.26
c (gpm per s.f.)	0.00035921	0.00034485	0.00033105	0.00031781	0.00030510	0.00029289
d (gpm)	0.00314071	0.00301509	0.00289448	0.00277870	0.00266755	0.00256085

These equations are represented graphically below:

Figure 1-11: Alternative PC2LT4, Passenger Car Fuel Economy, Target Curves

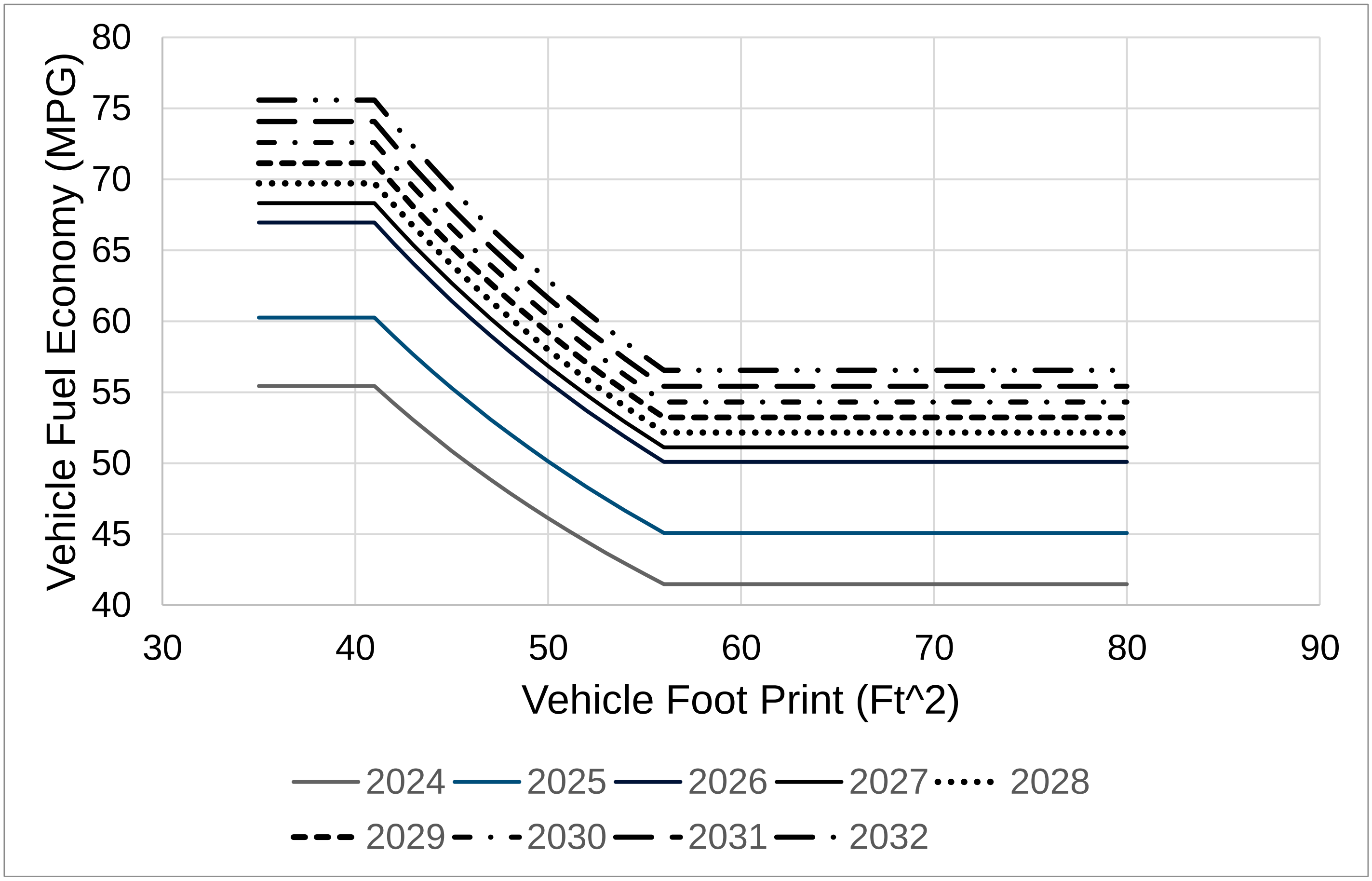
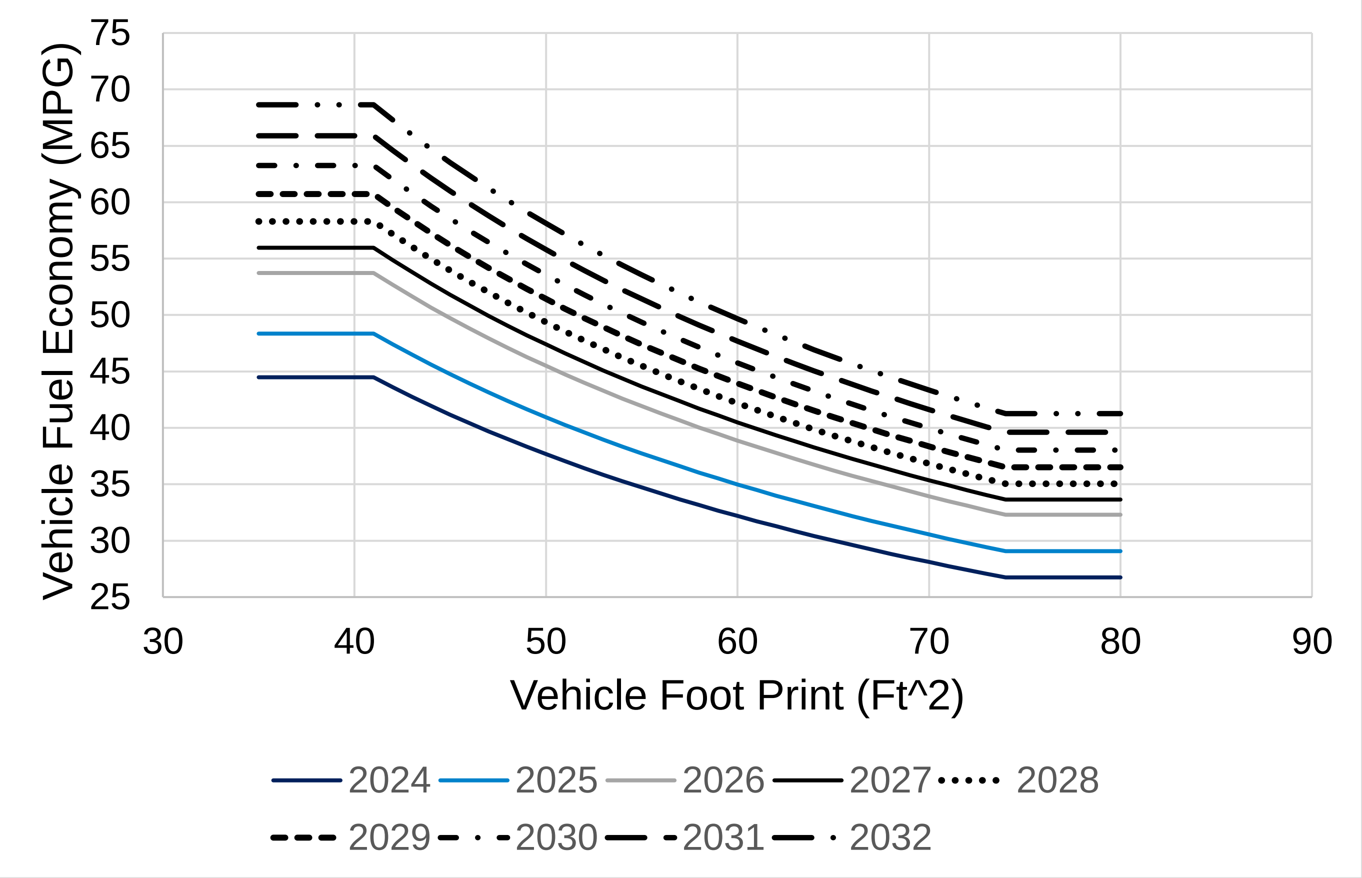


