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The Volpe National Transportation Systems Center (Volpe Center) of the United States Department of Transportation’s Research and Innovative Technology Administration has developed a modeling system to assist the National Highway Traffic Safety Administration (NHTSA) in the evaluation of potential new Corporate Average Fuel Economy (CAFE) standards. Given externally-developed inputs, the modeling system estimates how manufacturers could apply additional fuel-saving technologies in response to new CAFE standards, and estimates how doing so would increase vehicle costs, reduce national fuel consumption and carbon dioxide emissions, and result in other effects and benefits to society. The modeling system can also be used to estimate the stringency at which an attribute-based CAFE standard satisfies various criteria. For example, the system can estimate the stringency that produces a specified average required fuel economy level, or that maximizes net benefits to society.

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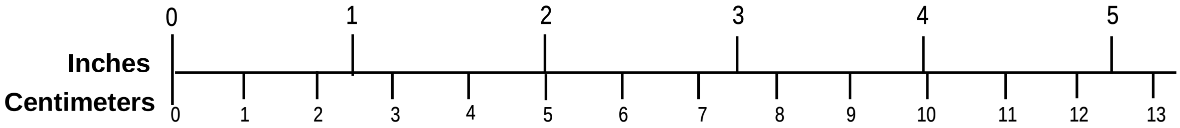

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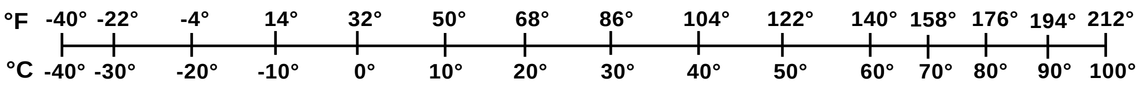

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PREFACE

The Volpe National Transportation Systems Center (Volpe Center) of the United States Department of Transportation's Research and Innovative Technology Administration has developed a modeling system to assist the National Highway Traffic Safety Administration (NHTSA) in the evaluation of potential new Corporate Average Fuel Economy (CAFE) standards. Given externally-developed inputs, the modeling system estimates how manufacturers could apply additional fuel-saving technologies in response to new CAFE standards, and estimates how doing so would, relative to a given baseline scenario, increase vehicle costs, reduce national fuel consumption and carbon dioxide emissions, and result in other effects and benefits to society. The modeling system can also be used to estimate the stringency at which an attribute-based CAFE standard satisfies various criteria. For example, the system can estimate the stringency that produces a specified average required fuel economy level, or that maximizes net benefits to society.

This report documents the design and function of the CAFE Compliance and Effects Modeling System as of August 1, 2012; specifies the content, structure, and meaning of inputs and outputs; and provides instructions for the installation and use of the modeling system.

The authors of this report are Mark Shaulov, Kevin Green, Ryan Harrington, Joe Mergel, Donald Pickrell, Ryan Keefe, and John Van Schalkwyk.

The authors acknowledge the technical contributions of individuals who have been involved in guiding recent changes to the modeling system, including Ken Katz, Gregory Powell, Jim Tamm, and Lixin Zhao of NHTSA. The authors further acknowledge former DOT staff who participated in the development of earlier versions of the modeling system, including Gregory Ayres, Phil Gorney, Kristina Lopez-Bernal, José Mantilla, Arthur Rypinski, and Kenneth William.

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Abbreviations

a	vehicle vintage
$\boldsymbol{A}_C$	values of attribute (*e.g.*, footprint) of vehicles in regulatory class *C*
AMT	automated manual (*i.e.*, clutch) transmission
ASL	aggressive shift logic
C	carbon dioxide emissions
C	regulatory class
c_d	distribution-related carbon emissions per gallon of fuel consumed
c_f	carbon content (by weight) of fuel
c_r	refining-related carbon emissions per gallon of fuel consumed
CAFE	Corporate Average Fuel Economy
$CAFE_C$	CAFE achieved by regulatory class *C*
CH_4	methane
Cost	technology cost after application of learning effects
CostD	rate of technology learning
CO	carbon monoxide
CO_2	carbon dioxide
$COST_{eff}$	effective cost
CostUpper	technology cost before application of learning effects
$CREDIT_C$	CAFE credits earned in regulatory class *C*
CVT	continuously variable transmission
d	discount rate
DOE	U.S. Department of Energy
DOHC	dual overhead cam
DOT	U.S. Department of Transportation
e_i	emission rate (per mile) for pollutant *i*
E_i	emissions of pollutant *i*
EIA	Energy Information Agency, U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPS	electric power steering
$\Delta FINE$	change in civil penalties owed
$\Delta m_{k,MY,t,CAFE}$	change in mileage accumulation resulting from rebound effect
$\Delta TECHCOST$	change in technology costs
ε_{cpm}	elasticity of vehicle use with respect to per-mile fuel cost
$FCReduction_{0,1\ldots}$	fuel consumption reduction from applied technologies 0, 1, …
$\boldsymbol{FE}_C$	fuel economy levels of vehicles in regulatory class *C*
FE_i	fuel economy of *i*th vehicle model
FE'_i	fuel economy of *i*th vehicle model, after application of technology
FE_{new}	fuel economy after application of a technology
FE_{orig}	fuel economy before application of a technology
FINE	civil penalties owed
FR	Final Rule (or Final Rulemaking)
$FUELPRICE_{MY+v}$	fuel price in calendar year *MY+v*
$g_{k,MY,t}$	fuel used in year *t* by model *k* vehicles from model year *MY*
gap	gap between laboratory and on-road fuel economy
GDI	gasoline direct injection
HC	hydrocarbons
HCCI	homogenous charge compression ignition

HDDV	heavy duty diesel vehicle
HDGV	heavy duty gasoline vehicle
i	vehicle index
ICP	intake cam phasing
IMA	integrated motor assist
ISAD	integrated starter/alternator/dampener
ISG	integrated starter/generator
j	vehicle cohort index
k	vehicle index
kD	number of technology learning cost reductions to apply
$kWeight$	percentage change in vehicle mass
LDDT	light duty diesel truck
LDDV	light duty diesel vehicle
LDGT	light duty gasoline truck
LDGV	light duty gasoline vehicle
$lVol_t$	intermediate variable for technology learning effect calculations
$m_{k,a}$	average mileage accumulated by model k vehicles of vintage a
$mpg_{k,CAFE}$	fuel economy of vehicle model k after CAFE standards
$mpg_{k,plan}$	fuel economy of vehicle model k before CAFE standards
$M_{k,MY,t}$	miles driven in year t by model k vehicles from model year MY
MI_v	average annual mileage accumulation at vintage v
MW_C	molecular weight of carbon
MW_{CO2}	molecular weight of carbon dioxide
MY	model year
$\boldsymbol{N}_C$	sales volumes of vehicles in regulatory class C
$n_{k,MY}$	number of vehicles of model k sold in model year MY
$n_{k,MY,t}$	number of k vehicles from model year MY in service in year t
$N_{k,MY}$	number of vehicles sold in model year MY
NA	naturally aspirated
NAS	National Academy of Sciences
NHTSA	National Highway Traffic Safety Administration
N_2O	nitrous oxide
NO_x	oxides of nitrogen
NPRM	Notice of Proposed Rulemaking
NRC	National Research Council
OHV	overhead valve
$P_{k,MY}$	market share of model k sold in model year MY
PM	particulate matter
r	discount rate
r	fraction of fuel refined domestically
$s_{k,a}$	share of vehicles of model k in service at vintage a
PV	present value
SI	spark ignition
STD_C	value of CAFE standard as applied to regulatory class C
$SURV_v$	average survival rate at vintage v
SO_x	sulfur oxides
SUV	sport utility vehicle
t	calendar year
v	vehicle vintage

$VALUE_{fuel}$	value of saved fuel
VMT	vehicle miles traveled
Volume	volume after which technology learning effects are realized
VVLT	variable valve lift and timing
VVT	variable valve timing

Chapter One Introduction

The Energy Policy and Conservation Act (EPCA), as amended by the Energy Independence and Security Act of 2007 (EISA), requires the National Highway Traffic Safety Administration (NHTSA), an agency within the U.S. Department of Transportation (DOT), to promulgate and enforce Corporate Average Fuel Economy (CAFE) standards. NHTSA has been administering these standards since 1975.

The Volpe National Transportation Systems Center (Volpe Center) provided technical support to the Department in connection with the establishment of the CAFE program in the 1970s, and has continued to provide such support since that time. The Volpe Center is a Federal fee-for-service organization within DOT's Research and Innovative Technology Administration (RITA).

In 2002, the Volpe Center began developing a new modeling system to support NHTSA’s analysis of options for future CAFE standards. Objectives included, but were not limited to, the following: the ability to utilize detailed projections of light vehicle fleets to be produced for sale in the United States, the ability to efficiently estimate how manufacturers could apply available technologies in response to CAFE standards, the ability to quickly evaluate various options for future CAFE standards, and the ability to estimate a range of outcomes (in particular, changes in fuel consumption and emissions) resulting from such standards.

Since 2002, the Volpe Center has made many changes to this modeling system. Some changes were made in response to comments submitted to NHTSA in connection with CAFE rulemakings, and in response to a formal peer review of the system. Some changes were made based on observations by NHTSA and Volpe Center technical staff. As NHTSA began evaluating attribute-based CAFE standards (*i.e.*, standards under which CAFE requirements depend on the mix of vehicles produced for U.S. sale), significant changes were made to enable evaluation of such standards. At the same time, the system was expanded to provide the ability to perform uncertainty analysis by randomly varying many inputs. Later, the system was further expanded to provide automated statistical calibration of attribute-based standards, through implementation of Monte Carlo techniques, as well as automated estimation of stringency levels that meet specified characteristics (such as maximizing estimated net benefits to society). In 2007, NHTSA and Volpe Center staff worked with technical staff of the U.S. Environmental Protection Agency (EPA) on major changes to the range of fuel-saving technologies accommodated by the model, as well as the logical pathways for applying such technologies. In 2008, NHTSA and Volpe Center staff collaborated on further revisions, particularly with respect to the representation of available fuel-saving technologies, support for the reexamination of which was provided by Ricardo, Inc.

In support of the 2010 rulemaking, a multi-year technology application feature was introduced into the modeling system. Additionally, for the 2011 rulemaking, a feature to evaluate voluntary overcompliance has been added as well.

Chapter Two System Design

Section 1 Overall Structure

The basic design of the CAFE Compliance and Effects Modeling System developed by the Volpe Center is as follows: The system first estimates how manufacturers might respond to a given CAFE scenario, and from that the system estimates what impact that response will have on fuel consumption, emissions, and economic externalities. A CAFE scenario involves specification of the form, or shape, of the standards (*e.g.*, flat standards, linear or logistic attribute-based standards, scope of passenger and nonpassenger regulatory classes), and stringency of the CAFE standard in each model year to be analyzed.

Manufacturer compliance simulation and effects estimation encompass numerous subsidiary elements. Compliance simulation begins with a detailed initial forecast, provided by the user, of the vehicle models offered for sale during the simulation period. The compliance simulation then attempts to bring each manufacturer into compliance with CAFE standards defined in an input file developed by the user; for example, CAFE standards that increase in stringency by 4 percent per year for 5 consecutive years, and so forth. The model sequentially applies various technologies to different vehicle models in each manufacturer's product line in order to simulate how a manufacturer might make progress toward compliance with CAFE standards. Subject to a variety of user-controlled constraints, the model applies technologies based on their relative cost-effectiveness, as determined by several input assumptions regarding the cost and effectiveness of each technology, the cost of CAFE-related civil penalties, and the value of avoided fuel expenses. For a given manufacturer, the compliance simulation algorithm applies technologies either until the manufacturer achieves compliance, or until the manufacturer exhausts all available technologies, or, if the manufacturer is assumed to be willing to pay civil penalties, until paying civil penalties becomes more cost-effective than increasing vehicle fuel economy. The user may disable the civil penalty paying option for manufacturers expected to be unwilling to pay them, thus effectively "forcing" the manufacturer to add additional technology even once it might otherwise be preferable to pay penalties (considering the cost to add further technology as compared to the estimated value of the resultant saved fuel). At this stage, the system assigns an incurred technology cost and updated fuel economy to each vehicle model, as well as any civil penalties incurred by each manufacturer.

This point marks the system's transition between compliance simulation and effects calculations. At the conclusion of the compliance simulation for a given model year, the system contains a new fleet of vehicles with new prices, fuel types (*e.g.*, diesel, electricity), fuel economy values, and curb weights that have all been updated to reflect the application of technologies in response to CAFE requirements. For each vehicle model in this fleet, the system then estimates the following: lifetime travel, fuel consumption, and carbon dioxide and criteria pollutant emissions. After aggregating model-specific results, the system estimates the magnitude of various economic externalities related to vehicular travel (*e.g.*, noise) and energy consumption (*e.g.*, the economic costs of short-term increases in petroleum prices).

Different categorization schemes are relevant to different types of effects. For example, while a fully disaggregated fleet is retained for purposes of compliance simulation, vehicles are grouped by type of fuel and regulatory class for the energy, carbon dioxide and criteria pollutant calculations, and by safety and regulatory classes for the additional fatalities calculations. The system may be expanded in the future to represent CAFE-induced market responses (*i.e.*, mix shifting), in which case such calculations would group vehicles by market segment. Therefore, this system uses model-by-model categorization and accounting when calculating most effects, and aggregates results only as required for efficient reporting.

Section 2 CAFE Compliance Simulation

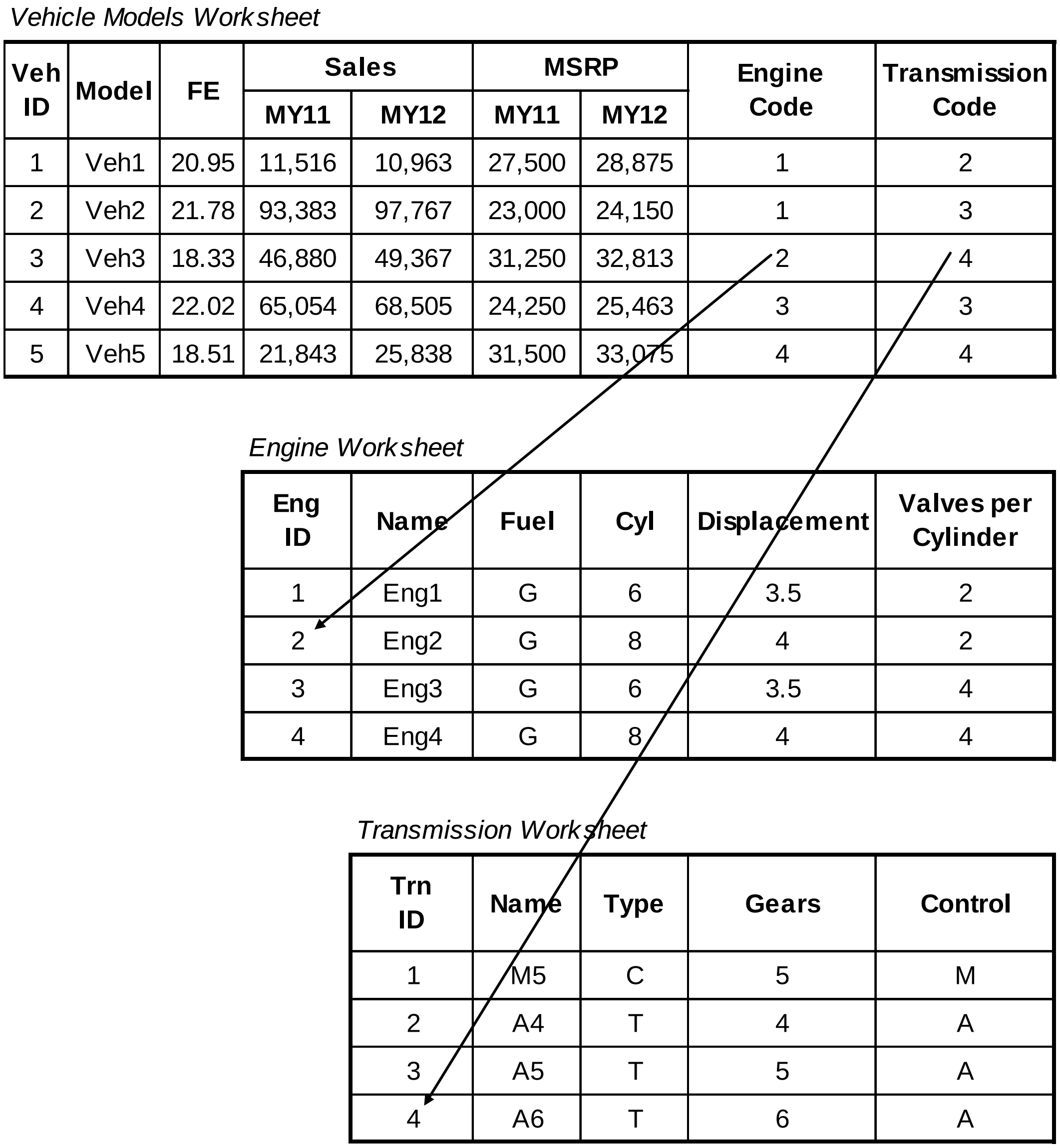
S2.1 Compliance Simulation Algorithm

Each time the modeling system is used, it evaluates one or more CAFE scenarios. Each of these scenarios is defined in the "scenarios" input file described in Section A.5 of Appendix A. Each scenario describes an overall CAFE program in terms of the program's coverage, applicability of multi-fuel vehicles, the structure and stringency of the standards applicable to passenger and nonpassenger automobiles, and the adjustments for improvements in air conditioning. The system is normally used to examine and compare at least two scenarios. The first scenario is identified as the baseline scenario, usually defined as the world in the absence of new CAFE standards (which itself can be considered in a variety of ways), providing results to which results for any other scenarios are compared. Although many scenarios can be examined with each run of the model, for simplicity in this overview, we will only describe one scenario occurring in one model year.

The compliance simulation applies technology to each manufacturer's product line based on the CAFE program described by the current scenario and the assumed willingness of each manufacturer to pay civil penalties rather than complying with the program. The first step in this process involves definition of the fleet's *initial state*—that is, the volumes, prices, and attributes of all vehicles as projected without knowledge of future CAFE standards—during the study period, which can cover one or more consecutive model years (MYs). The second step involves evaluating the applicability of each available technology to each vehicle model, engine, and transmission in the fleet. The third and final step involves the repeated application of technologies to specific vehicle models, engines, and transmissions in each manufacturer's fleet. For a given manufacturer, this step terminates when CAFE standards have been achieved or all available technologies have been exhausted. Alternatively, if the user specifies that some or all manufacturers should be considered willing to pay civil penalties for noncompliance, this step terminates when it would be less expensive to pay such penalties than to continue applying technology. Furthermore, if the system has been configured to evaluate voluntary overcompliance, this step would not terminate until all cost-effective solutions, for all manufacturers, were applied, beyond what is necessary to meet the CAFE standard.

S2.1.1 Initial State of the Fleet

The fleet's initial state is developed using information contained in the vehicle models, engine, and transmission worksheets described in Section A.1 of Appendix A. The set of worksheets uses identification codes to link vehicle models to appropriate engines, transmissions, and preceding vehicle models. Figure 1 provides a simplified example illustrating the basic structure and interrelationship of these three worksheets, focusing primarily on structurally important inputs. These identification codes make it possible to account for the use of specific engines or transmissions across multiple vehicle models. They also help the compliance simulation algorithm to realistically "carry over" technologies between model years.



Vehicle Models Worksheet

Veh ID	Model	FE	Sales		MSRP		Engine Code	Transmission Code
			MY11	MY12	MY11	MY12		
1	Veh1	20.95	11,516	10,963	27,500	28,875	1	2
2	Veh2	21.78	93,383	97,767	23,000	24,150	1	3
3	Veh3	18.33	46,880	49,367	31,250	32,813	2	4
4	Veh4	22.02	65,054	68,505	24,250	25,463	3	3
5	Veh5	18.51	21,843	25,838	31,500	33,075	4	4

Engine Worksheet

Eng ID	Name	Fuel	Cyl	Displacement	Valves per Cylinder
1	Eng1	G	6	3.5	2
2	Eng2	G	8	4	2
3	Eng3	G	6	3.5	4
4	Eng4	G	8	4	4

Transmission Worksheet

Trn ID	Name	Type	Gears	Control
1	M5	C	5	M
2	A4	T	4	A
3	A5	T	5	A
4	A6	T	6	A

Figure 1. Basic Structure of Input File Defining the Fleet's Initial State

S2.2 Vehicle Technology Application within the CAFE Model

Vehicle technologies are a set of possible improvements available for the vehicle fleet. The vehicle technologies, referred to below simply as ‘technologies’, are defined by the user in the technology input file for the model (see Section A.2 in Appendix A). As a part of the definition for each technology there is an associated cost for the technology, an improvement factor (in terms of percent reduction of fuel consumption), the introduction year for the technology, whether it is applicable to a given class of vehicle, grouping (by technology group – engine, transmission, etc.), and phase-in parameters (the amount of fleet penetration allowed in a given year). Also defined in the technology inputs file are cost synergies and improvement synergies.

Having defined the fleet’s initial state, the system applies technologies to each manufacturer’s fleet based on the CAFE program for the current model year. The set of technologies accommodated by the model is discussed in the Preliminary Regulatory Impact Analysis (PRIA) and Technical Support Document (TSD) for the 2017-2025 Notice of Proposed Rulemaking (NPRM) regarding CAFE standards for passenger cars and light trucks produced for sale in the United States in model years 2017-2025[1].

As discussed in the PRIA and TSD, the set of technologies, and the methods for considering their application, include all of those discussed in the 2012-2016 final rule documentation[2] albeit with updated fuel efficiency effectiveness estimates as well as newly defined technologies for the 2017-2025 timeframe. The technologies discussed in 2012-2016 final rule were based on a 2002 National Academy of Sciences report.[3] That study estimated that the applicability of different technologies would vary based on vehicle type. Since the publication of the 2002 NAS study, NHTSA and EPA have agreed on technology-related estimates extending through MY2025, based on a range of newer studies and research, and NHTSA has developed corresponding inputs for use in the CAFE model. The development of these technology estimates is discussed in the preamble to the proposed rule, and in the supporting technical support document and regulatory impact analysis. Although the model now represents a wider range of technologies than the 2002 NAS study, and uses different logical sequences for considering their addition to manufacturers’ fleets, the model retains the ability for differentiation based on vehicle type.

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[1] *Available at* http://www.nhtsa.gov/fuel-economy.

[2] 75 FR 25324 (May 7, 2010).

[3] National Research Council, ‘‘Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards,’’ National Academy Press, Washington, DC (2002). *Available at* http://www.nap.edu/openbook.php?isbn=0309076013 (last accessed Nov. 13, 2011).

S2.2.1 Vehicle Technology Class

The CAFE model uses twelve technology classes as shown in Table 1:

Table 1. CAFE Technology Vehicle Classes

Class	Description
Subcompact PC	Subcompact passenger car.
Subcompact Perf PC	Subcompact performance oriented passenger car
Compact PC	Compact passenger car
Compact Perf PC	Compact performance oriented passenger car
Midsize PC	Midsized passenger car
Midsize Perf PC	Midsized performance oriented passenger car
Large PC	Large passenger car
Large Perf PC	Large performance oriented passenger car
Small LT	Small sport utility vehicles and pickups
Midsize LT	Midsize sport utility vehicles and pickups
Large LT	Large sport utility vehicles and pickups
Minivan	Minivans

S2.2.2 Technology Groups

The CAFE Model organizes technologies into groups, which allows the model to seek the next "best" technology application in any of these groups.[4] There are seven groups defined: engine technologies, transmission technologies, electrical accessory technologies, mass reduction technologies, low rolling resistance tires technologies, dynamic load reduction technologies, and aerodynamic load reduction technologies. The table below lists the technologies represented by the system, and the grouping we have applied to enable the system to follow a logical incremental path within any given group without being unnecessarily prevented from considering technologies in other groups. This "parallel path" approach is discussed below.

Table 2. Technology Group Assignments

Technology Group	Group Members[5]
Vehicle Engine Technology Group (EngMod)	Low Friction Lubricants - Level 1 (LUB1) Engine Friction Reduction - Level 1 (EFR1) Low Friction Lubricants and Engine Friction Reduction - Level 2 (LUB2_EFR2) Variable Valve Timing (VVT) • VVT - Coupled Cam Phasing on SOHC (CCPS) • VVT - Intake Cam Phasing (ICP) • VVT - Dual Cam Phasing (DCP) Cylinder Deactivation • Cylinder Deactivation on SOHC (DEACS) • Cylinder Deactivation on DOHC (DEACD)

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[4] Within the context of the compliance simulation, "best" is defined from the manufacturers' perspective. The system assumes that the manufacturer will seek to progress through the technology decision trees in a manner that minimizes effective costs, which include (a) vehicle price increases associated with added technologies, (b) reductions in civil penalties owed for noncompliance with CAFE standards, and (c) the value vehicle purchasers are estimated to place on fuel economy.

[5] Some technologies were evaluated during the initial development of the modeling system; however, they were later excluded from analysis. These technologies appear grayed out in the table.

	• Cylinder Deactivation on OHV (DEACO) Variable Valve Lift & Timing • Discrete Variable Valve Lift (DVVL) on SOHC (DVVLS) • Discrete Variable Valve Lift (DVVL) on DOHC (DVVLD) • Continuously Variable Valve Lift (CVVL) (CVVL) • Variable Valve Actuation - CCP and DVVL on OHV (VVA) Stoichiometric Gasoline Direct Injection (GDI) (SGDI) Stoichiometric Gasoline Direct Injection (GDI) on OHV (SGDIO) Turbocharging and Downsizing - Level 1 (18 bar BMEP) • Small Displacement (TRBDS1_SD) • Medium Displacement (TRBDS1_MD) • Large Displacement (TRBDS1_LD) Turbocharging and Downsizing - Level 2 (24 bar BMEP) • Small Displacement (TRBDS2_SD) • Medium Displacement (TRBDS2_MD) • Large Displacement (TRBDS2_LD) Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) • Small Displacement (CEGR1_SD) • Medium Displacement (CEGR1_MD) • Large Displacement (CEGR1_LD) Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) • Small Displacement (CEGR2_SD) • Medium Displacement (CEGR2_MD) • Large Displacement (CEGR2_LD) Advanced Diesel[6] • Small Displacement (ADSL_SD) • Medium Displacement (ADSL_MD) • Large Displacement (ADSL_LD)
Vehicle Transmission Technology Group (TrMod)	6-Speed Manual/Improved Internals (6MAN) High Efficiency Gearbox (Manual) (HETRANSM) Improved Auto. Trans. Controls/Externals (IATC) 6-Speed Trans with Improved Internals (NAUTO) 6-speed Dual Clutch Transmission (DCT) 8-Speed Trans (Auto or DCT) (8SPD) High Efficiency Gearbox (Auto or DCT) (HETRANS) Shift Optimizer (SHFTOPT)
Electrical Accessory Technology Group (ELEC) ***Includes Hybrid Technologies***	Electric Power Steering (EPS) Improved Accessories - Level 1 (IACC1) Improved Accessories - Level 2 (IACC2) 12V Micro-Hybrid (MHEV) Integrated Starter Generator (ISG) Strong Hybrid - Level 1 (SHEV1) Conversion from SHEV1 to SHEV2 (SHEV1_2) Strong Hybrid - Level 2 (SHEV2) Plug-in Hybrid - 30 mi range (PHEV1) *Plug-in Hybrid (PHEV2)* Electric Vehicle (Early Adopter) - 75 mile range (EV1) *Electric Vehicle (Early Adopter) - 100 mile range (EV2)* *Electric Vehicle (Early Adopter) - 150 mile range (EV3)* Electric Vehicle (Broad Market) - 150 mile range (EV4) *Fuel Cell Vehicle (FCV)*
Mass Reduction	Mass Reduction - Level 1 (MR1)

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[6] Replacing a gasoline engine with a diesel engine.

Technology Group (MSM)	Mass Reduction - Level 2 (MR2) Mass Reduction - Level 3 (MR3) Mass Reduction - Level 4 (MR4) Mass Reduction - Level 5 (MR5)
Low Rolling Resistance Tires Technology Group (ROLL)	Low Rolling Resistance Tires - Level 1 (ROLL1) Low Rolling Resistance Tires - Level 2 (ROLL2) *Low Rolling Resistance Tires - Level 3 (ROLL3)*
Dynamic Load Reduction Technology Group (DLR)	Low Drag Brakes (LDB) Secondary Axle Disconnect (SAX)
Aerodynamic Reduction Technology Group (AERO)	Aero Drag Reduction, Level 1 (AERO1) Aero Drag Reduction, Level 2 (AERO2)

Input estimates for each of these technologies are specified in the technologies input file, and are specific to each of the CAFE technology vehicle classes, as shown in the following table. Table 3 lists some of the input assumptions specified in this file[7].

Table 3. Technology Input Assumptions

Input	Definition
Applicable	If the technology is available for applicability.
Year Available	First model year the technology is available for applicability.
Year Retired	Last model year the technology is available for applicability.
TechType	Technology group of which the technology is a member, as shown in Table 2 above.
FC	Overall fuel consumption improvement estimate of the technology.
FCg	Fuel consumption improvement estimate to apply to the gasoline fuel economy value when a vehicle is being converted to a PHEV.
FCg Share	Assumed percentage of miles driven by the vehicle on the gasoline fuel after being converted to a PHEV.
Off-Cycle Credit PC	Amount of off-cycle credit that the vehicles regulated as passenger automobiles incur as a result of applying the technology.
Off-Cycle Credit LT	Amount of off-cycle credit that the vehicles regulated as light trucks incur as a result of applying the technology.
Cost Table	Fully learned-out table of costs by model year[8] (in 2009 dollars).
Maintenance Cost Table	Fully learned-out table of additional maintenance costs, by model year, incurred by a vehicle as a result of applying additional technologies.
Repair Cost Table	Fully learned-out table of additional non-warranty repair costs, by model year, incurred by a vehicle as a result of applying additional technologies.
Loss of Value	The consumer welfare loss resulting from the decreased range of electric vehicles.
Delta Weight (%)	Percentage by which the vehicle's weight changes after technology is applied.

Among other things, the technology input assumptions define applicability, cost, fuel consumption reduction factors, off-cycle credits, consumer welfare losses, as well as the technology group of which the technology is a member.

S2.2.3 Technology Availability

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[7] Additional technology assumptions are further discussed in Section A.2 of Appendix A.

[8] Because mass reduction is applied as a percentage of curb weight, the corresponding cost estimates are in dollars per pound of incremental change in curb weight.

The technology input assumptions provide two methods of defining technology availability. First, the *Applicability* field determines whether the technology is generally available for application on a particular class of vehicle. If this field is set to **TRUE**, the technology may be considered for application by the modeling system; otherwise, the technology will be unavailable.

If *Applicability* is set to **TRUE**, the *Year Available* and *Year Retired* fields from the input assumptions are further considered in determining the technology's availability. Together, these two fields define a range of model years during which the technology may be applied. If the year being evaluated by the CAFE Model is prior to the setting in the *Year Available* field or after the *Year Retired* field, then the technology will be unavailable for the particular class of vehicle.

Besides those mentioned, additional technology applicability factors are considered by the modeling system. For example, there are controls for individual vehicles, engines, or transmissions in the market data file that can override the controls here (see Sections A.1.2, A.1.3, and A.1.4 in Appendix A). There are also dynamic considerations made while the model is running based on vehicle configuration (*e.g.*, cylinder deactivation is not applied to vehicles with manual transmissions), as well as technology combination factors (*e.g.*, DVVLD is incompatible with CVVL). Additionally, technology phase-in caps may limit the availability of technologies if a particular penetration rate is reached for a vehicle's manufacturer.

S2.2.4 Technology Fuel Consumption Reduction Factors

The technology input assumptions define the fuel consumption reduction factors *FC* and *FCg*. The reduction in fuel consumption values are on a gallons-per-mile basis and represent a percent reduction in fuel consumption. The formula to find the increase in fuel economy (miles-per-gallon) of a vehicle with fuel consumption reduction factors from one or more technologies is:

$$FE_{new} = FE_{orig} * \frac{1}{\left(1 - FCReduction_0\right)} * \frac{1}{\left(1 - FCReduction_1\right)} \cdots * \frac{1}{\left(1 - FCReduction_n\right)} \qquad \textbf{(1)}$$

where FE_{orig} is the original fuel economy for the vehicle, $FCReduction_{0,1,\ldots n}$ are the fuel consumption reduction factors attributed to *0-th* to *n-th* technologies, and FE_{new} is the resulting fuel economy for the same vehicle.

Whenever the modeling system converts a vehicle model to a Plug-In Hybrid/Electric Vehicle (PHEV), that vehicle is assumed to operate on gasoline and electricity fuel types simultaneously. In such a case the *FC* field represents the overall improvement in the combined (gasoline and electricity) vehicle fuel economy, while the *FCg* field specifies what the improvement in the gasoline-only component of the vehicle's fuel economy would be.[9] Lastly, the *FCg Share* field specifies the assumed amount of miles driven by the vehicle in gasoline-only operation.

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[9] When being converted to a Plug-In Hybrid, the vehicle's fuel economy while operating on gasoline may potentially increase due to improvements in regenerative breaking associated with a bigger battery. Presently, however, it is assumed that no such improvement exists, and the *FCg* field is listed as zero (0).

S2.2.5 Technology Cost Tables

The technology input assumptions provide a fully "learned-out" table of year-by-year technology costs, as specified by the *Cost Table* field.

Some technology costs have a cost basis associated with them. For instance, for mass reduction technologies, the technology input costs must be multiplied by the reduction of vehicle curb weight, in pounds, to get the full cost of applying the technology. Similarly some engine technologies have costs determined on a per-cylinder or per-bank (configuration) basis.

Along with the base *Cost Table*, the input assumptions also define the *Maintenance Cost Table* and the *Repair Cost Table*. Both of these tables are specified for each model year and account for the learning effect, wherever applicable. The former identifies the changes in the amount buyers are expected to pay for maintaining a new vehicle[10], while the latter identifies the increases in non-warranty repair costs attributed to application of additional technology.