Figure 1-12: Alternative PC2LT4, Light Truck Fuel Economy, Target Curves



Under this alternative, the MDPCS is as follows:

Table 1-22: Alternative PC2LT4 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
55.2	56.3	57.5	58.6	59.8	61.1

1.4.3.4. Alternative PC3LT5

Alternative PC3LT5 would increase CAFE stringency by 3 percent per year, year over year for model years 2027-2032 passenger cars, and by 5 percent per year, year over year for model years 2027-2032 light trucks.

Table 1-23: Passenger Car CAFE Target Function Coefficients for Alternative PC3LT5[74]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	69.02	71.16	73.36	75.63	77.97	80.38
b (mpg)	51.64	53.24	54.89	56.58	58.33	60.14
c (gpm per s.f.)	0.00032506	0.00031531	0.00030585	0.00029668	0.00028777	0.00027914
d (gpm)	0.00116024	0.00112544	0.00109167	0.00105892	0.00102716	0.00099634

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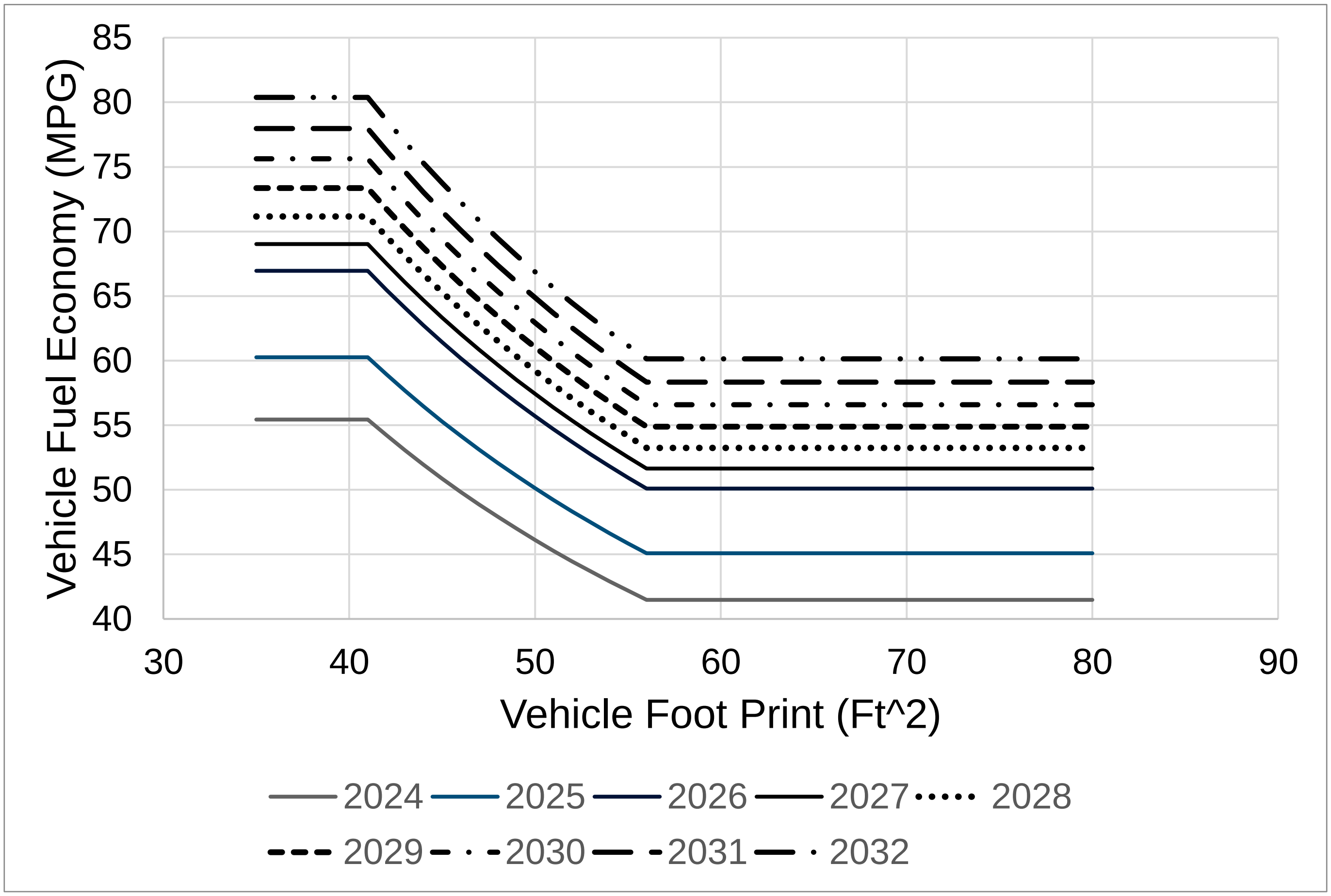
[74] The Function Coefficients ‘a’,’b’,’c’, and ‘d’ are defined in Equation 1-1 of Chapter 1.2.1.