Further discussion of the technology cost input assumptions can be found in Section A.2 of Appendix A.

S2.2.6 Technology Synergies

Technology synergies exist when the combination of two technologies yields a fuel consumption reduction which differs from the value that would be derived directly from equation (1). The synergy can be positive (*e.g.*, increased reduction of fuel consumption) or negative (decreased reduction of fuel consumption). The model also uses some cost "synergies" to ensure correct cost accounting as the model proceeds down the decision trees.

Synergy relationships between technologies are captured in the two synergies table in the technology input file. The system reads the information from the table and, for each technology, stores the synergy factors between that technology and all other technologies. For cases where there is no synergy relationship, there will be no listing in the table, and the synergy factor will be zero (0.0). In cases where there are synergies, that applicable factor is added to the fuel consumption reduction or to the cost value.

In the case of fuel consumption reduction synergies, negative synergies lessen the fuel consumption reductions of a technology, the system assumes technologies will not combine to degrade fuel economy (*i.e.,* to produce negative reductions in fuel consumption). For synergies involving technology costs, the final result is allowed to become negative.

The layout of the synergy table in the technology input file is discussed in Section A.2.1 of Appendix A.

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[10] The maintenance costs may lead to increases in cost to consumers, such as for advanced diesel engines, or in cost saving to consumers, such as for of electric vehicles. In the case of electric vehicles, the cost savings result from avoiding traditional vehicle maintenance such as engine oil changes.

S2.2.7 Technology Applicability and Backfill

The modeling system determines the applicability of each technology to each vehicle model, engine, and transmission. If the technology is available in the current model year, the system identifies the technology as potentially applicable. However, technology "overrides" can be specified for specific vehicle models, engines, and transmissions in the corresponding input files.[11] If any such overrides have been specified, the algorithm reevaluates the technology's applicability, as shown in Figure 2.

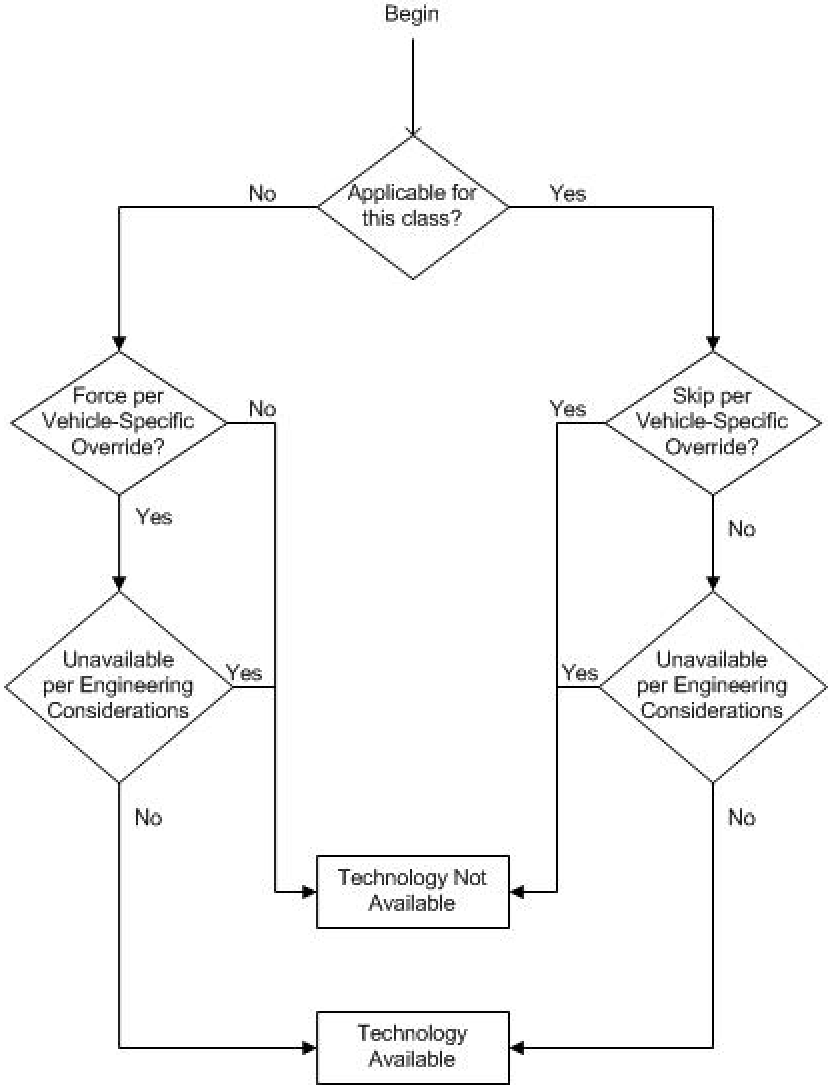

Figure 2. Technology Applicability Determination

In some cases, technologies may be bypassed because they are not cost-effective. If the modeling system applies a technology that resides later in the sequence, it will 'backfill' anything that was previously skipped in order to fully account for technology costs and improvements, each of which are specified on an incremental basis. This backfill, however, will not occur if a

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[11] These overrides, described in Sections A.1.2, A.1.3, and A.1.4 of Appendix A, provide a means of accounting for engineering and other constraints not otherwise represented by input data or the overall system.

technology is not applicable to the vehicle. In the case where the backfill operation requires backtracking through branches in the sequence, the modeling system will first resolve any engineering constraints and limitations, as well as applicability issues to determine whether the branch still exists. If there is still a branch, the system will follow the technology path that would result in lower overall costs.[12]

S2.2.8 Technology Sequencing and Branching

The sequence of applying technology works in the following way: Within each group, the technology sequence of application proceeds as shown in the technology input file. There are some points where the sequence path can branch onto a different course, as discussed below. The groups are independent of each other, although there may be some interactions.

S2.2.8.1 Sequencing and Branching within a Technology Group

Within each technology group, the choice of technologies that can be applied may vary from vehicle to vehicle based on the baseline configuration of the vehicle or on the previous application of technologies. Both the engine and transmission technology groups have optional paths. The choice of which path depends upon a variety of factors, which include the vehicle class, the vehicle configuration, technology override settings for that vehicle, previous applications of technology, technology availability (year available), and phase-in restrictions. When left with a choice of two or more technologies, cost-effectiveness is used to choose the technology to apply.

S2.2.8.2 Bypassing a Technology

In cases where a technology is already installed in the baseline vehicle configuration or is unavailable for other reasons (*e.g.,* it is not compatible with this vehicle class), that technology is simply bypassed in the technology path. For example, if engine friction reduction has previously been installed, the next available engine technology after low-cost lubricants on a vehicle with overhead valves (OHV) is cylinder deactivation.

Branching within a technology group sequence occurs for the following reasons: 1) normal branch where there are two or more different (and mutually incompatible) technology choices – the model can choose one or another path; 2) limitations of technology choice based on vehicle configuration; 3) combination of both.

An example of normal branching is DVVLD and CVVL in the engine technology group.

An example of the limitations would be within the engine technology group, as shown in Figure 3, below, where there is a separate path for engines with overhead valves (OHV) engines, single

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[12] Given the complexity associated with having to evaluate the effectiveness of backfilled branches (due to its recursive nature), and considering the extremely rare situations where such branches occur, the modeling system does not attempt to evaluate the full cost-effectiveness of a technology for the purposes of picking a backfill path. Instead, the model simply determines the path to follow based on lower costs. However, once a backfill path is chosen, the model does evaluate the full cost-effectiveness of all technologies in that path.

overhead cam engines (SOHC), and for engines with dual overhead cams (DOHC). Likewise, as shown in Figure 4 further down, the transmission technology group follows two distinct paths – one for manual transmissions and another for automatics.

S2.2.8.3 Engine Technology Sequencing and Branching

The engine technology sequence, shown in Figure 3, includes there primary paths: single overhead cam (SOHC); dual overhead cam (DOHC); and overhead valve (OHV). The modeling system determines the choice of path for a vehicle model based on that vehicle's engine attributes. An additional branch, between DVVLD and CVVL technologies, exists within the DOHC branch. The model chooses which path to follow based on availability for the specific vehicle and the vehicle technology class, the technology phase-in constraints, and the technology cost-effectiveness.

Further down within the engine technology sequence is another branch, which culminates in a choice between dieselization and a strong hybrid path. The path that the model chooses is, again, based on availability for the specific vehicle and the vehicle technology class, the technology phase-in constraints, and the technology cost-effectiveness.

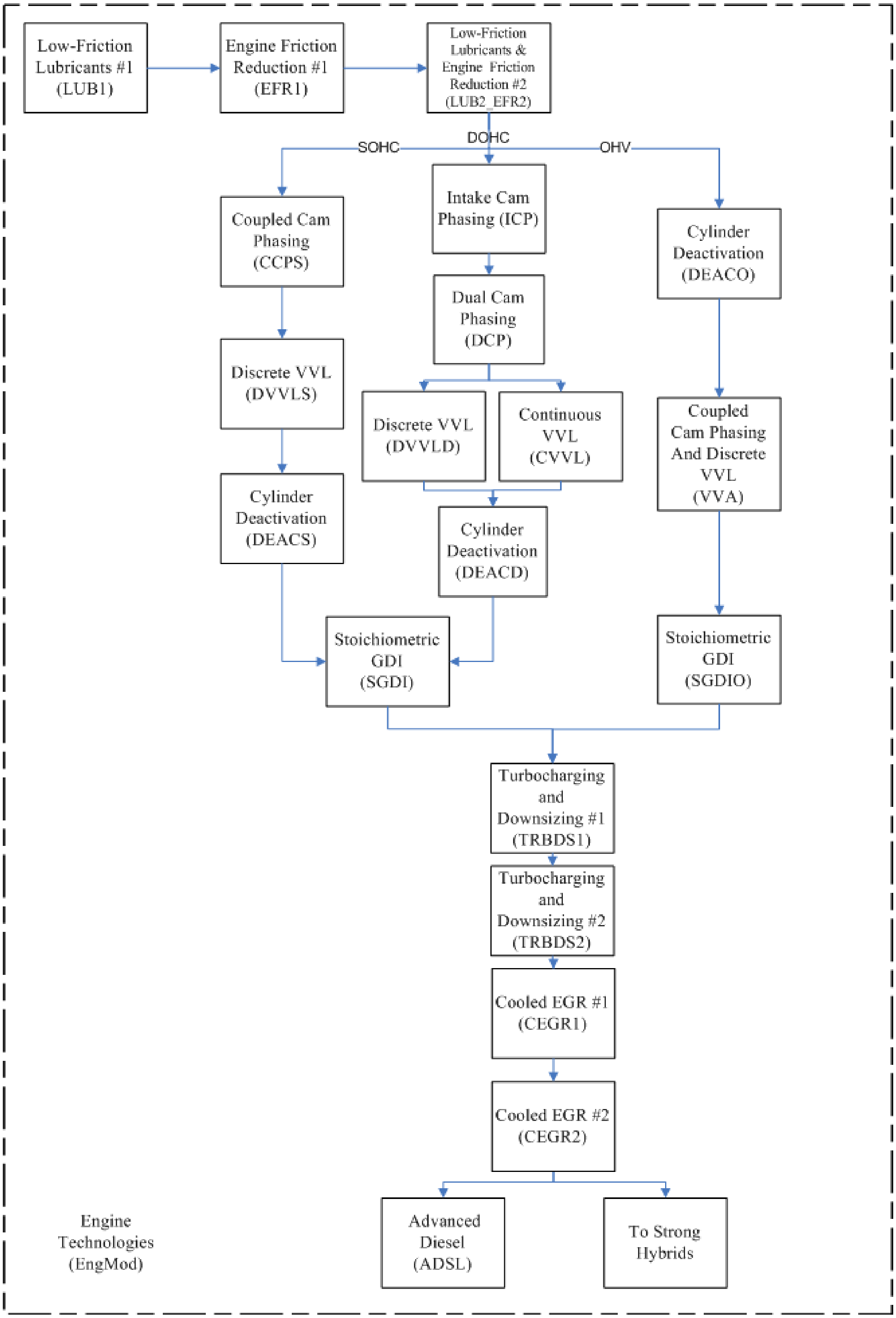

Figure 3. Engine Technology Group Technology Sequence

S2.2.8.4 Transmission Technology Sequencing

The transmission technology sequence, shown in Figure 4, contains two separate paths, one used for automatic transmissions, and the other for manual transmissions. Depending on the transmission that the vehicle initially starts with, one sequence or the other will be followed.

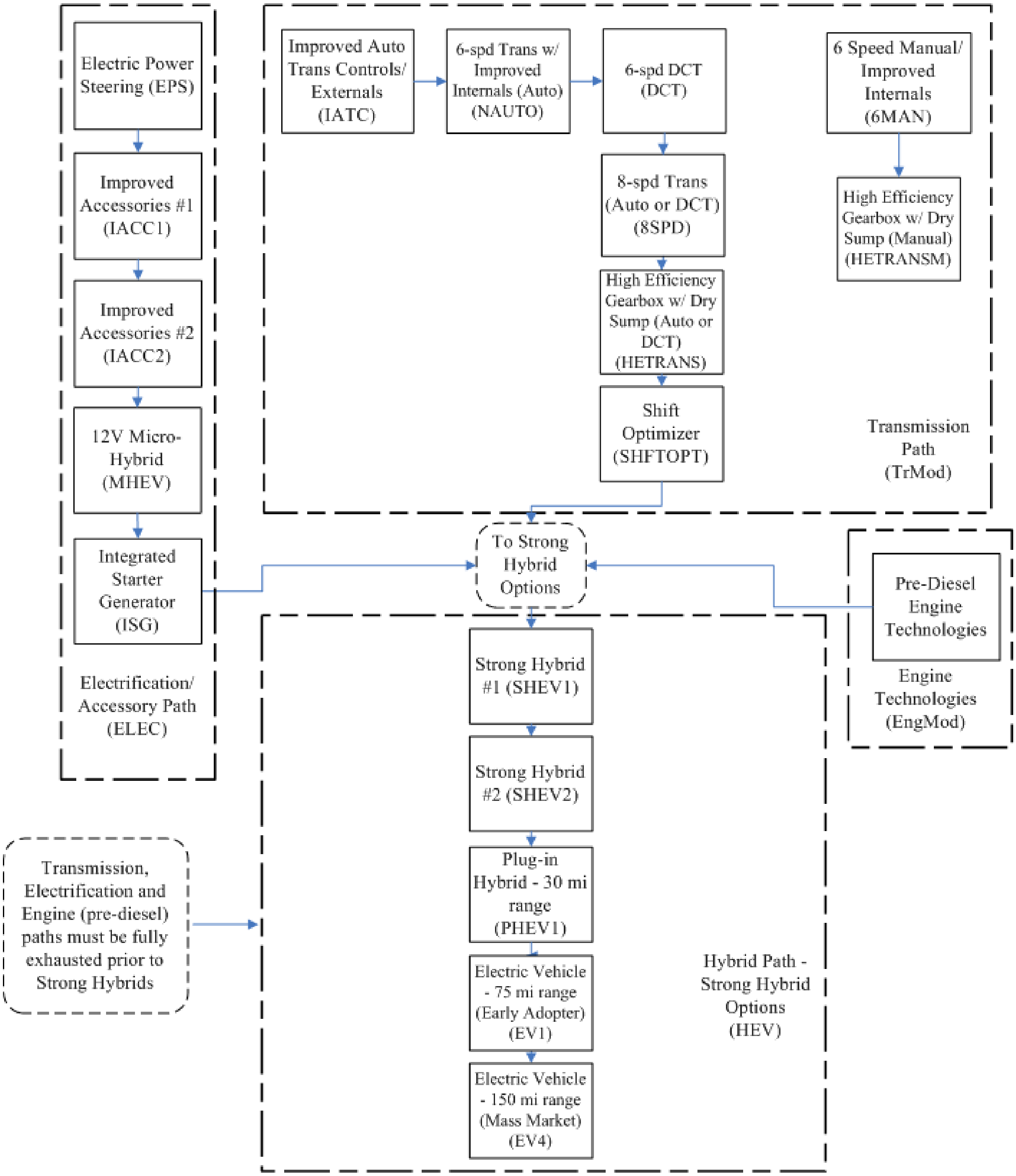

Figure 4. Transmission, Electrification/Accessory, and Hybrid Technology Decision Tree

S2.2.8.5 Electrical Accessory & Strong Hybrid Technology Sequencing

The electrical accessory technology sequence has no branches, as shown in Figure 4. The technologies on the electrical accessory path can be applied to a vehicle any time, provided they meet engineering and phase-in constraints. However, the technologies in the strong hybrid path (*i.e.*, strong hybrids, plug-in hybrids and electric vehicles) can only be applied once the engine (with the exception of the Advanced Diesel technology) and transmission paths have been fully applied. Furthermore, if a strong hybrid technology is applied before exhausting the electrification path, any preceding electrification technologies will be backfilled. Thus the engine, transmission, and (to a certain extent) electrification technologies are considered "enablers" that must be installed on a vehicle prior to the application of the strong hybrid technologies.

S2.2.8.6 Vehicle (Other) Technology Sequencing

The rest of the technology sequences (mass reduction, low rolling resistance tires, dynamic load reduction, and aerodynamic load reduction), shown in Figure 5, have no branches. However, with the exception of dynamic load reduction technologies, before the modeling system is able to apply a technology appearing later on the decision tree, the preceding technologies must be applied to a vehicle.