Table 1-24: Light Truck CAFE Target Function Coefficients for Alternative PC3LT5[75]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	56.55	59.53	62.66	65.96	69.43	73.09
b (mpg)	34.00	35.79	37.67	39.65	41.74	43.94
c (gpm per s.f.)	0.00035547	0.00033770	0.00032081	0.00030477	0.00028954	0.00027506
d (gpm)	0.00310800	0.00295260	0.00280497	0.00266472	0.00253148	0.00240491

These equations are represented graphically below:

Figure 1-13: Alternative PC3LT5, Passenger Car Fuel Economy, Target Curves



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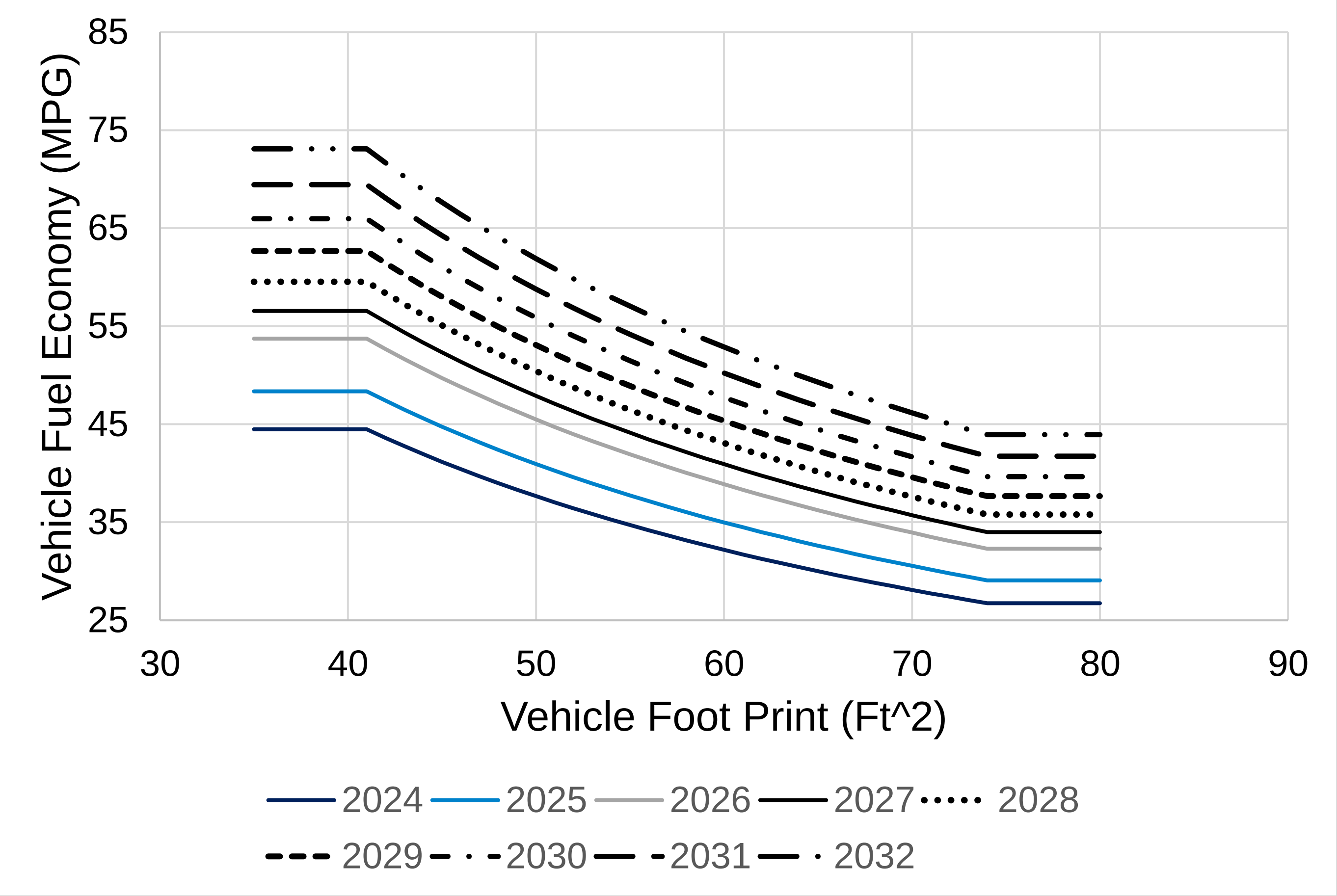
[75] The Function Coefficients 'a','b','c', and 'd' are defined in Equation 1-1 of Chapter 1.2.1.

Figure 1-14: Alternative PC3LT5, Light Truck Fuel Economy, Target Curves



Under this alternative, the MDPCS is as follows:

Table 1-25: Alternative PC3LT5 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
55.8	57.5	59.3	61.1	63.0	64.9

1.4.3.5. Alternative PC6LT8

Alternative PC6LT8 would increase CAFE stringency by 6 percent per year, year over year for model years 2027-2032 passenger cars, and by 8 percent per year, year over year for model years 2027-2032 light trucks.

Table 1-26: Passenger Car CAFE Target Function Coefficients for Alternative PC6LT8[76]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	71.23	75.77	80.61	85.75	91.23	97.05
b (mpg)	53.29	56.69	60.31	64.16	68.26	72.61
c (gpm per s.f.)	0.00031501	0.00029611	0.00027834	0.00026164	0.00024594	0.00023119

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[76] The Function Coefficients 'a','b','c', and 'd' are defined in Equation 1-1 of Chapter 1.2.1.

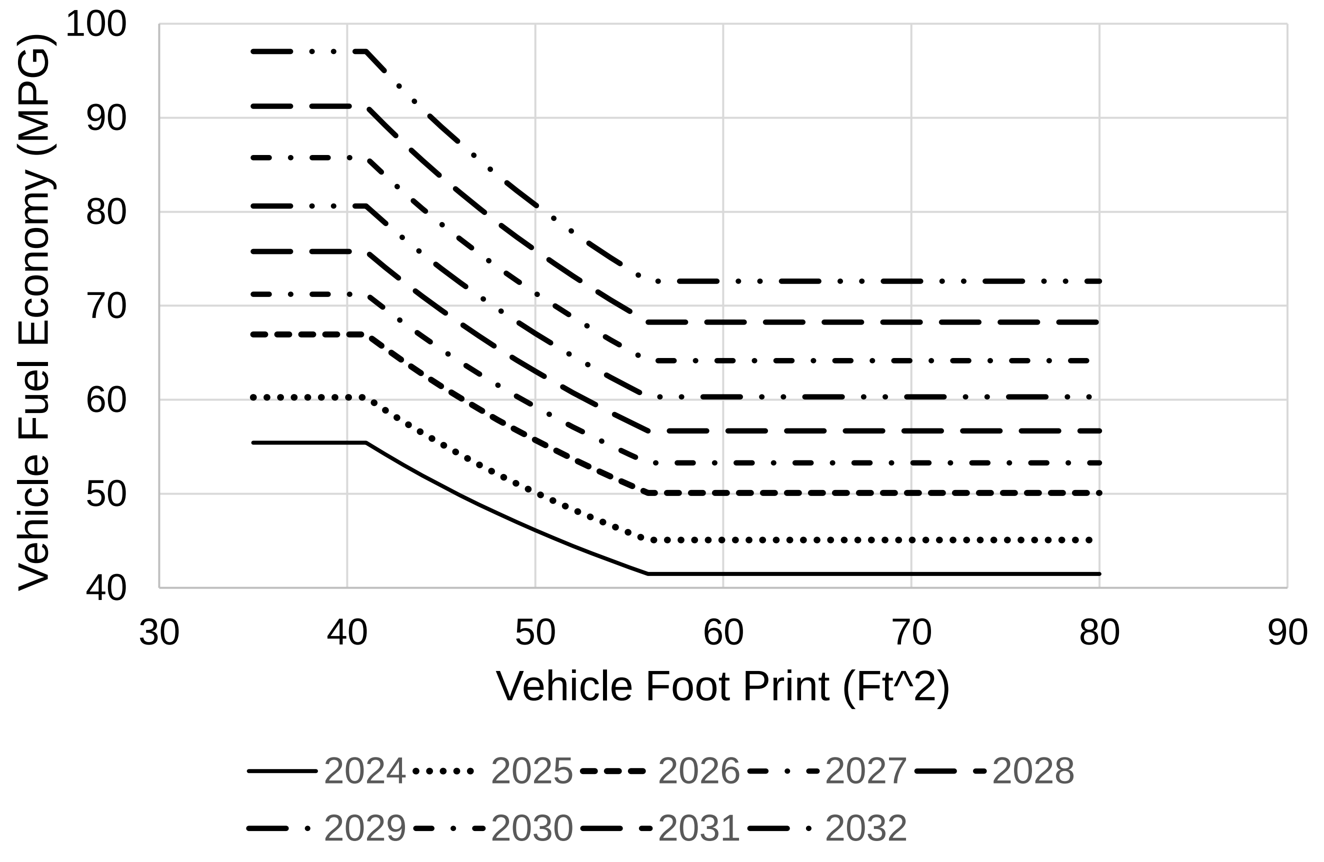
d (gpm)	0.00112436	0.00105690	0.00099348	0.00093388	0.00087784	0.00082517

Table 1-27: Light Truck CAFE Target Function Coefficients for Alternative PC6LT8[77]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	58.40	63.48	69.00	74.99	81.52	88.60
b (mpg)	35.11	38.16	41.48	45.09	49.01	53.27
c (gpm per s.f.)	0.00034425	0.00031671	0.00029137	0.00026806	0.00024662	0.00022689
d (gpm)	0.00300985	0.00276906	0.00254754	0.00234373	0.00215624	0.00198374

These equations are represented graphically below:

Figure 1-15: Alternative PC6LT8, Passenger Car Fuel Economy, Target Curves



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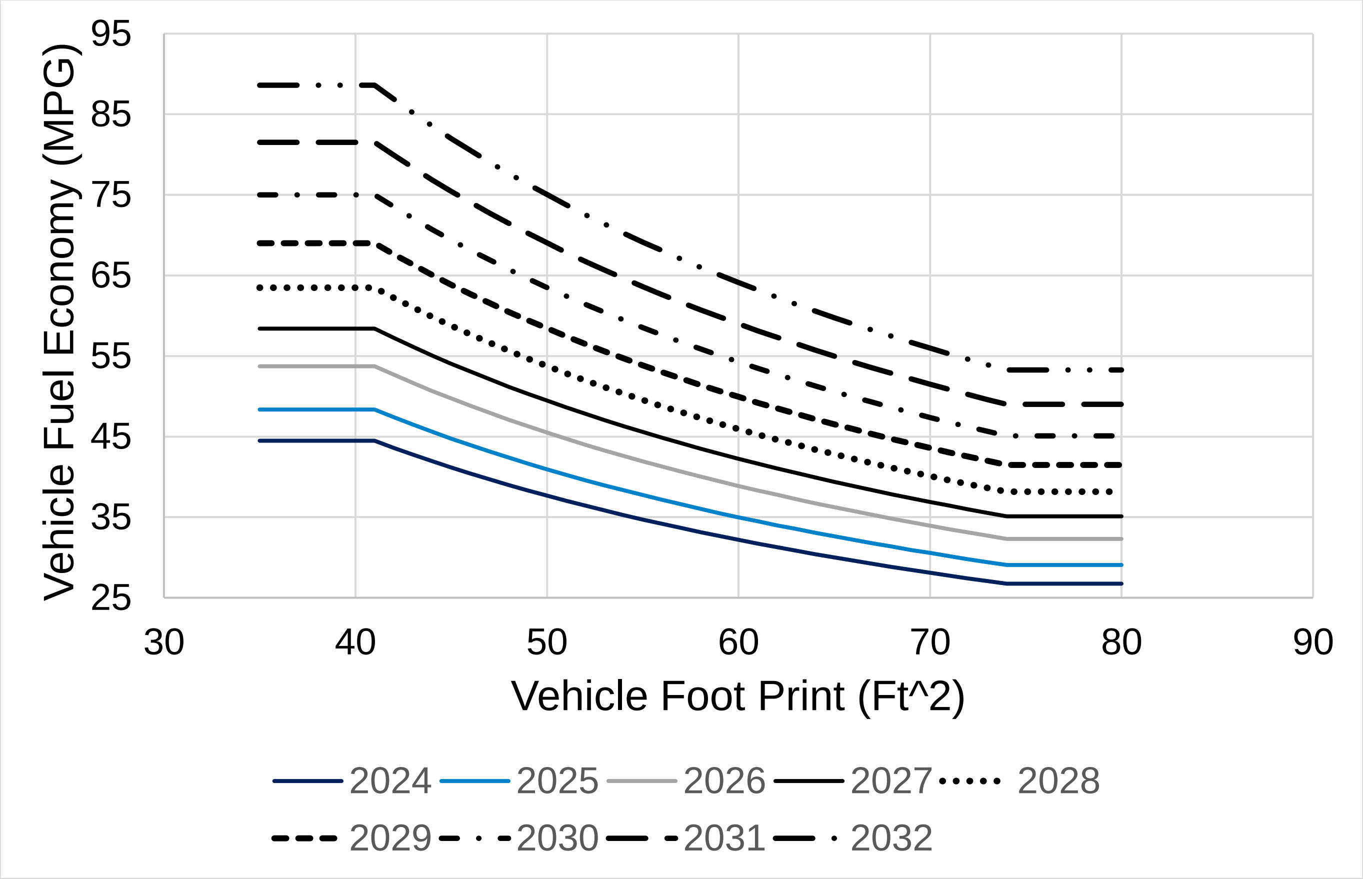
[77] The Function Coefficients ‘a’,’b’,’c’, and ‘d’ are defined in Equation 1-1 of Chapter 1.2.1.