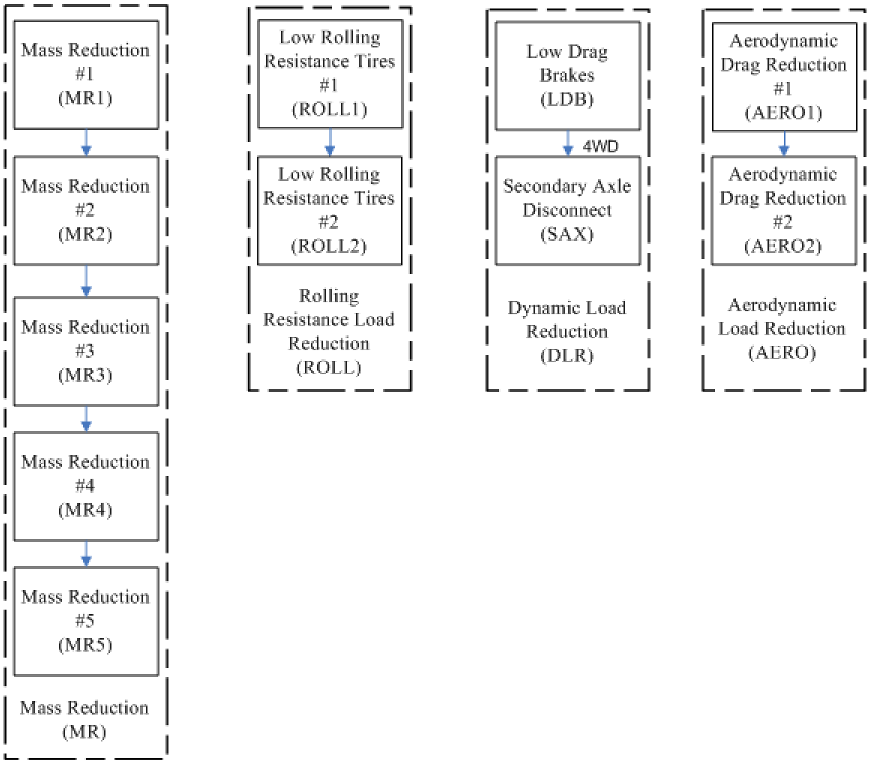

Figure 5. Vehicle Technology Decision Tree

S2.3 Compliance Simulation Loop

If a given technology is still considered applicable after considering any overrides, the algorithm again re-evaluates applicability based the following engineering conditions:

Table 4. Engineering Conditions for Technology Applicability

Technology	Constraint
All technologies	Do not apply if already present on the vehicle.
Low-Friction Lubricants	Do not apply if engine oil is better than 5W30.
Variable Valve Timing Family	Do not apply to diesel or rotary engines.
Variable Valve Lift and Timing Family	Do not apply to diesel or rotary engines. Do not apply to vehicles with VVLT technology already in place. Once a VVLT (continuous or discrete) are applied, the other VVLT cannot be applied.
Cylinder Deactivation	Do not apply to engines with inline configuration, and/or fewer than 6 cylinders. Do not apply to turbocharged and downsized, diesel or rotary engines. Do not apply to vehicles with manual transmissions.
Turbocharging and downsizing	Do not apply to diesel or rotary engines.
Turbocharging and downsizing, Level 2	Do not apply if vehicle has a manual transmission with fewer than 6 gears or an automatic/DCT transmission with fewer than 8 gears.
Cooled Exhaust Gas Recirculation (Level 1 & 2)	Do not apply if vehicle has a manual transmission with fewer than 6 gears or an automatic/DCT transmission with fewer than 8 gears.
Stoichiometric GDI	Do not apply to diesel or rotary engines.
Advanced Diesel	Do not apply to strong hybrid, plug-in hybrid, or electric vehicles.
Strong Hybrids, Plug-in Hybrids, and Electric Vehicles	Do not apply to diesel vehicles. Do not apply until all engine and transmission technology improvements were already made to a vehicle.

Having determined the applicability of each technology to each vehicle model, engine, and/or transmission, the compliance simulation algorithm begins the process of applying technologies based on the CAFE standards applicable during the current model year. This involves repeatedly evaluating the degree of noncompliance, identifying the “best next” (as described above) technology available on each of the parallel technology paths mentioned above, and applying the best of these. Figure 6 gives an overview of the process. If, considering all regulatory classes, the manufacturer owes no CAFE civil penalties, then the algorithm applies no technologies beyond any carried over from the previous model year, because the manufacturer is already in compliance with the standard. If the manufacturer does owe CAFE civil penalties, then the algorithm first finds the best next applicable technology in each of the technology groups (*e.g.*, engine technologies), and applies the same criterion to select the best among these. If this manufacturer is assumed to be unwilling to pay CAFE civil penalties (or, equivalently, if the user has set the system to exclude the possibility of paying civil penalties as long as some technology can still be applied), then the algorithm applies the technology to the affected vehicles. If the manufacturer is assumed to be willing to pay CAFE civil penalties and applying this technology would have a lower “effective cost” (discussed below) than simply paying penalties, then the algorithm also applies the technology. In either case, the algorithm then reevaluates the manufacturer’s degree of noncompliance. If, however, the manufacturer is assumed to be willing to pay CAFE civil penalties and doing so would be less expensive than applying the best next technology, then the algorithm stops applying technology to this manufacturer’s products. After this process is repeated for each manufacturer. It is then repeated again for each modeling year. Once all modeling years have been processed, the compliance simulation algorithm concludes.

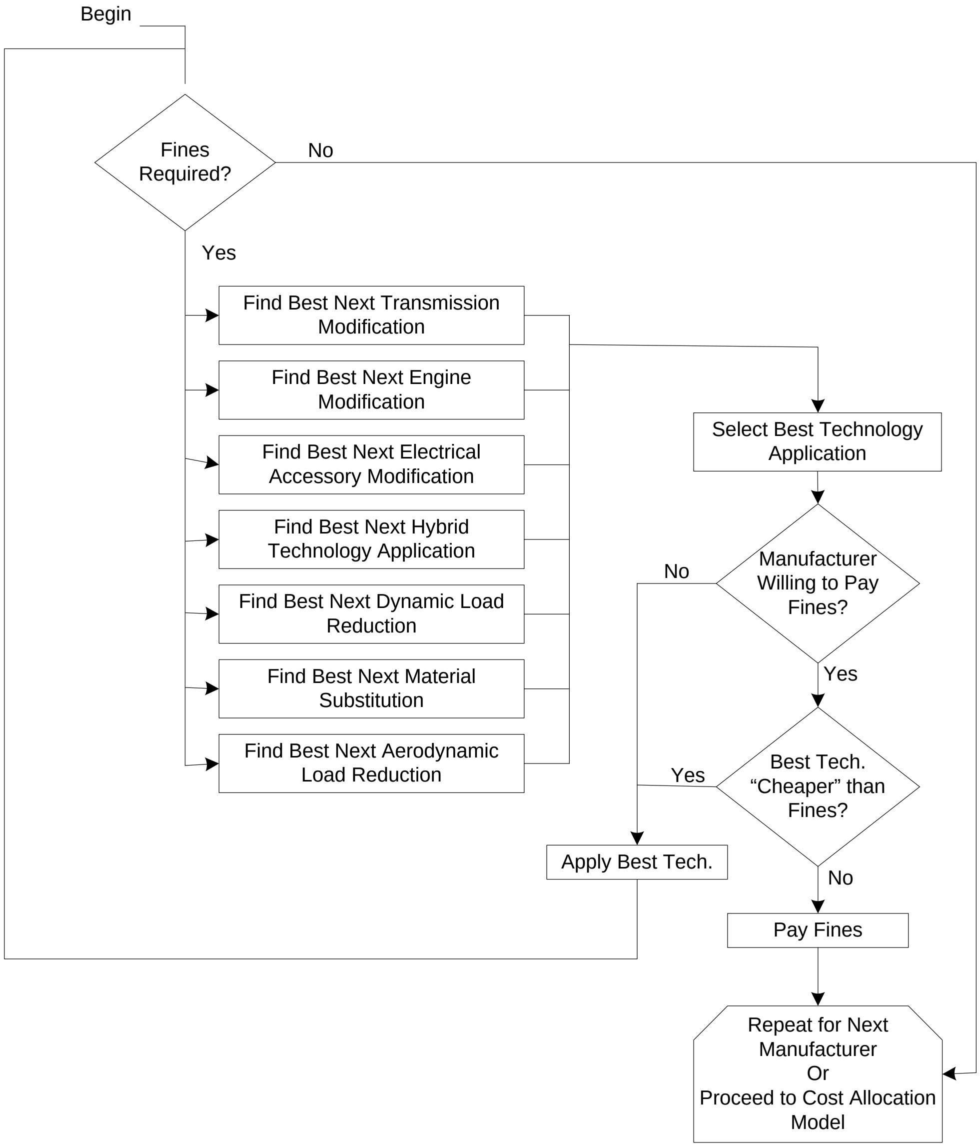

Figure 6. Compliance Simulation Algorithm

Whether or not the manufacturer is assumed to be willing to pay CAFE penalties, the algorithm uses CAFE penalties not only to determine whether compliance has been achieved, but also to determine the relative attractiveness of different potential applications of technologies. Whenever the algorithm is evaluating the potential application of a technology, it considers the effective cost of applying that technology to the group of vehicles in question, and chooses the option that yields the lowest effective cost.[13] The effective cost is used for evaluating the relative attractiveness of different technology applications, not for actual cost accounting. The effective

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[13] Such groups can span regulatory classes. For example, if the algorithm is evaluating a potential upgrade to a given engine, that engine might be used by a station wagon in the domestic passenger automobile fleet, a large car in the imported passenger automobile fleet, and a minivan in the nonpassenger automobile fleet. If the manufacturer's domestic and imported passenger automobile fleets both comply with the corresponding standard, the algorithm accounts for the fact that upgrading this engine will incur costs and realize fuel savings for all three of these vehicle models, but will only yield reductions of CAFE fines for the nonpassenger fleet.

cost is defined as the change in total technology costs incurred by the manufacturer (adjusted downward by 23% to account for vehicles' future resale value) plus the change in CAFE penalties incurred by the manufacturer minus the value of any reduction of fuel consumed by vehicles sold by the manufacturer. The calculation can span multiple modeling years. If the candidate technology was enabled for application in a previous year and not used, then it can remain as a candidate to be applied and then carried forward to the current model year. The impact of the technology application in each of these years is summed to obtain the effective cost.

$$\boldsymbol{COST_{eff}} = \sum_{\boldsymbol{i=BaseMY}}^{\boldsymbol{i=PresentMY}} \frac{0.77 \times \Delta \boldsymbol{TECHCOST_i} + \Delta \boldsymbol{FINE_i} - (\boldsymbol{VALUE_{FUEL}})_{\boldsymbol{i}} + \boldsymbol{WELFARELOSS_i}}{(\boldsymbol{N_j})_{\boldsymbol{i}}} \qquad \textbf{(2)}$$

where *PresentMY* is the current modeling year, *BaseMY* is the first year of the potential application of the technology (can be less than or equal to *PresentMY*), $\Delta TECHCOST$ is simply the product of the unit cost of the technology, $WELFARELOSS_i$ is the loss of value to the consumer resulting from the reduction in travel range of electric vehicles, and the total sales (Nj) of the affected cohort of vehicles (j) for all years involved in the candidate technology application. The value of the reduction in fuel consumption achieved by applying the technology in question to all vehicles i in cohort j is calculated as follows:[14]

$$\boldsymbol{VALUE_{FUEL}} = \sum_{\boldsymbol{i \in j}} \left[\boldsymbol{N_i} \times \sum_{\boldsymbol{FT}} \left(\left(\sum_{\boldsymbol{v=0}}^{\boldsymbol{v=PB}} \frac{\boldsymbol{SURV_v} \times \boldsymbol{MI_v} \times \boldsymbol{VMTGROWTH_{MY+v}} \times (\boldsymbol{PRICE_{FT}})_{\boldsymbol{MY+v}}}{(\boldsymbol{1} - \boldsymbol{GAP_{FT}}) \times (\boldsymbol{1} + \boldsymbol{r})^{\boldsymbol{V}}} \right) \times \left(\frac{(\boldsymbol{FS_{FT}})_{\boldsymbol{i}}}{(\boldsymbol{FE_{FT}})_{\boldsymbol{i}}} - \frac{(\boldsymbol{FS'_{FT}})_{\boldsymbol{i}}}{(\boldsymbol{FE'_{FT}})_{\boldsymbol{i}}} \right) \right) \right] \qquad \textbf{(3)}$$

where $SURV_v$ is the car and truck average probability that a vehicle of that vintage will remain in service, MI_v is the car and truck average number of miles driven in a year at a given vintage v, $VMTGROWTH_{MY+v}$ is the growth factor to apply to the base miles driven in the current model year MY at the given vintage v, FT is the fuel type the vehicle operates on (gasoline, diesel, or electricity), $(FE_{FT})_i$ and $(FE'_{FT})_i$ are the vehicle's fuel economy for a specific fuel type prior to and after the pending application of technology, $(FS_{FT})_i$ and $(FS'_{FT})_i$ are the vehicle's assumed share of operating on a specific fuel type prior to and after the pending application of technology, GAP_{FT} is the relative difference between on-road and laboratory fuel economy for a specific fuel type, N_i is the sales volume for model i in the current model year MY, $(PRICE_{FT})_{MY+v}$ is the price of the specific fuel type in year $MY+v$, and PB is a "payback period", or number of years in the future the consumer is assumed to take into account when considering fuel savings. As discussed in Section A.3 of Appendix A, $SURV_v$, MI_v, $VMTGROWTH_{MY+v}$, $(PRICE_{FT})_{MY+v}$, and GAP_{FT} are

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[14] This is not necessarily the actual value of the fuel savings, but rather the increase in vehicle price the manufacturer is assumed to expect to be able impose without losing sales.

all specified in the parameters input file, while the values for *PB* are specified in the market data input file (see Section A.1.1 in Appendix A).

In equation (2), *FINE* is the change in total CAFE penalties (*i.e.*, accounting for all regulatory classes in the current CAFE scenario and model year). Typically, *FINE* is negative because applying a technology would increase CAFE.[15] *FINE* is calculated by evaluating the following before and after the pending technology application, and taking the difference between the results:

$$FINE = -k_F \sum_{C} \mathrm{MIN}\left(CREDIT_C, 0\right) \tag{4}$$

Here, k_F is in dollars per mpg (*e.g.*, \$55/mpg) and specified in the scenarios file.

Within each regulatory class *C*, the net amount of CAFE credit created (noncompliance causes credit creation to be negative, which implies the use of CAFE credits or the payment of CAFE penalties) is calculated by subtracting the CAFE level achieved by the class from the standard applicable to the class, and multiplying the result by the number of vehicles in the class. Taking into account attribute-based CAFE standards, this is expressed as follows:

$$CREDIT_C = N_C \left[\mathrm{STD}_C\left(\mathbf{N}_C, \mathbf{A}_C\right) - \mathrm{CAFE}_C\left(\mathbf{N}_C, \mathbf{FE}_C\right) \right] \tag{5}$$

where $\mathbf{A}_C$ is a vector containing the value of the relevant attribute for each vehicle model in regulatory class *C*, $CAFE_C$ is the CAFE level for regulatory class *C* (*e.g.*, if the standard depends on curb weight, $\mathbf{A}_C$ contains each vehicle model's curb weight), $\mathbf{FE}_C$ is a vector containing the fuel economy level of each vehicle model in regulatory class *C*, N_C is the total sales volume for regulatory class *C*, $\mathbf{N}_C$ is a vector containing the sales volume for each vehicle model in regulatory class *C*, and $\mathrm{STD}_C(\mathbf{N}_C, \mathbf{A}_C)$ is a function defining the standard applicable to regulatory class *C*. Figure 7 gives an overview of the logic the algorithm follows in order to identify the best next technology application for each technology group.

Within a given technology group, the algorithm considers technologies in the order in which they appear. If the phase-in limit for a given technology has been reached, the algorithm proceeds to the next technology. If not, the algorithm determines whether or not the technology remains applicable to any sets of vehicles, evaluates the effective cost of applying the technology to each such set, and identifies the application that would yield the lowest effective cost.

As shown in Figure 7, the algorithm repeats this process for each technology group, and then selects the technology application yielding the lowest effective cost. As discussed above, the algorithm operates subject to expectations of the willingness of each manufacturer to pay fines. $COST_{eff}$ is determined, as above, by equations (2), (3), and (4), irrespective of the manufacturer's willingness to pay fines.

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[15] Exceptions can occur, for example, if mass reduction is applied under a CAFE system in which attribute standards are weight-based rather than footprint-based.

At the end of each year in the model year loop, the vehicle/technologies combinations that can be candidates for application in multi-year processing are identified.