Figure 1-16: Alternative PC6LT8, Light Truck Fuel Economy, Target Curves



Under this alternative, the MDPCS is as follows:

Table 1-28: Alternative PC6LT8 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
57.5	61.2	65.1	69.3	73.7	78.4

1.4.3.6. Alternative HDPUV4

Alternative HDPUV4 would increase HDPUV standard stringency by 4 percent per year for model years 2030-2035 HDPUVs. The four-wheel drive coefficient is maintained at 500 (coefficient ‘a’) and the weighting multiplier coefficient is maintained at 0.75 (coefficient ‘b’).

Table 1-29: Characteristics of Alternative HDPUV4 – CI Vehicle Coefficients[78]

	2030	2031	2032	2033	2034	2035
e	0.00032813	0.00031500	0.00030240	0.00029031	0.00027869	0.00026755
f	2.528	2.427	2.330	2.236	2.147	2.061

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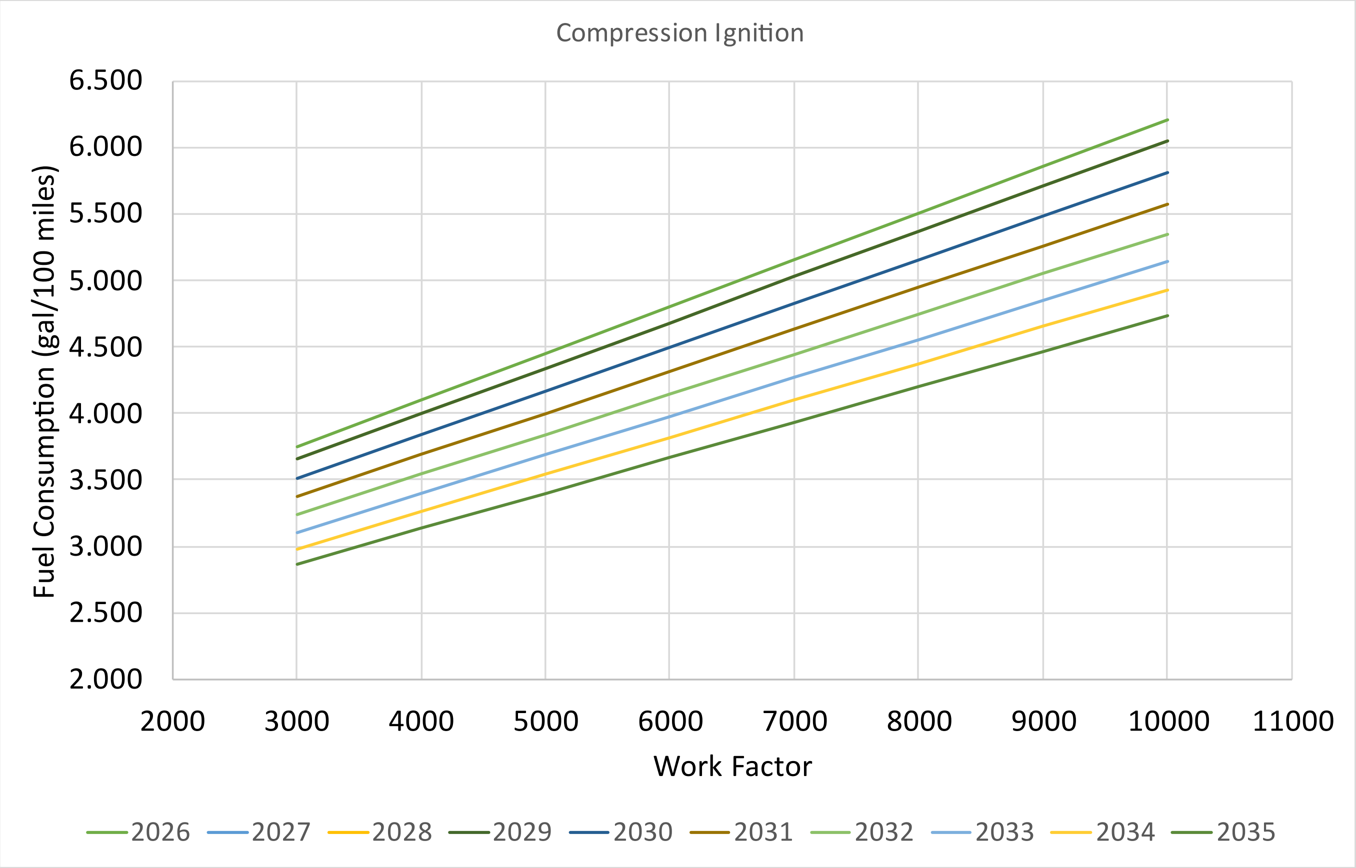
[78] In the CAFE Model, these are Linear work-factor-based function where coefficients e and f are for diesels, BEVs and FCEVs. See Equation 1-3 in Chapter 1.2.1.