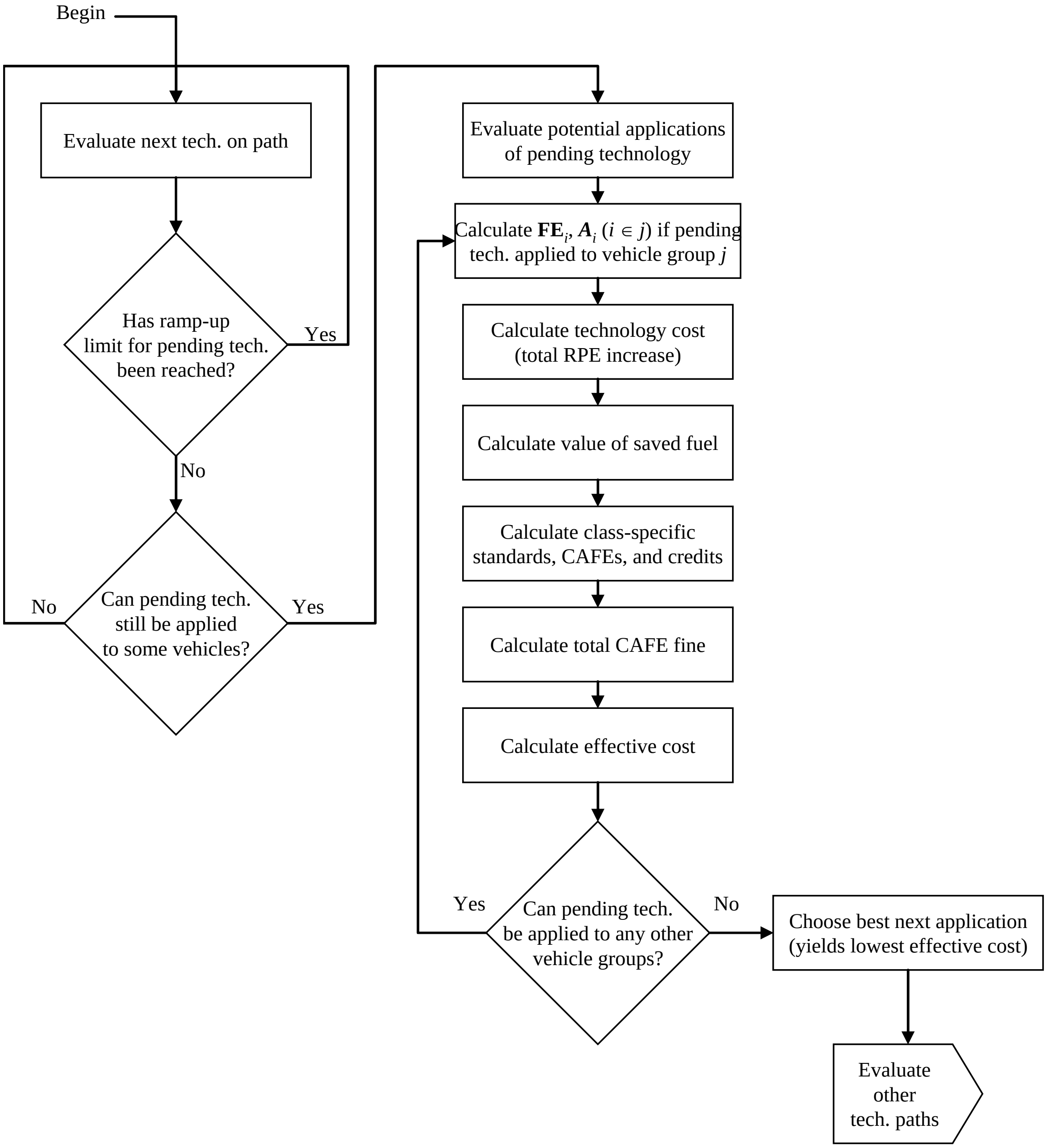

Figure 7. Determination of "Best Next" Technology Application

Chapter Three Calculation of Effects

This chapter describes the way the CAFE modeling system estimates the effects of potential new CAFE standards on energy use, as well as on emissions of greenhouse gases and other air pollutants. These effects are caused by improvements in the fuel economy of individual vehicle models that manufacturers make in response to the implosion of higher CAFE standards. This section also describes how these energy use and environmental impacts are translated into estimates of economic benefits or costs, and identifies which of these economic impacts are borne privately by vehicle owners and by society as a whole.

The effects on energy use and emissions from tightening or reforming CAFE standards are estimated separately for each individual vehicle model and vintage (or model year) over its expected life span in the U.S. vehicle fleet. A vehicle model's life span extends from the initial model year when it is produced and sold, through the year when vehicles produced during that model year have reached the maximum age assumed in the CAFE model.[16] Each of the effects of raising CAFE standards is measured by the difference in the value of a variable – such as total gallons of fuel consumed by a vehicle model and vintage over its lifetime – with its baseline fuel economy level, and its estimated fuel economy if that model were instead required to comply with a stricter CAFE standard. A vehicle model's baseline fuel economy level is usually (but not necessarily) defined as the level of fuel economy it would be expected to have if the CAFE standard currently in effect for its vehicle class (automobiles or light trucks) remained in effect for the future model year when it is produced.

Although these effects are calculated for individual vehicle models, vintages, and future calendar years over their respective lifetimes, they are typically reported at the aggregate level for all vehicle models in a CAFE regulatory class (domestic automobiles, imported automobiles, and light trucks) produced during each model year affected by a proposed standard. Cumulative impacts for each CAFE regulatory class and model year over its expected life span are reported both in undiscounted terms and as their present value discounted to the calendar year when each model year is produced.

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[16] We adopt the simplifications that vehicle model years and calendar years are identical, and that all vehicles produced during a model year are sold and placed into service during the corresponding calendar year.

Section 1 Light-Duty Vehicle Production and Lifetimes

The forecast number of new vehicles of a specific model *k* produced and sold during a given model year *MY* is:

$$n_{k,MY} = N_{MY} P_{k,MY} \quad \textbf{(6)}$$

Where N_{MY} denotes total sales of all models produced during that model year, and $P_{k,MY}$ is the proportion of total production and sales during that model year that is accounted for by model *k*.

The number of vehicles of a specific model and model year (or vintage) that remains in service during each subsequent calendar year is calculated by multiplying the number originally produced by estimates (model inputs) of the proportion expected to remain in service at each age up to an assumed maximum lifetime. Thus the number of vehicles of model *k* produced during model year MY that remain in use during a future calendar year *t*, or $n_{k,MY,t}$, is:

$$n_{k,MY,t} = n_{k,MY} s_{k,a} \quad \textbf{(7)}$$

where $s_{k,a}$ denotes the proportion of vehicles of model *k* expected to remain in use at the age *a* that vehicles produced during model year *MY* will have reached during calendar year *t*. The age of a vehicle model produced in model year *MY* during calendar year *t* is defined as:

$$a = t - MY.^{17} \quad \textbf{(8)}$$

The CAFE model currently accommodates different schedules of survival rates by vehicle age for passenger automobiles and light trucks, where light trucks are separated into vans, SUVs, and pickups, as reported in Section A.3.1 of Appendix A. Based on analysis of recent registration data, the maximum ages of passenger automobiles and light trucks are estimated to be 30 years and 37 years, respectively.[18]

Each vehicle model *k* produced during a model year *MY* is designated as operating on a specific fuel type or employing a specific technology; all units of that model produced during a model year are assumed to be of the same fuel or technology type. The CAFE model currently recognizes five fuel or technology types: gasoline, diesel, flexible-fuel vehicles (or FFVs, which are capable of operating on gasoline or on gasoline blended with up to 85% ethanol), plug-in hybrid electric vehicles (or PHEVs, which can operate on either gasoline or electricity generated off-board and stored in on-board batteries), and electric vehicles (or EVs, which operate only on electricity generated off-board and stored in on-board batteries). The fractions of total mileage

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[17] We define a vehicle's age to be 0 during the year when it is produced and sold; that is, when *t*=*MY*. Thus, for example, a model year 2005 vehicle is defined to be 10 years old during calendar year 2015. Because we do not attempt to forecast *changes* in the proportion of vehicles produced during future model years that are expected to survive to each age, a vehicle's age depends only on the difference between its model year (*MY*) and the calendar year (*t*) for which these calculations are performed, and not on their specific values.

[18] These are defined as the ages when the number of vehicles of a model year that remain in service has declined to fewer than 2% of those originally produced.

for which FFVs operate on gasoline and ethanol-blend fuels, and the fractions of total mileage for which PHEVs operate on gasoline and stored electricity, are inputs to the model.

Section 2 Vehicle Use and Total Lifetime Mileage

The CAFE model employs the widely-documented relationship between vehicle age and declining average vehicle use to estimate the number of miles that individual vehicle models are driven annually and in total over their expected lifetimes. Initial estimates of the relationship between vehicle age and average annual miles driven were tabulated from the sample of approximately 140,000 household vehicles included in the 2009 National Household Travel Survey (NHTS).[19] Separate schedules of average annual miles driven by age of vehicle were developed for passenger automobiles and light trucks, where light trucks are separated into vans, SUVs, and pickups, as reported in Section A.3.1 of Appendix A.

Two adjustments are applied to these mileage schedules to forecast the average number of miles that vehicles produced during future model years will be driven each year over their expected lifetimes. First, the estimates of annual miles driven by passenger cars and light trucks during 2008 are adjusted to reflect assumed future growth in average vehicle use.[20] The average number of miles driven by cars and light trucks of all ages is assumed to grow by 0.5% per year from 2008 on.

Second, the estimates of average annual miles driven by cars and light trucks of each age derived from the NHTS (and adjusted for expected future growth as described above) are further adjusted by applying the estimated elasticity of vehicle use with respect to fuel cost per mile to the difference in inflation-adjusted gasoline price per gallon between 2008 (when the NHTS data on vehicle use were collected) and each subsequent calendar year. This adjustment employs actual gasoline prices for the years 2009-2010, forecasts for 2011-2035 reported in the U.S. Energy Information Administration's ***Annual Energy Outlook 2011***, and extrapolations of gasoline prices beyond the year 2035 developed by EPA.[21] This adjustment assumes an elasticity of annual vehicle use with respect to fuel cost per mile of -0.10, corresponding to a fuel economy rebound effect of 10%.

Thus the average number of miles driven by surviving vehicles of model k and model year MY during calendar year t, or $m_{k,MY,t}$, is given by:

$$m_{k,MY,t} = m_{type,t-MY,2008}(1+r)^{t-2008}\left[1+\varepsilon_{m,cpm}\left(\frac{C_{k,MY,t}}{C_{k,t-MY,2008}}-1\right)\right] \qquad \textbf{(9)}$$

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[19] For a description of the survey and methods for estimating annual vehicle use, see ***2009 National Household Travel Survey User's Guide***, Version 3, January 2004, available at http://nhts.ornl.gov/2001/usersguide/UsersGuide.pdf (last accessed November 30, 2011).

[20] Increases in the average number of miles cars and trucks are driven each year have been an important source of historical growth in *total* car and light truck use, and are expected to represent an important source of future growth in total light-duty vehicle travel as well.

[21] See U.S. Energy Information Administration, ***Annual Energy Outlook 2011,*** Reference Case, "Petroleum Product Prices," available at http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2011&subject=0-AEO2011&table=12-AEO2011&region=0-0&cases=ref2011-d020911a (last accessed November 30, 2011).

where $m_{type,t\text{-}MY,2008}$ is the average annual mileage for a car or light truck that was of age $t\text{-}MY$ during 2008, r is the rate of growth in average annual miles per vehicle beginning in 2008, $t\text{-}2008$ is the number of years that have elapsed between 2008 and calendar year t, $\varepsilon_{m,cpm}$ is the elasticity of annual vehicle use with respect to fuel cost per mile, $C_{k,MY,t}$ is fuel cost per mile during year t for a car or light truck model k, and $C_{k,t\text{-}MY,2008}$ is fuel cost per mile for a car or light truck that was of age $t\text{-}MY$ during 2008.

Because the value of $m_{type,t\text{-}MY,t,2008}$ in equation (9) differs between cars and light trucks, the value of $m_{k,MY,t}$ will take one of two values, depending on whether model k is classified as an automobile or a light truck.

The value of fuel cost per mile for vehicle model k of model year MY during each year t of its expected lifetime, denoted $C_{k,MY,t,CAFE}$ in equation (9), depends on both the price per gallon of gasoline during year t and the actual fuel economy model k achieves in on-road driving. Specifically,

$$C_{k,MY,t,CAFE} = \frac{P_t}{mpg_{k,MY,CAFE}(1-gap)} \tag{10}$$

where P_t is the inflation-adjusted price per gallon of gasoline forecast for year t, and $mpg_{k,MY,CAFE}$ is the rated fuel economy that model k achieves for model year MY with the assumed CAFE standard in effect. Each model's rated fuel economy is assumed to be determined during the model year when it is produced, and to remain fixed throughout its lifetime. However, its actual on-road fuel economy is assumed to fall short of that rating by the on-road fuel economy "gap" (a model input, currently assumed to be 20% for gasoline, diesel, and ethanol-85 fuel types, and 30% for electricity fuel type). Furthermore, the on-road fuel economy of electric vehicles, as well as the electricity fuel economy component of plug-in hybrid/electric vehicles, is further reduced by the petroleum equivalency factor.

Equations (9) and (10) together indicate that the average number of miles that surviving vehicles of a model k and model year MY are driven during each year t of their lifetimes depends on their fuel economy. The fuel economy that each vehicle model is projected to achieve can differ between the baseline market forecast for model year MY, which assumes that the CAFE standard prevailing during the previous model year would be extended to apply to model year MY, and any alternative CAFE standard that is considered for model year MY.

As a consequence, the average number of miles that vehicles of model k and model year MY are driven during year t will also differ between the baseline market forecast and an alternative CAFE standard, depending on whether its manufacturer elects to increase that model's fuel economy as part of its strategy to comply with the alternative standard. This difference reflects the fuel economy rebound effect, which occurs because buyers of new vehicles respond to the reduction in their operating costs that results from their higher fuel economy by driving slightly more.[22]

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[22] Average annual vehicle use under both the baseline market forecast of fuel economy and a higher CAFE standard are calculated by reference to the schedules of average annual mileage by age derived from the 2001 NHTS, as equations (9) and (10) indicate. Thus the difference between a model's annual use under those two scenarios differs slightly from the estimate that would have resulted from first calculating annual use under the baseline market

The ***total*** number of miles driven by all vehicles of a specific model and vintage (model year) during each calendar year they remain in the fleet is then calculated by multiplying the appropriate estimate of annual miles driven per vehicle by the number of vehicles of that model year remaining in service during that year. Thus the total miles driven during year *t* by the surviving vehicles of model *k* that were originally produced during model year *MY*, denoted $M_{k,MY,t,CAFE}$, is calculated as:

$$M_{k,MY,t,CAFE} = n_{k,MY,t} m_{k,MY,t,CAFE} \tag{11}$$

where $m_{k,MY,t,CAFE}$ is as defined above.

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forecast of MPG from the 2001 NHTS, and then adding the increase in use estimated by applying the rebound effect to the reduction in fuel cost per mile resulting from the increase in its fuel economy between the baseline forecast and a higher CAFE standard.

Section 3 Fuel Consumption and Savings

Fuel consumption by vehicles of each model and vintage during a future year depends on the total mileage that the surviving vehicles are driven during that year, as well as on the fuel efficiency they obtain in actual driving. As indicated previously, the fuel economy levels that new vehicles achieve in real-world driving falls significantly short of the rated fuel economy levels that are used to assess manufacturers' compliance with CAFE standards.

The number of gallons of each type of fuel (or gasoline gallon equivalents of fuel energy, in the case of electricity) consumed by vehicles of model *k* and model year *MY* during year *t*, denoted $g_{k,MY,t,fuel}$, is calculated from:

$$g_{k,MY,t,CAFE,fuel} = \frac{m_{k,MY,t,CAFE} s_{k,MY,CAFE,fuel}}{mpg_{k,MY,CAFE,fuel}\left(1 - gap_{fuel}\right)} \qquad \textbf{(12)}$$

where $s_{k,MY,CAFE,fuel}$ is the share of miles that model *k* produced in model year *MY* operates on each type of fuel, $mpg_{k,MY,CAFE,fuel}$ is its fuel economy in miles per gallon (or miles per gasoline gallon equivalent, in the case of electricity) on each type of fuel, and gap_{fuel} (a model input) indicates the proportional difference between the fuel economy of vehicles using that fuel as measured for CAFE purposes and their actual on-road fuel economy.[23]

The CAFE models estimates use of four different types of fuel energy: gasoline, diesel, E85 (a blend of 85% ethanol and 15% gasoline), and electricity. Dedicated gasoline, diesel, and electric vehicle models will each have mileage shares of 100% for the fuel they are designed to utilize, and 0% mileage shares for all other fuels. FFVs are currently assumed to operate on E85 for 15% of their annual mileage each year over their lifetimes, while PHEVs are assumed to operate on electricity for 50% of their annual mileage and on gasoline for the remaining 50%. These values are inputs to the CAFE model, and can be adjusted by the user.

As equation (12) indicates, many of the factors determining a vehicle model's consumption of different fuels can vary depending on the CAFE standard that is in effect during the model year it is produced. Specifically, the shares of miles for which it operates on different fuels, its fuel economy when using each different fuel, and as discussed previously, its average annual mileage can each differ between the baseline market forecast and any alternative CAFE level that the model is used to analyze. These differences occur because manufacturers will increase the fuel economy of some models in response to increases in CAFE standards from their baseline level, and may convert some gasoline-powered models to diesel, FFVs, or PHEVs.