Table 1-30: Characteristics of Alternative HDPUV4 – SI Vehicle Coefficients[79]

	2030	2031	2032	2033	2034	2035
c	0.00039859	0.00038265	0.00036734	0.00035265	0.00033854	0.00032500
d	3.068	2.945	2.828	2.715	2.606	2.502

These equations are represented graphically below:

Figure 1-17: Alternative HDPUV4, HDPUV Fuel Efficiency – CI Vehicles, Target Curves



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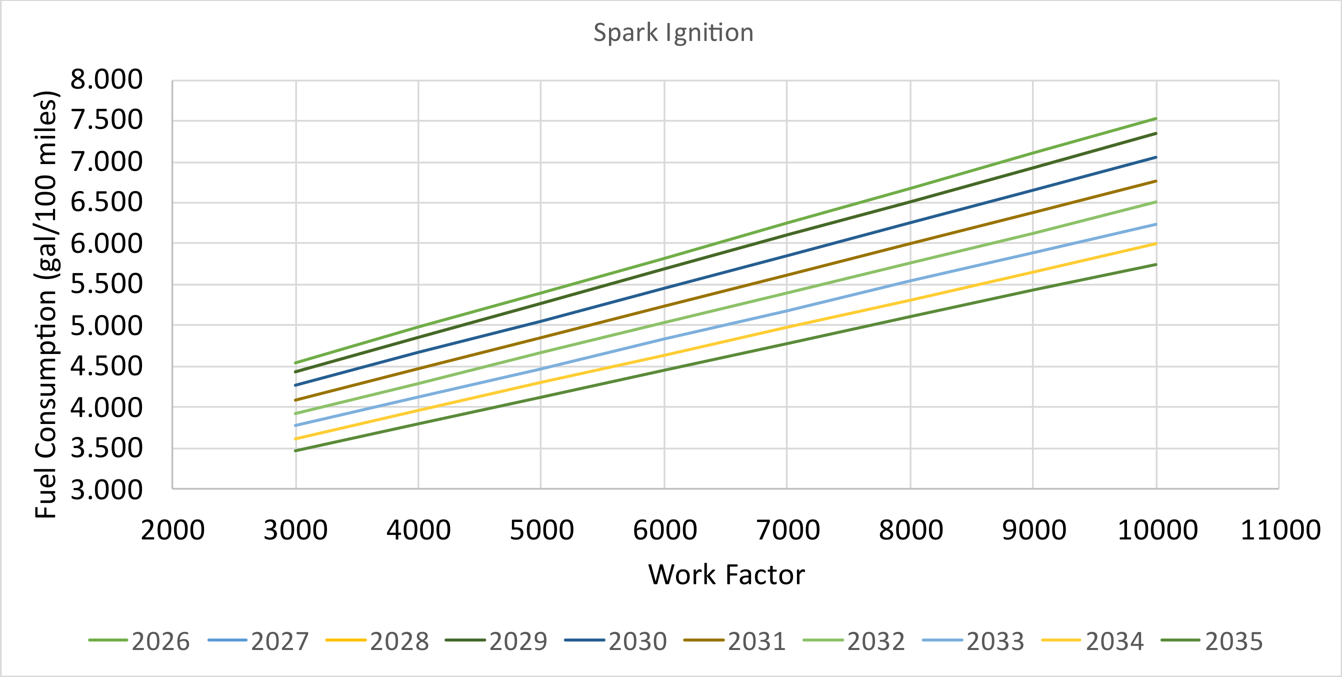
[79] In the CAFE Model, these are Linear work-factor-based function where coefficients c and d are for gasoline, CNG, strong hybrid vehicles and PHEVs. See Equation 1-3 in Chapter 1.2.1.

Figure 1-18: Alternative HDPUV4, HDPUV Fuel Efficiency – SI Vehicles, Target Curves



1.4.3.7. Alternative HDPUV108 – Preferred Alternative

Alternative HDPUV108 would increase HDPUV standard stringency by 10 percent per year, year over year for model years 2030-2032, and by 8 percent per year, year over year for model years 2033-2035 HDPUVs. The four-wheel drive coefficient is maintained at 500 (coefficient ‘a’) and the weighting multiplier coefficient is maintained at 0.75 (coefficient ‘b’).

Table 1-31: Characteristics of Alternative HDPUV108 – CI Vehicle Coefficients[80]

	2030	2031	2032	2033	2034	2035
e	0.00030762	0.00027686	0.00024917	0.00022924	0.00021090	0.00019403
f	2.370	2.133	1.919	1.766	1.625	1.495

Table 1-32: Characteristics of Alternative HDPUV108 – SI Vehicle Coefficients[81]

	2030	2031	2032	2033	2034	2035
c	0.00037368	0.00033631	0.00030268	0.00027847	0.00025619	0.00023569
d	2.876	2.589	2.330	2.143	1.972	1.814

---

[80] In the CAFE Model, these are linear work-factor-based functions where coefficients e and f are for diesels, BEVs and FCEVs. See Equation 1-3 in Chapter 1.2.1.

[81] In the CAFE Model, these are linear work-factor-based functions where coefficients c and d are for gasoline, CNG, strong hybrid vehicles and PHEVs. See Equation 1-3 in Chapter 1.2.1.

Figure 1-19: Alternative HDPUV108, HDPUV Fuel Efficiency – CI Vehicles, Target Curves

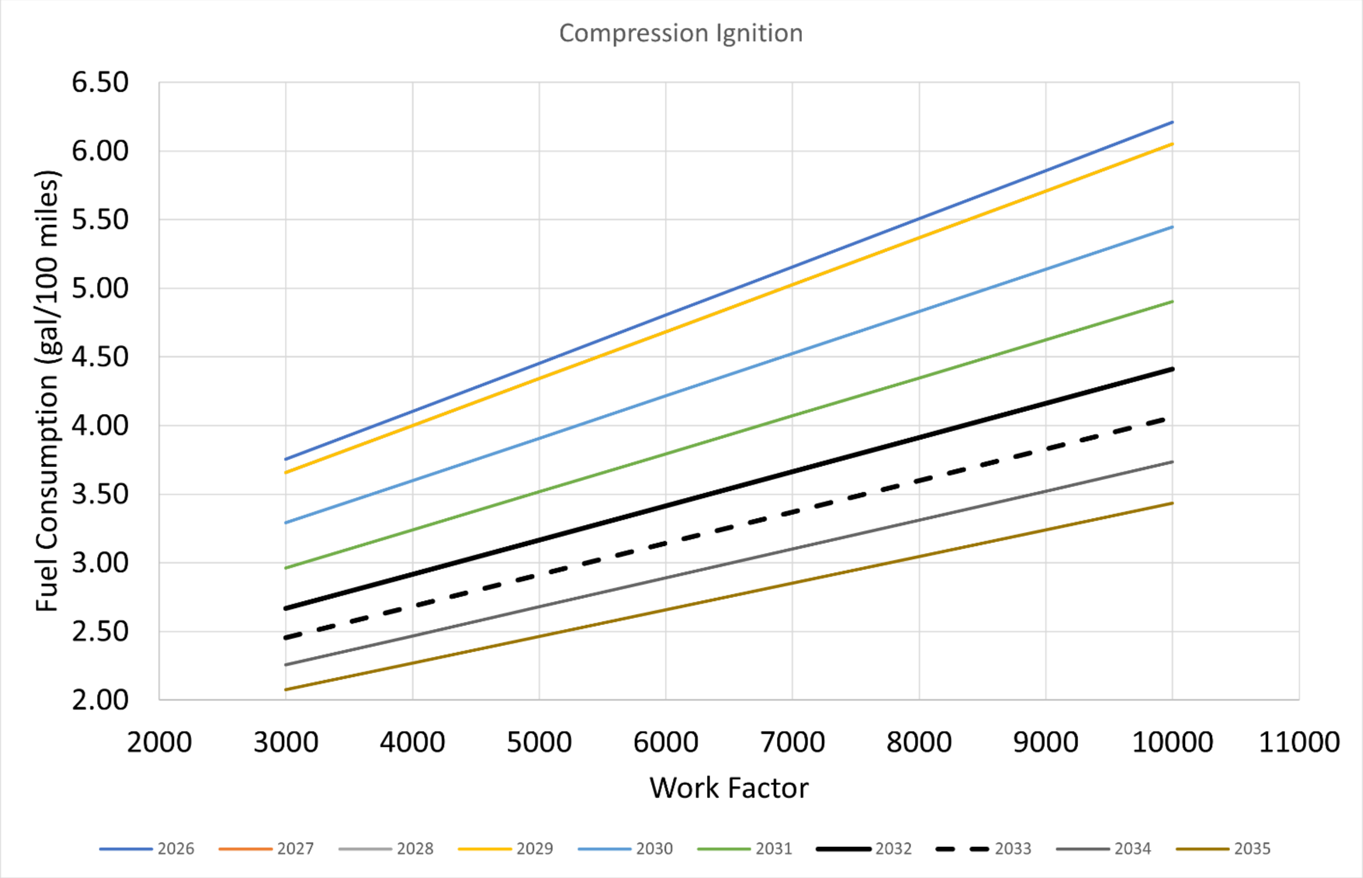
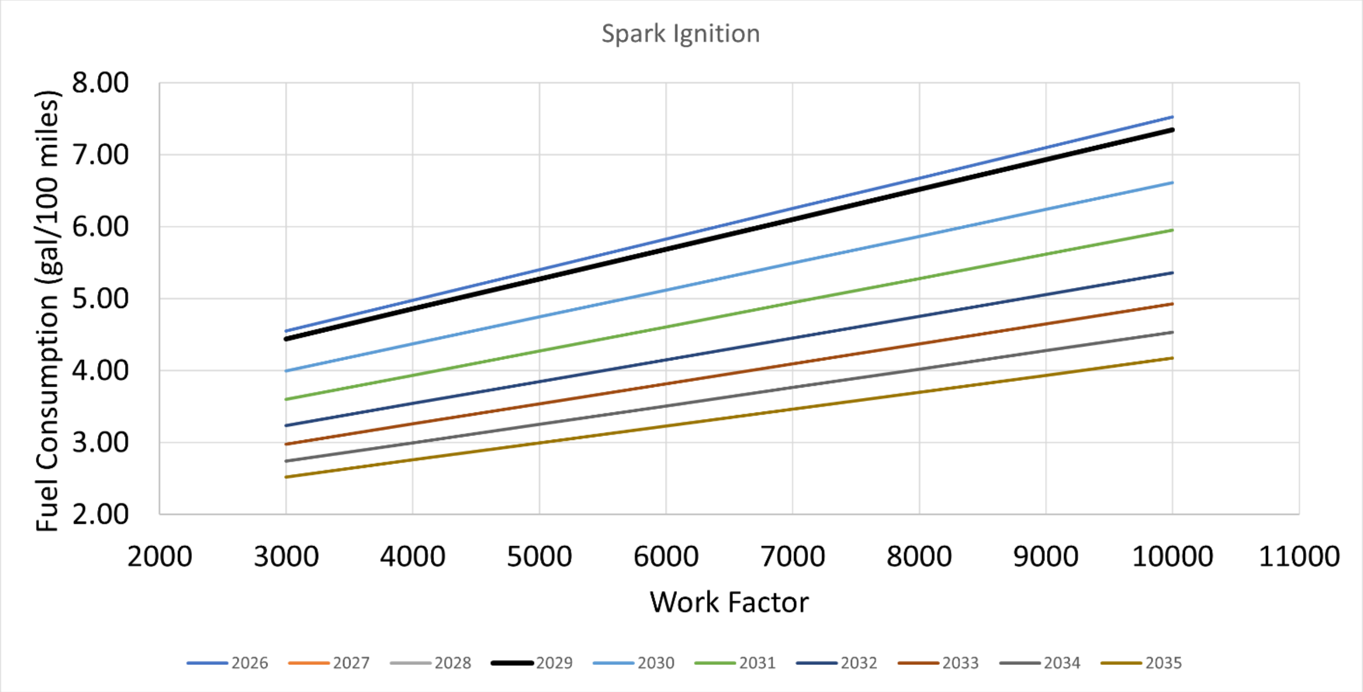


Figure 1-20: Alternative HDPUV108, HDPUV Fuel Efficiency – SI Vehicles, Target Curves



1.4.3.8. Alternative HDPUV10

Alternative HDPUV10 would increase HDPUV standard stringency by 10 percent per year for model years 2030-2035 HDPUVs. The four-wheel drive coefficient is maintained at 500 (coefficient ‘a’) and the weighting multiplier coefficient is maintained at 0.75 (coefficient ‘b’).