Total use of each type of fuel during year *t* by all vehicles in use that were originally produced during a single model year is the sum of fuel consumed by the surviving vehicles of each model operating on that type of fuel. Denoting this quantity $G_{MY,t,CAFE,fuel}$, it is computed as:

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[23] We assume that a vehicle's fuel economy is constant over its lifetime, and that the test versus on-road fuel economy gap for each fuel is identical for all vehicle types and ages using that fuel.

$$G_{MY,t,CAFE,fuel} = \sum_{k} g_{k,MY,t,CAFE,fuel} \tag{13}$$

Similarly, total consumption of each type of fuel by all vehicle models produced during a model year over their expected lifetimes, denoted $G_{MY,CAFE,fuel}$, is given by:

$$G_{MY,CAFE,fuel} = \sum_{t} \sum_{k} g_{k,MY,t,CAFE,fuel} \tag{14}$$

As with annual consumption of different types of fuels by individual vehicle models, total annual consumption of each fuel by all vehicle models will differ depending on the CAFE standard that prevailed during the model year when they were originally produced. The change in fuel use that results from imposing a different CAFE standard is always measured *relative to* expected fuel use with some baseline or comparison standard in effect.

The usual assumption employed in the CAFE model is that the baseline fuel economy levels for vehicles produced during a future model year would be those that manufacturers would provide if the most recently adopted standard were extended to apply to future model years. Thus for example, the baseline fuel economy levels projected for vehicles produced during model years 2017-25 are estimated under the assumption that the recently-adopted CAFE standards for model year 2016 cars and light trucks would be extended to apply to model years 2017-25. Estimated fuel consumption with the 2016 CAFE standard assumed to remain in effect for model years after 2016 provides the baseline for measuring reductions in fuel use expected to result from adopting higher CAFE standards for model years 2017-25.

The change in total consumption of each fuel type during year *t* from imposing a higher CAFE standard for model year MY than that assumed to be in effect under the baseline forecast is given by:

$$\Delta G_{MY,t,CAFE,fuel} = G_{MY,t,CAFE,fuel} - G_{MY,t,BASE,fuel} \tag{15}$$

Similarly, the savings in total consumption of each type of fuel by all vehicle models produced during a model year over their expected lifetimes is computed as:

$$\Delta G_{MY,CAFE,fuel} = \sum_{t} G_{MY,t,CAFE,fuel} = \sum_{t} G_{MY,t,CAFE,fuel} - \sum_{t} G_{MY,t,BASE,fuel} \tag{16}$$

In addition, the model calculates corresponding energy consumption (in British thermal units) total energy consumption attributable to each fuel (and to electricity), reporting these quantities on a total and incremental basis.

Section 4 Greenhouse Gas Emissions

Fuel savings from imposing stricter CAFE standards will result in lower emissions of carbon dioxide (CO_2), the primary greenhouse gas emitted during the refining, distribution, and combustion of transportation fuels.[24] Lower fuel consumption reduces carbon dioxide emissions directly, because the largest source of these emissions from transportation activity is fuel use by internal combustion engines. The CAFE model calculates CO_2 emissions from vehicle operation by multiplying the number of gallons of fuel consumed by the carbon content per gallon of fuel, and then applying the ratio of carbon dioxide emissions generated per unit of carbon consumed during the combustion process.[25]

Emissions of carbon dioxide resulting from fuel consumption by all vehicle models produced in model year *MY* during year *t*, denoted $CO2^{veh}_{MY,t,CAFE}$, are calculated from their consumption of each fuel type as:

$$CO2^{veh}{}_{MY,t,CAFE} = \sum_{fuel} \left(G_{MY,t,CAFE,fuel}\, d_{fuel} C_{fuel} \right) \left(\frac{44}{12} \right) \quad \textbf{(17)}$$

where d_{fuel} is the mass density of a fuel (measured in grams per gallon), C_{fuel} is the fraction of each fuel's mass that represents carbon, and (44/12) is the ratio of the molecular weight of carbon dioxide to that of elemental carbon. This ratio measures the mass of carbon dioxide that is produced by complete combustion of mass of carbon contained in each gallon of fuel. Vehicles operating on electricity are assumed to generate no CO_2 emissions during vehicle use.

As with the model's calculations of fuel consumption, estimates of annual CO_2 emissions from fuel use are summed over the calendar years that cars and light trucks produced during each model year are projected to remain in use to obtain estimates of lifetime emissions. Specifically, lifetime CO_2 emissions from fuel consumption by cars or light trucks produced during model year *MY* are given by:

$$CO2^{veh}{}_{MY,CAFE} = \sum_{t} CO2_{MY,t,CAFE} \quad \textbf{(18)}$$

where *t* ranges from *MY* to *MY* plus the maximum age of a car or light truck.

By reducing the volume of fuel consumed, raising CAFE standards will also affect carbon dioxide emissions from refining and distributing liquid fuels, as well as from generating electricity. Carbon dioxide emissions occur during the production of petroleum-based fuels as a

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[24] Carbon dioxide emissions account for more than 97% of total greenhouse gas emissions from the refining and use of transportation fuels; see U.S. Environmental Protection Agency, *Draft Inventory of GHG Emissions and Sinks (1990-1999)*, Tables ES-1 and ES-4, http://www.epa.gov/globalwarming/publications/emissions/us2001/energy.pdf.

[25] The carbon content of gasoline used in the CAFE model is a weighted average of those for different types of gasoline in use. Although the model does not explicitly account for incomplete conversion of carbon to carbon dioxide, input values specifying carbon content can be adjusted accordingly (*i.e.*, reduced to 99-99.5% of actual carbon content).

result of energy use for petroleum extraction, transportation, storage, and refining, as well as during storage and distribution of refined fuel. Producing the chemical feedstocks or agricultural products from which non-petroleum fuels such as ethanol are derived also entails energy use and generates CO_2 emissions, as does refining, storing, and distributing those fuels. Generating electricity for use by PHEVs and EVs using fossil energy sources such as coal or natural gas also produces CO_2 emissions.

The CAFE model calculates reductions in carbon dioxide emissions from each stage of liquid fuel production and distribution using estimates of emissions in each stage of these processes per unit of fuel energy supplied. These estimates are converted to a per-gallon basis using the energy content per gallon of gasoline, diesel, and ethanol, and multiplied by the volume of each fuel consumed to estimate total carbon dioxide emissions from fuel production and distribution. Emissions from generating electricity are estimated from electricity consumption by PHEVs and EVs together with average CO_2 emissions per unit of energy generated, assuming the U.S. average mix of fuel sources and transmission distances.

Total CO_2 emissions from producing and distributing fuel consumed by vehicles of model year *MY* during year *t* of their lifetimes, denoted $CO2^{ref}_{MY,t,CAFE}$, is given by:

$$CO2^{ref}{}_{MY,t,CAFE} = \sum_{fuel} G_{MY,t,CAFE,fuel}\left(CO2^{f}{}_{fuel} + CO2^{r}{}_{fuel} + CO2^{d}{}_{fuel}\right) \qquad \textbf{(19)}$$

where $CO2^{f}_{fuel}$ represents carbon dioxide emissions from feedstock production or extraction per gallon of each type of fuel, $CO2^{r}_{fuel}$ represents emissions per gallon of each type of fuel refined, and $CO2^{d}_{fuel}$ represents carbon dioxide emissions per gallon from transportation, storage, and distribution of liquid fuels. For electricity, the sum of these three emission rates is replaced by a single rate, CO_2 emissions per gasoline gallon equivalent of electrical energy generated. This rate depends on the mix of fuels that is assumed to be used for generating electricity, and can be adjusted by the model user.

Annual CO_2 emissions generated by fuel production and distribution are then summed over the lifetimes of automobiles and light trucks produced during each model year:

$$CO2^{ref}{}_{MY,CAFE} = \sum_{t} CO2_{MY,T,CAFE} \qquad \textbf{(20)}$$

where *t* again ranges from *MY* to *(MY+30)* for cars or *(MY+37)* for light trucks.

Finally, CO_2 emissions from fuel consumption are combined with emissions generated during the fuel supply process to yield total CO_2 emissions from fuel production and consumption by vehicles produced during a model year over their expected lifetimes. Total lifetime emissions attributable to cars or light trucks produced during model year *MY* are:

$$CO2^{tot}{}_{MY,CAFE} = CO2^{veh}{}_{MY,CAFE} + CO2^{ref}{}_{MY,CAFE} \qquad \textbf{(21)}$$

The presence of the CAFE subscript on total emissions indicates that these depend on the specific CAFE standard in effect, because that standard affects the fuel economy of individual vehicle models and their lifetime total fuel consumption. The change in CO_2 emissions expected to result from imposing a new CAFE standard for that model year is calculated as the difference in total lifetime emissions of cars or light trucks produced in that model year with the new standard in effect, and their total emissions with the baseline CAFE standard in effect:

$$\Delta CO2^{tot}{}_{MY,CAFE} = CO2^{tot}{}_{MY,CAFE} - CO2^{tot}{}_{MY,BASE} \tag{22}$$

Because imposing a higher CAFE standard reduces fuel consumption over the lifetimes of vehicles produced during the model years it affects, and CO_2 emissions are a direct product of the volume of fuel produced and consumed, imposing a higher CAFE standard also reduces their lifetime CO_2 emissions.

Section 5 Air Pollutant Emissions

Stricter CAFE standards can result in higher or lower emissions of criteria air pollutants, by-products of fuel combustion that are also emitted during the production and distribution of fuel. Criteria pollutants that are emitted in significant quantities by light-duty motor vehicles include carbon monoxide, various hydrocarbon compounds, nitrogen oxides, sulfur dioxide, and fine particulate matter.

The increased use of vehicle models with improved fuel economy that occurs through the fuel economy rebound effect causes increased emissions of most criteria pollutants, since federal standards regulate permissible emissions of these pollutants on a per-mile basis.[26] In contrast, reductions in the volume of fuel consumed that result from requiring higher fuel economy cause emissions of criteria pollutants during fuel production and distribution to decline. The net change in total emissions of each criteria pollutant that results from imposing a higher CAFE standard depends on the relative magnitudes of changes in emissions from vehicle use and from fuel refining and distribution.

The CAFE model calculates emissions of most criteria pollutants resulting from vehicle operation by multiplying the number of miles driven by vehicles of a model year during each year they remain in service by per-mile emission rates for each pollutant, which are derived from EPA's Motor Vehicle Emissions Simulator (MOVES). These emission rates differ among automobiles and light trucks operating on different fuel types; PHEVs operating on electricity and EVs are assumed to generate no emissions of criteria air pollutants during vehicle use.

Total emissions of a criteria pollutant from the use of cars or light trucks produced during model year MY during year t of their lifetimes, denoted $E^{veh}{}_{MY,t}$, are thus:

$$E^{veh}{}_{MY,t,CAFE} = \sum_{fuel}\sum_{k} M_{k,MY,t,CAFE}\, s_{k,MY,CAFE,fuel}\, e_{k,t-MY,fuel} \tag{23}$$

where, as in equation (12) above, $M_{k,MY,t,CAFE}$ is total miles driven during year t by vehicles of model k originally produced during model year MY, and $s_{k,MY,CAFE,fuel}$ is the share of those miles that model k operates on each type of fuel.[27]

In equation (23), $e_{k,t-MY,fuel}$ is the per-mile rate at which vehicles of model k emit a criteria air pollutant during year t when using each type of fuel. These emission rates can depend on a vehicle model's age and accumulated mileage, and during year t, vehicles produced during model year MY will have reached age (t-MY).[28] Emission rates from vehicle use also depend on

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[26] The exception is sulfur dioxide, which is estimated from the sulfur content of each type of fuel using a procedure exactly analogous to the estimation of CO_2 emissions from the carbon content of each fuel type.

[27] As in equation (12), the CAFE subscript on s indicates that the type of fuel on which a vehicle model produced during a specific model year operates can depend on the CAFE standard in effect for that model year.

[28] The emission rates derived from MOVES are projected to be identical for all model years after 2011, and to remain constant over those vehicles' lifetimes.

fuel type, although vehicles using electricity are assumed to produce no emissions during their operation.

As with fuel use and CO_2 emissions, annual emissions of each criteria air pollutant are summed over the future years that vehicle models originally produced during each model year are expected to be in service, in order to produce estimates of their total lifetime emissions:

$$E^{veh}{}_{MY,CAFE} = \sum_{t} E^{veh}{}_{MY,t,CAFE} \tag{24}$$

where as usual, t begins at a value of MY and increases to MY plus the maximum lifetimes assumed for automobiles and light trucks.

Emissions of criteria air pollutants that occur during fuel refining and distribution are estimated by applying emission factors for each pollutant per gallon of fuel refined to the total volumes of gasoline, diesel, and ethanol projected to be consumed during future years. Emissions from generating electricity used by PHEVs and EVs are calculated using emission factors for each criteria air pollutant per unit of electricity generated. In contrast to CO_2 emissions, which are included regardless of where petroleum extraction and fuel refining occur throughout the world, only domestic emissions of criteria air pollutants are included.

Thus emissions of each criteria air pollutant from producing and distributing the fuel consumed by cars or light trucks of model year MY during year t of their lifetimes, denoted $E^{ref}{}_{MY,t,CAFE}$, are:

$$E^{ref}{}_{MY,CAFE} = \sum_{t} G_{my,t,CAFE,fuel}[e^{f}{}_{fuel} r_{fuel} f_{fuel}) + e^{r}{}_{fuel} r_{fuel} + e^{d}{}_{fuel}) \tag{25}$$

where $e^{f}{}_{fuel}$, $e^{r}{}_{fuel}$, and $e^{d}{}_{fuel}$ are emissions of a criteria air pollutant per gallon of fuel supplied that occur during feedstock production or extraction, fuel refining, and transportation, storage, and distribution of refined fuel. Because different fuels utilize different feedstocks, refining processes, and distribution networks, each of these factors can differ by type of fuel. The parameter r_{fuel} indicates the fraction of each type of fuel that is refined domestically (using either domestically-produced or imported feedstocks), while f_{fuel} indicates fraction of domestic refining that utilizes domestically-produced feedstocks.

For vehicles operating on electricity, the bracketed expression in equation (25) is replaced by a single factor measuring criteria pollutant emissions per gasoline gallon equivalent of electricity generated. As with CO_2 emissions, the values of these emission factors for each criteria air pollutant depend on the fuel mix assumed to be used for generating electricity, and can be adjusted accordingly by the model user. All electricity consumed by PHEVs and EVs is assumed to be generated domestically.

Emissions of each criteria pollutant attributable to producing and distributing the fuel consumed by cars or light trucks initially produced during model year MY over their lifetimes are:

$$E^{ref}{}_{MY,CAFE} = \sum_{t} E^{ref}{}_{MY,T,CAFE} \tag{26}$$

Finally, total emissions of each criteria pollutant over the lifetimes of cars or light trucks of model year *MY* are the sum of emissions that occur as a result of their lifetime use, and emissions from producing and distributing the fuel they consume over their lifetimes:

$$E^{tot}{}_{MY,CAFE} = E^{veh}{}_{MY,CAFE} + E^{ref}{}_{MY,CAFE} \quad \textbf{(27)}$$

Again, the presence of the CAFE subscript in equation (27) indicates that vehicles' lifetime emissions depend on the CAFE standard in effect during the model year they are produced, through its effect on their fuel economy, usage, and fuel consumption.

As a consequence, total lifetime emissions of each criteria air pollutant by cars and light trucks produced during future model years will differ between the baseline CAFE standard and any alternative standard that is specified. The model calculates the effect of imposing a higher CAFE standard on emissions of criteria air pollutants as the difference between lifetime emissions by cars and light trucks produced during each model year it would affect, and those vehicles' emissions under the baseline CAFE standard:

$$\Delta E^{tot}{}_{MY,CAFE} = E^{tot}{}_{MY,CAFE} - E^{tot}{}_{MY,BASE} \quad \textbf{(28)}$$

Section 6 Private versus Social Costs and Benefits

Improving the fuel efficiency of new vehicles produces a wide range of benefits and costs, many of which affect buyers of those vehicles directly. Depending upon how manufacturers attempt to recoup the costs they incur for improving the fuel efficiency of selected models, buyers are likely to face higher prices for some – and perhaps even most – new vehicle models. Purchasers of models whose fuel economy is improved benefit from the resulting savings in the cost of fuel their vehicles consume, from any increase in the range they can travel before needing to refuel, and from the added driving they do as a result of the rebound effect. Depending on the technology manufacturers use to improve fuel economy and its consequences for vehicle power and weight, these benefits may be partly offset by a slight decline in the performance of some new models.

At the same time, the reduction in fuel production and use resulting from improved fuel economy produces certain additional benefits and costs to society as a whole. Potential social benefits from reduced fuel use include any value that society or the U.S. economy attaches to saving fuel over and above its private value to new vehicle buyers, lower emissions of air pollutants and greenhouse gases generated from fuel production, distribution, and consumption, and reduced economic costs associated with U.S. imports of crude petroleum and refined fuel. By causing some additional driving through the rebound effect, improving fuel economy can also increase a variety of social costs, including the economic value of health effects and property damages caused by increased air pollution, the value of time delays to motorists from added traffic congestion, added costs of injuries and property damage resulting from more frequent traffic accidents, and economic costs from higher levels of traffic noise.

The following sections discuss how each of these benefits and costs can result from improving the fuel economy of new vehicles, the factors affecting their likely magnitudes, and how their values are commonly measured or estimated. Section A.3 of Appendix A provides examples of specific unit economic values and other parameters used to estimate the aggregate value of these various benefits and costs, and explains how these sample values were derived.

S6.1 Benefits and Costs to New Vehicle Buyers

S6.1.1 Increases in New Vehicle Prices

Depending upon how manufacturers attempt to recover the costs they incur in complying with CAFE regulations, purchase prices for some new models are likely to increase. Because we assume that manufacturers fully recover all costs they incur for installing fuel economy technologies to comply with CAFE in the form of higher prices for some models, the total increase in vehicle sales prices has already been accounted for in estimating technology costs to manufacturers. Nevertheless, the total value of these price increases represent a cost of CAFE regulation from the viewpoint of buyers of vehicle models whose prices rise.

In addition to increases in the prices paid by buyers who elect to purchase these models even at the higher price points, higher prices result in losses in welfare or consumer surplus to buyers who decide to purchase different models instead. These losses are extremely complex to estimate if prices change for a large number of models, and in any case are likely to be small even in total. Thus we do not attempt to estimate their value.

S6.1.2 The Value of Fuel Savings

The CAFE modeling system estimates the economic value of fuel savings to buyers of new vehicle models whose fuel economy is improved by applying the forecast (an input to the model) of future retail fuel prices to each year's estimated fuel savings for those models. The annual fuel savings for a model during each year of its lifetime in the vehicle fleet is multiplied by the number of those initially sold that are expected to remain in use during that year to determine the total annual value of fuel savings to buyers of that model.

The forecast retail price of fuel per gallon – including federal and average state fuel and other taxes – during that year is used to estimate the value of these fuel savings as viewed from the perspective of their buyers. Based on evidence from previous studies of consumer purchases of automobiles and durable appliances, we assume that new vehicle buyers value these savings over the approximate number of years (an input to the model) they expect to own a new vehicle, and that they discount these expected savings to the year in which they purchase new vehicles.

S6.1.3 Benefits from Additional Driving

The rebound effect also results in additional benefits to new vehicle buyers in the form of consumer surplus from the increased driving it produces. These benefits arise from the value to drivers and passengers of the social and economic opportunities made available to them by additional traveling. As evidenced by the fact that they elect to make more frequent or longer trips when improved fuel economy reduces the cost of driving, the benefits from this additional travel exceed the costs drivers and their passengers incur in making more frequent or longer trips. The amount by which these benefits from additional travel exceed its cost to them – which has been reduced by improved fuel economy – represents the increase in consumer surplus associated with additional rebound effect driving.

The system estimates the value of these benefits using the conventional approximation of one half of the product of the decline in fuel cost per mile driven and the resulting increase in the annual number of miles driven. This value is calculated for each year that a model whose fuel economy is improved remains in the fleet, multiplied by the number of vehicles of that model expected to remain in use during each year of its lifetime, and discounted to its present value as of the year it was purchased. Given typical input values (*e.g.*, for fuel prices), this benefit is relatively small by comparison to most other economic impacts of raising CAFE standards.

S6.1.4 The Value of Extended Refueling Range

Manufacturers' efforts to improve the fuel economy of selected new vehicle models will also increase their driving range per tank of fuel. By reducing the frequency with which drivers typically refuel their vehicles, and by extending the upper limit of the range they can travel before requiring refueling, improving fuel economy thus provides some additional benefits to their owners.[29] No direct estimates of the value of extended vehicle range are readily available, so the CAFE model calculates the reduction in the annual number of required refueling cycles that results from improved fuel economy. The change in required refueling frequency for vehicle models with improved fuel economy reflects the increased driving associated with the rebound effect, as well as the increased driving range stemming from higher fuel economy.

S6.1.5 Changes in Performance and Utility

The system currently assumes that the costs and effects of fuel-saving technologies reflect the application of these technologies in a manner that holds vehicle performance and utility constant. Therefore, the system currently does not estimate changes in vehicle performance or utility.

S6.1.6 Social Benefits and Costs from Increased Fuel Economy

S6.1.6.1 The "Social Value" of Fuel Savings

The economic value to society of the annual fuel savings resulting from stricter CAFE standards is also assessed by applying estimated future fuel prices to each year's estimated fuel savings. Unlike the value of fuel savings to vehicle buyers themselves, however, the *pre-tax* price per gallon is used in assessing the value of fuel savings *to the economy as a whole*. This is because reductions in payments of state and federal taxes by purchasers of fuel will be exactly offset by reduced spending on the construction and maintenance of streets and highways that fuel taxes are mainly used to finance, and thus do not reflect a net savings in resources to the economy.

When estimating the nationwide aggregate economic benefits and costs from CAFE regulation, we include this "social" value of fuel savings rather than their private value to vehicle buyers. In computing the social value of fuel savings, we include their annual value over the *entire* expected lifetimes of vehicle models whose fuel economy is improved, reflecting the presumably longer-term horizon of society as a whole compared to that of vehicle buyers, who may be concerned with fuel savings only over the time they expect to own newly-purchased vehicles.

S6.1.6.2 Economic Benefits from Reduced Petroleum Imports

Importing petroleum into the United States is widely believed to impose significant costs on households and businesses that are not reflected in the market price for imported oil, and thus are not borne by consumers of refined petroleum products. These costs include three components: (1) higher costs for oil imports resulting from the combined effect of U.S. import demand and OPEC market power on the world oil price; (2) the risk of reductions in U.S. economic output and disruption of the domestic economy caused by sudden reductions in the supply of imported oil; and (3) costs for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the Strategic Petroleum Reserve (SPR) to cushion against price increases. By reducing domestic demand for gasoline, tighter CAFE standards can reduce petroleum imports, and thus reduce these social costs to the extent that their magnitude varies

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[29] If manufacturers instead respond to improved fuel economy by reducing the size of fuel tanks to maintain a constant driving range, the resulting savings in costs will presumably be reflected in lower sales prices.

with the volume of U.S. oil imports. Any reduction in their magnitude represents an additional category of economic benefits from tighter fuel economy standards.

In this analysis, the reduction in petroleum imports resulting from higher CAFE standards is estimated by assuming that the resulting savings in gasoline use during each future year is translated directly into a corresponding reduction in the annual volume of U.S. oil imports during that same year. The value to the U.S. economy of reducing petroleum imports – in the form of lower crude oil prices and reduced risks of oil supply disruptions – is estimated by applying the sum of the previously reported estimates of these benefits to the estimated annual reduction in oil imports.

S6.1.6.3 Valuing Changes in Environmental Impacts

The CAFE modeling system estimates the economic value of the net change in emissions of criteria pollutants, including carbon monoxide, volatile organic compounds, nitrogen oxides, sulfur dioxide, and fine particulates, using estimates of the economic damage costs per ton of emissions of each of these pollutants. As indicated previously, emissions of criteria pollutants can rise or fall when fuel economy increases, so the economic costs of these emissions can increase or decline in response to higher CAFE standards.

The model estimates changes in damage costs caused by carbon dioxide emissions by multiplying the magnitude of the change in emissions by the estimated value of damages per unit of emissions.

S6.1.7 Social Costs of Added Driving

In addition to increasing emissions of criteria pollutants, any added driving associated with the fuel economy rebound effect may contribute to increased traffic congestion, motor vehicle accidents, and highway noise. Additional vehicle use can contribute to traffic congestion and delays partly by increasing recurring congestion on heavily-traveled facilities during peak travel periods, depending on how the additional travel is distributed over the day and on where it occurs. Added driving can also increase the frequency of incidents such as collisions and disabled vehicles that cause prolonged delays, although the extent to which it actually does do will again depend partly on when and where the added travel occurs. Finally, added vehicle use from the rebound effect may also increase traffic noise, which causes inconvenience, irritation, and potentially even discomfort to occupants of other vehicles, pedestrians and other bystanders, and residents or occupants of surrounding property.

The CAFE modeling system uses estimates of the increases in external costs – that is, the marginal social costs – from added congestion, property damages and injuries in traffic accidents, and noise levels caused by additional vehicle usage. It does so by applying estimates of the increases in these costs that result from each added mile of travel by different types of vehicles (passenger and nonpassenger automobiles) to the increase in the total number of miles driven projected to result from the rebound effect.

Appendix A Model Inputs

The CAFE Compliance and Effects Modeling System utilizes a set of data files used as input to the analysis. All input files are specified in Microsoft® Excel format and are outline in Table 5 below. The user can define and edit all inputs to the system. For example, the system does not require market data constructed using confidential business information.

Table 5. Input Files

Input File	Contents
Market Data (Manufacturers Worksheet)	Contains an indexed list of manufacturers available during the study period, along with manufacturer's willingness to pay fines and other manufacturer-specific modeling settings.
Market Data (Vehicles Worksheet)	Contains an indexed list of vehicle models available during the study period, along with sales volumes, fuel economy levels, prices, other attributes, domestic labor utilization, references to specific engines and transmissions used, and optional settings related to technology applicability, designation as a passenger or nonpassenger automobile, and coverage of vehicles with GVWR above 8,500 pounds.
Market Data (Engines Worksheet)	Contains an indexed list of engines available during the study period, along with various engine attributes and optional settings related to technology applicability.
Market Data (Transmissions Worksheet)	Contains an indexed list of transmissions available during the study period, along with various transmission attributes and optional settings related to technology applicability.
Technologies	Specifies estimates of the availability, cost, and effectiveness of various technologies, specific to various vehicle categories.
Parameters	Provides inputs used to calculate travel demand, fuel consumption, carbon dioxide and criteria pollutant emissions, and economic externalities related to highway travel and petroleum consumption.
Tailpipe Emissions	Provides inputs used to project the tailpipe emissions of various pollutants.
Scenarios	Specifies coverage, structure, and stringency of CAFE standards for scenarios to be simulated.
EIS Parameters	Provides additional inputs necessary for calculating VMT and fuel use for the EIS. This input file is required for EIS modeling only.
EIS Tailpipe Emissions	Provides inputs necessary for calculating tailpipe emissions for the EIS . This input file is required for EIS modeling only.

A.1 Market Data File

The market data file contains four worksheets: Manufacturers, Vehicles, Engines and Transmissions. Taken together, the manufacturers, vehicle models, engines, and transmissions worksheets provide “initial state” historical and/or forecast data for the light vehicle fleet. The sections below describe each worksheet in greater detail.

A.1.1 Manufacturers Worksheet

The manufacturers input worksheet contains a list of all manufacturers that produce vehicle models offered for sale during the study period. Each manufacturer has a unique code and is represented by a unique manufacturer name. For each manufacturer, the manufacturer code, name, cost allocation strategy, discount rate, payback periods, and willingness to pay CAFE fines must all be specified. Available credits, if applicable, should be expressed in Vehicle/MPG and is applied directly as a credit (positive or negative) to the CAFE level for the given manufacturer in the given model year. If no available credits are to be specified, a value of zero (0.0) can be used or the cell can be left blank.

Table 6. Manufacturers Worksheet

Category	Column	Units	Definition/Notes
General	Manufacturer Code	integer	Unique number assigned to each manufacturer.
	Manufacturer Name	text	Name of the manufacturer.
	Cost Allocation Strategy	integer	The cost allocation strategy the manufacturer will use for allocating costs. 0 = allocate technology costs on an as-incurred basis 1 = distribute technology costs and fines based on the share of aggregate sales revenue 2 = not used 3 = distribute technology costs and fines evenly
	Discount Rate	number	Represents the manufacturer specific discount rate, which factors into the effective cost calculation.
	Payback Period	number	The number of years required for an initial investment to be repaid in the form of future benefits or cost savings.
	Payback Period (After Compliance)	number	The payback period to use after the manufacturer reached compliance.
	Optimize	text	Y = consider the manufacturer during optimization N = do not consider the manufacturer during optimization
Willingness to Pay CAFE Fines	2011	text	Represents the manufacturer's willingness to pay fines. Y = pay fines instead of applying ineffective technologies N = apply ineffective technologies instead of paying fines
	2012	text	
	…		
	2024	text	
	2025	text	
Available Domestic Auto Credits (mpg)	2011	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Domestic Automobiles.
	2012	vehicle-mpg	
	…		
	2024	vehicle-mpg	
	2025	vehicle-mpg	
Available Imported Auto Credits (mpg)	2011	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Imported Automobiles.
	2012	vehicle-mpg	
	…		
	2024	vehicle-mpg	
	2025	vehicle-mpg	
Available Light Truck Credits (mpg)	2011	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Light Trucks.
	2012	vehicle-mpg	
	…		
	2024	vehicle-mpg	
	2025	vehicle-mpg	
Credits Apply to Baseline		text	Y = apply manufacturer's credits to the baseline scenario N = do not apply manufacturer's credits to the baseline scenario

A.1.2 Vehicles Worksheet

The vehicles worksheet contains information regarding each vehicle model offered for sale during the study period. Each vehicle model is represented as a single row of input data. Data in Table 7, Table 8, and Table 9 list the different columns of information specified in the vehicle models file. To make the information readable, the Vehicle Models tables are presented vertically and divided into sections.

In the “General” category, the vehicle code, manufacturer, model, nameplate, engine code, transmission code, and origin must be specified for each vehicle model. The engine and transmission codes must refer to a valid engine and transmission, respectively, for the relevant manufacturer in the engines and transmissions worksheets. Vehicle’s fuel economy and assumed share of operating on a specific fuel are specified in the “Fuel Economy” section. Known or projected sales are specified in the “Sales” section for each model year in which the model is offered. The known or projected MSRP should be specified in its corresponding section for each model year in which the vehicle model is offered for sale. In the “Regulatory Classification” section, the regulatory, technology, and safety class assignments for each vehicle must be specified.

Table 7. Vehicles Worksheet (1)

Category	Column	Units	Definition/Notes
General	Vehicle Code	integer	Unique number assigned to each vehicle.
	Manufacturer	text	The manufacturer of the vehicle.
	Model	text	Name of the vehicle model.
	Nameplate	text	The nameplate of the vehicle.
	Engine Code	integer	The engine code of the engine that the vehicle uses.
	Transmission Code	integer	The transmission code of the transmission that the vehicle uses.
	Origin	text	D = domestic; I = imported
Fuel Economy	Fuel Economy (Gasoline)	number	The CAFE fuel economy rating of the vehicle for each fuel type.
	Fuel Economy (Diesel)	number	
	Fuel Economy (Ethanol-85)	number	
	Fuel Economy (Electricity)	number	
	Fuel Economy (Hydrogen)	number	
	Fuel Share (Gasoline)	number	The percent share that the vehicle runs on each fuel type.
	Fuel Share (Diesel)	number	
	Fuel Share (Ethanol-85)	number	
	Fuel Share (Electricity)	number	
	Fuel Share (Hydrogen)	number	
Sales	MY2011	units	Vehicle's projected production for sale in the US.
	MY2012	units	
	…		
	MY2024	units	
	MY2025	units	
MSRP	MY2011	dollars	Vehicle's projected average MSRP (sales-weighted, including options).
	MY2012	dollars	
	…		
	MY2024	dollars	
	MY2025	dollars	
Regulatory Classification	Regulatory Class	text	The regulatory assignment of the vehicle. PC = the vehicle should be regulated as a passenger automobile LT = the vehicle should be regulated as a light truck
	Technology Class	text	The technology class of the vehicle.
	Safety Class	text	The safety class assignment of the vehicle. PC = the vehicle belongs to a passenger automobile safety class LT = the vehicle belongs to a light truck/SUV safety class CM = the vehicle belongs to a light CUV/minivan safety class

Within the "Vehicle Information" category, it is important that each vehicle model's class, style, structure, drive, footprint, curb weight, GVWR, and fuel capacity be specified. For any hybrid vehicle models, it is necessary to specify the type of hybridization as well. If a vehicle also operates on electricity, the electric power and range need to be available as well. In the "Planning & Assembly" section, the redesign and refresh years must be comma separated and contain all known previous and projected future redesign and refresh years.

Table 8. Vehicles Worksheet (2)

Category	Column	Units	Definition/Notes
Vehicle Information	Class	text	Vehicle class.
	Style	text	Vehicle style.
	Structure	text	Vehicle structure (ladder or unibody).
	Drive	text	Vehicle drive (A=all-wheel drive, F=front-wheel drive, R=rear-wheel drive, 4=four-wheel drive).
	Footprint	sq. feet	The vehicle footprint; wheelbase times average track width.
	Curb Weight	pounds	Total weight of the vehicle, including batteries, lubricants, and other expendable supplies, but excluding the driver, passengers, and other payloads (SAE J1100).
	GVWR	pounds	Gross Vehicle Weight Rating; weight of loaded vehicle, including passengers and cargo.
	Seating (Max)	integer	The number of usable seat belts before folding and removal of seats (where accomplished without specific tools).
	Fuel Capacity	gallons	The capacity of the vehicle's fuel tank in gallons of diesel fuel or gasoline; MJ (LHV) of other fuels (or chemical battery energy).
Hybridization	Type of Hybrid/Electric Vehicle	text	Hybridization type of the vehicle, if any.
	Electric Power	number	The power rating (equivalent to engine horsepower) for an electric vehicle.
	Electric Range	number	The range of an electric vehicle, in miles, when operating on a battery.
Planning and Assembly	Refresh Years	model year	Comma separated list of previous and future refresh years of the vehicle.
	Redesign Year	model year	Comma separated list of previous and future redesign years of the vehicle.
	Employment Hours per Vehicle	hours	Employment hours associated with the production of each vehicle model.