Table 1-33: Characteristics of Alternative HDPUV10 – CI Vehicle Coefficients[82]

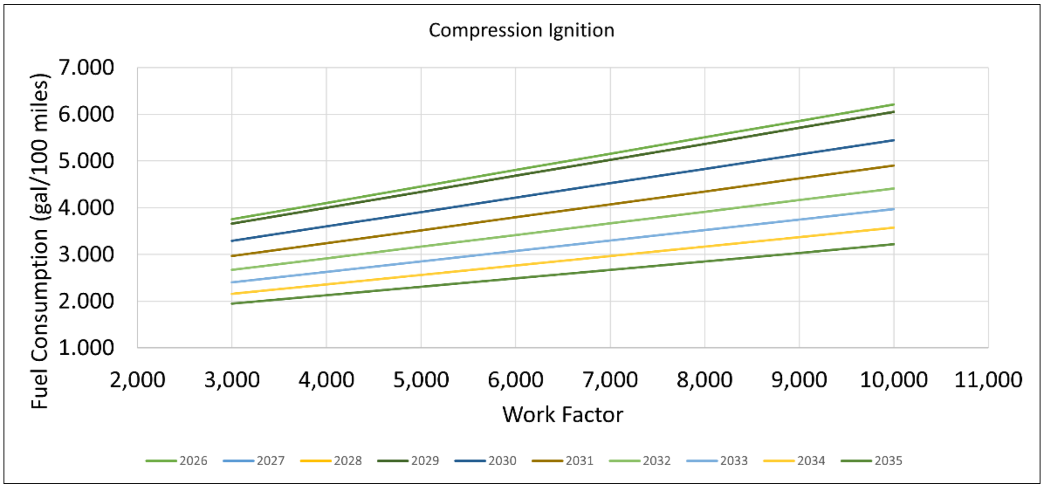
	2030	2031	2032	2033	2034	2035
e	0.00030762	0.00027686	0.00024917	0.00022425	0.00020183	0.00018165
f	2.370	2.133	1.919	1.728	1.555	1.399

Table 1-34: Characteristics of Alternative HDPUV10 – SI Vehicle Coefficients[83]

	2030	2031	2032	2033	2034	2035
c	0.00037368	0.00033631	0.00030268	0.00027241	0.00024517	0.00022065
d	2.876	2.589	2.330	2.097	1.887	1.698

These equations are represented graphically below:

Figure 1-21: Alternative HDPUV10, HDPUV Fuel Efficiency – CI Vehicles, Target Curves



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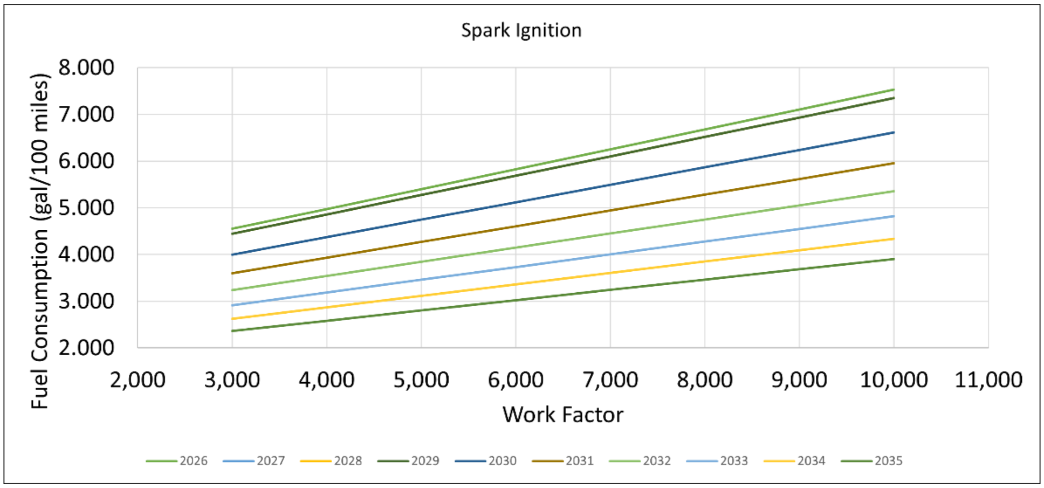
[82] In the CAFE Model, these are linear work-factor-based functions where coefficients e and f are for diesels, BEVs and FCEVs. See Equation 1-3 in Chapter 1.2.1.

[83] In the CAFE Model, these are linear work-factor-based functions where coefficients c and d are for gasoline, CNG, strong hybrid vehicles and PHEVs. See Equation 1-3 in Chapter 1.2.1.

Figure 1-22: Alternative HDPUV10, HDPUV Fuel Efficiency – SI Vehicles, Target Curves



1.4.3.9. Alternative HDPUV14

Alternative HDPUV14 would increase HDPUV standard stringency by 14 percent per year for model years 2030-2035 HDPUVs. The four-wheel drive coefficient is maintained at 500 (coefficient ‘a’) and the weighting multiplier coefficient is maintained at 0.75 (coefficient ‘b’).

Table 1-35: Characteristics of Alternative HDPUV14 – CI Vehicle Coefficients[84]

	2030	2031	2032	2033	2034	2035
e	0.00029395	0.00025280	0.00021740	0.00018697	0.00016079	0.00013828
f	2.264	1.947	1.675	1.440	1.239	1.065

Table 1-36: Characteristics of Alternative HDPUV14 – SI Vehicle Coefficients[85]

	2030	2031	2032	2033	2034	2035
c	0.00035707	0.00030708	0.00026409	0.00022712	0.00019532	0.00016798
d	2.749	2.364	2.033	1.748	1.503	1.293

These equations are represented graphically below:

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[84] In the CAFE Model, these are linear work-factor-based functions where coefficients e and f are for diesels, BEVs and FCEVs. See Equation 1-3 in Chapter 1.2.1.

[85] In the CAFE Model, these are linear work-factor-based functions where coefficients c and d are for gasoline, CNG, strong hybrid vehicles and PHEVs. See Equation 1-3 in Chapter 1.2.1.

Figure 1-23: Alternative HDPUV14, HDPUV Fuel Efficiency – SI Vehicles, Target Curves