The applicability of technologies considered on a vehicle model basis (as opposed, for example, on an engine basis) can be controlled for each vehicle model by using the "Technology Applicability" category. This section must be completed to prevent double counting of technologies.

Table 9. Vehicles Worksheet (3)

Category	Column	Units	Definition/Notes
Technology Applicability	EPS	text	<blank> = the technology is not used on the vehicle USED = the technology is used on the vehicle SKIP = the technology is not applicable to the vehicle
	IACC1	text	
	IACC2	text	
	MHEV	text	
	ISG	text	
	SHEV1	text	
	SHEV1_2	text	
	SHEV2	text	
	PHEV1	text	
	PHEV2	text	
	EV1/EV2/EV3/EV4	text	
	FCV	text	
	MR1/MR2/MR3/MR4/MR5	text	
	ROLL1/ROLL2/ROLL3	text	
	LDB	text	
	SAX	text	
	AERO1	text	
	AERO2	text	

A.1.3 Engines Worksheet

Similar to the vehicles input sheet, the engines worksheet contains a list of all engines used in vehicle models offered for sale during the study period. For each manufacturer, the engine code is a unique number assigned to each such engine. This code is referenced in the engine code field on the vehicles worksheet. For each engine, the engine code, manufacturer, configuration, fuel, cycle, aspiration, valve actuation/timing, valve lift, number of cylinders, number of valves per cylinder, and horsepower must all be specified. As in the vehicles worksheet, the technology applicability for any engine technology must be specified for any specific engine.

Table 10. Engines Worksheet

Category	Column	Units	Definition/Notes
General	Engine Code	integer	Unique number assigned to each engine.
	Manufacturer	text	The manufacturer of the engine.
	Configuration	text	Configuration of the engine.
	Fuel	text	One or more fuel types with which the engine is compatible: G = gasoline only; D = diesel only; E85 = ethanol-85 only; G+E85 = flex fuel engine, running on gasoline and ethanol-85
	Engine Oil Viscosity	text	Ratio between the applied shear stress and the rate of shear, which measures the resistance of flow of the engine oil (as per SAE Glossary of Automotive Terms).
	Cycle	text	Combustion cycle of the engine.
	Fuel Delivery System	text	The mechanism that delivers fuel to the engine.
	Aspiration	text	Breathing or induction process of the engine (as per SAE Automotive Dictionary).
	Valvetrain Design	text	Design of the total mechanism from camshaft to valve of an engine that actuates the lifting and closing of a valve (as per SAE Automotive Dictionary).
	Valve Actuation/Timing	text	Valve opening and closing points in the operating cycle (SAE J604).
	Valve Lift	text	The manner in which the valve is raised during combustion (as per SAE Automotive Dictionary).
	Cylinders	integer	Number of engine cylinders.
	Valves/Cylinder	integer	Number of valves per cylinder.
	Deactivation	text	Weighted (FTP+highway) aggregate degree of deactivation.
	Displacement	liters	Total volume displaced by a piston in a single stroke.
	Max. Horsepower	number	Maximum horsepower of the engine (horsepower).
	Max. Torque	number	Maximum torque of the engine (pound-foot).
Technology Applicability	LUB1	text	<blank> = the technology is not used on the engine USED = the technology is used on the engine SKIP = the technology is not applicable to the engine
	EFR1	text	
	LUB2_EFR2	text	
	CCPS	text	
	DVVLS	text	
	DEACS	text	
	ICP	text	
	DCP	text	
	DVVLD	text	
	CVVL	text	
	DEACD	text	
	SGDI	text	
	DEACO	text	
	VVA	text	
	SGDIO	text	
	TRBDS1 (_SD/_MD/_LD)	text	
	TRBDS2 (_SD/_MD/_LD)	text	
	CEGR1 (_SD/_MD/_LD)	text	
	CEGR2 (_SD/_MD/_LD)	text	
	ADSL (_SD/_MD/_LD)	text	

A.1.4 Transmissions Worksheet

Similar to the vehicles and engines input sheets, the transmissions worksheet contains a list of all transmissions used in vehicle models offered for sale during the study period. For each manufacturer, the transmission code is a unique number assigned to each such transmission. This code is referenced in the transmission code field on the vehicles worksheet. For each transmission, the transmission code, manufacturer, type, and number of forward gears must all be specified. As in the vehicles worksheet, the technology applicability for any transmission technology must be specified for any specific transmission.

Table 11. Transmissions Worksheet

Category	Column	Units	Definition/Notes
General	Transmission Code	integer	Unique number assigned to each transmission.
	Manufacturer	text	The manufacturer of the transmission.
	Type	text	Type of the transmission.
	Number of Forward Gears	integer	Number of forward gears the transmission has.
Technology Applicability	6MAN	text	<blank> = the technology is not used on the transmission USED = the technology is used on the transmission SKIP = the technology is not applicable to the transmission
	HETRANSM	text	
	IATC	text	
	NAUTO	text	
	DCT	text	
	8SPD	text	
	HETRANS	text	
	SHFTOPT	text	

A.2 Technologies File

The technologies input file contains assumptions regarding the fuel consumption benefit, cost, applicability, and availability of different vehicle, engine, and transmission technologies during the study period. Input assumptions are specific to each of the following vehicle technology classes: subcompact cars, subcompact performance cars, compact cars, compact performance cars, midsize cars, midsize performance cars, large cars, large performance cars, minivans, small pickups and SUVs, midsize pickups and SUVs, and large pickups and SUVs. Input assumptions that are common among all technology classes are listed on a separate technologies definitions tab. Table 12 shows the contents of a technologies definitions tab for all classes while Table 13 shows the contents of the technology assumptions tabs.

Table 12. Technologies Definitions

Category	Column	Units	Definition/Notes
General	Index	integer	Unique number assigned to each technology.
	Technology	text	Name of the technology.
	Abbr.	text	Abbreviation of the technology.
	TechType	text	The group of a technology: EngMod = the type of the technology is engine modification TrnMod = the type of the technology is transmission modification ELEC = the type of the technology is electric system improvement MR = the type of the technology is mass reduction ROLL = the type of the technology is rolling resistance tires DLR = the type of the technology is dynamic load reduction AERO = the type of the technology is aerodynamics modification
Phase-in Values	PV-1	percentage	Percentage of the entire fleet to which the technology may be applied.
	PV-2	percentage	
	…		
	PV-16	percentage	
	PV-17	percentage	
Early Replacement Penalty Cost Table	ERC-1	dollars	Penalty costs associated with replacing (or superseding) a technology early.
	ERC-2	dollars	
	…		
	ERC-9	dollars	
	ERC-10	dollars	

The technologies are organized into technology groups specified by the TechType column. Each technology group is populated with specific technologies following the sequence specified by the Index column. The modeling system also follows the index sequence as it evaluates technologies for applicability. The sequence of engine and transmission technologies may be split to follow slightly different paths, based on the original vehicle, engine, or transmission characteristics, or depending on which technologies have already been applied to a vehicle. For example, if the original vehicle uses a manual transmission with fewer than six gears, the available technologies would be the 6-speed manual transmission and high efficiency gearbox (HETRANSM). If the original vehicle, however, starts out with a 5-speed automatic transmission, the technologies applied would follow the following path: IATC, 6-speed automatic transmission (NAUTO), 6-speed DCT, 8-speed automatic transmission, high efficiency gearbox (HETRANS), and shift optimizer (SHFTOPT).

Table 13. Technologies Assumptions

Category	Column	Units	Definition/Notes
General	Index	integer	Unique number assigned to each technology.
	Technology	text	Name of the technology.
	Abbr.	text	Abbreviation of the technology.
	TechType	text	The group of a technology: EngMod = the type of the technology is engine modification TrnMod = the type of the technology is transmission modification ELEC = the type of the technology is electric system improvement MR = the type of the technology is mass reduction ROLL = the type of the technology is rolling resistance tires DLR = the type of the technology is dynamic load reduction AERO = the type of the technology is aerodynamics modification
Availability	Applicable	boolean	TRUE = the technology is available for applicability in a technology class FALSE = the technology is not available for applicability in a technology class
	Year Avail.	model year	First year the technology is available for applicability.
	Year Retired	model year	Last year the technology is available for applicability.
Misc Attributes	Electric Range	number	What the range, in miles, of an electric vehicle would be when operating on a battery, as a result of applying the technology; applies to PHEV and EV technologies only.
	Delta Weight (%)	percentage	Percentage by which the vehicle's weight changes as a result of applying the technology.
	Delta Weight (lbs)	number	Amount of pounds by which the vehicle's weight changes as a result of applying the technology.
	Loss of Value	dollars	The consumer welfare loss associated with application of the technology.
FC Improvements	FC	percentage	Overall fuel consumption improvement estimate of the technology.
	FCG	percentage	Fuel consumption improvement estimate to apply to the gasoline fuel economy value (applicable to plug-in HEVs only).
	FCG Share	percentage	Percentage of time the vehicle is expected to run on the gasoline fuel after applying the technology (applicable to plug-in HEVs only).
	Off-Cycle Credit PC	number	Amount of off-cycle credit that the vehicles regulated as passenger automobiles incur as a result of applying the technology
	Off-Cycle Credit LT	number	Amount of off-cycle credit that the vehicles regulated as nonpassenger automobiles inccur as a result of applying the technology
Cost Table	Cost 2009	dollars	Table of learned out cost estimates for the technology, per model year.
	Cost 2010	dollars	
	…		
	Cost 2024	dollars	
	Cost 2025	dollars	
Maint. Table	Maint. 2009	dollars	Table of learned out maintenance cost estimates for the technology, per model year.
	Maint. 2010	dollars	
	…		
	Maint. 2024	dollars	
	Maint. 2025	dollars	
Repair Table	Repair 2009	dollars	Table of learned out repair cost estimates for the technology, per model year.
	Repair 2010	dollars	
	…		
	Repair 2024	dollars	
	Repair 2025	dollars	

A.2.1 Technology Synergies

Technology synergies occur when the combined effect of two technologies is greater than (or less than) the fuel consumption reduction for the two technologies combined. To support synergies, the technology input file has synergy sections for cost and fuel improvements. Contents of the synergy tables are shown in Table 14 below.

The synergy table is most commonly used for synergistic interactions in vehicle technologies from differing technology groups (*e.g.*, between engine technologies and transmission technologies). Synergies within a technology group are already built into the cost and fuel reduction values for the technologies. Therefore, in-group synergies are not likely to occur, unless special circumstances arise, such as branching of technology paths.

Table 14. Technology Synergies

Category	Column	Units	Definition/Notes
General	Type	text	The synergy type relation between two technologies. The "accounting" type indicates that the synergy relation between two technologies is to provide accounting adjustments for the decision trees and is the only synergy type applied to technology costs. The "physical" type indicates that the synergy relation between two technologies is to address physical energy losses.
	Technology A	text	Abbreviation of the first technology in a synergy pair.
	Technology B	text	Abbreviation of the second technology in a synergy pair.
Technology Class	Subcompact PC	percentage	Values to offset the technology cost or fuel consumption when either of technology A or B is being applied when the other is already installed.
	Subcompact Perf. PC		
	Compact PC		
	Compact Perf. PC		
	Midsize PC		
	Midsize Perf. PC		
	Large PC		
	Large Perf. PC		
	Minivan LT		
	Small LT		
	Midsize LT		
	Large LT		

When a technology is being applied (or is being tested for application), a lookup is performed in the "Technology A" and "Technology B" columns of the table. If found, the vehicle is examined to determine if the paired technology (or technologies) have been applied (or are installed as part of the base vehicle definition). If so, the offset value for the applicable vehicle class is obtained, summed, and applied to the cost or fuel consumption reduction of the technology being examined.

A.3 Parameters File

The benefits model parameters file contains a variety of input data and assumptions used to estimate various impacts of the simulated response of the industry to CAFE standards. The file contains a series of worksheets, the contents of which are summarized below.

A.3.1 Vehicle Age Data

The Vehicle Age Data worksheet contains age-specific (*i.e.*, vintage-specific) estimates of the survival rate and annual accumulated mileage applicable to different vehicle categories.

Table 15. Vehicle Age Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Vehicle Age Data	Survival Rates	proportion	Proportion of original vehicle sales that remain in service by vehicle age (year 1 to 30 for cars, 1 to 37 for trucks).
	Miles Driven	miles	Average annual miles driven by surviving vehicles by vehicle age (year 1 to 30 for cars, 1 to 37 for trucks).

Separate survival fractions and annual miles driven are used for cars, vans, SUVs, and pickups. The survival fractions measure the proportion of vehicles originally produced during a model year that remain in service at each age (up to 30 years for automobiles and 37 years for light trucks), by which time only a small fraction typically remain in service.

A.3.2 Forecast Data

The Forecast Data worksheet contains estimates of future fuel prices, which are used when calculating pre-tax fuel outlays and fuel tax revenues.

Table 16. Forecast Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Forecast Data	Retail Fuel Prices (low, average, high)	$/gallon	2010 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-1975.
	Fuel Taxes	$/gallon	2010 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-2000.

A.3.3 Fuel Economy Data

The fuel Economy Data worksheet contains historic and projected fuel economy levels for passenger cars and light trucks, for each fuel type (gasoline, diesel, ethanol-85, electricity, and hydrogen). The associated fuel shares are also provided.

Table 17. Fuel Economy Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Fuel Economy Data	Passenger Cars (FE)	mpg	Historic and projected fuel economy levels for passenger cars.
	Passenger Cars (Share)	percentage	Historic and projected fuel shares for passenger cars.
	Light Trucks (FE)	mpg	Historic and projected fuel economy levels for light trucks.
	Light Trucks (Share)	percentage	Historic and projected fuel shares for light trucks.

A.3.4 Economic Values

The Economic Values worksheet contains an estimate of the magnitude of the “rebound effect”, as well as the rates used to compute the economic value of various direct and indirect impacts of CAFE standards, and the discount rate to apply when calculating present value. As mentioned above, the user can define and edit all inputs. For example, although the economic values in Table 18 were obtained from various sources of information, the system does not require that the user rely on these sources.

Table 18. Economic Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
Economic Values	Rebound Effect	percentage	Increase in the annual use of vehicle models in response to lower per-mile cost of driving a more fuel-efficient vehicle.
	Social Discount Rate	percentage	Percent rate by which the dollar value of a benefit or cost is reduced when its receipt or payment is postponed by one additional year into the future; used for calculating socially-valued benefits.
	Private Discount Rate	percentage	Same as social discount rate, but used for calculating consumer-valued benefits.
	Kf	$/mpg	The CAFE fine rate a manufacturer would pay for non-compliance.
	Value of Travel Time per Vehicle	$/hour	Amount that the driver of a vehicle would be willing to pay to reduce the time required to make a trip.
	Economic Costs of Oil Imports	***various***	Economic costs of various oil imports.
	"Monopsony" Component	$/gallon	Demand cost for imported oil; increasing domestic petroleum demand that is met through higher oil imports can cause the world price of oil to rise, and conversely that declining imports can reduce the world price of oil; determined by a complex set of factors, including the relative importance of U.S. imports in the world oil market and demand to its world price among other participants in the international oil market.
	Price Shock Component	$/gallon	Expected value of costs to U.S. economy from reduction in potential output resulting from risk of significant increases in world petroleum price; includes costs resulting from inefficiencies in resource use caused by incomplete adjustments to industry output levels and mixes of production input when world oil price changes rapidly.
	Military Security Component	$/gallon	Costs of taxpayers for maintaining a military presence to secure the supply of oil imports from potentially unstable regions of the world and protect the nation against their interruption.
	Total Economic Costs ($/gallon)	$/gallon	Total economic costs of oil imports (sum of monopsony, price shock, and military security components).
	Total Economic Costs ($/BBL)	$/BBL	Total economic costs of oil imports, specified in $/BBL.
	External Costs from Additional Vehicle Use Due to "Rebound" Effect	***$/vehicle-mile***	Estimates intended to represent costs per vehicle-mile of increased travel compared to approximately current levels, assuming current distribution of travel by hours of the day and facility types.
	Congestion	$/vehicle-mile	Congestion component of external costs from additional vehicle use.
	Accidents	$/vehicle-mile	Accidents component of external costs from additional vehicle use.
	Noise	$/vehicle-mile	Noise component of external costs from additional vehicle use.
	Emission Damage Costs	***$/ton***	Additional costs arising from emission damage.
	Carbon Monoxide	$/ton	Economic costs arising from Carbon Monoxide damage.
	Volatile Organic Compounds	$/ton	Economic costs arising from Volatile Organic Compounds damage.
	Nitrogen Oxides	$/ton	Economic costs arising from Nitrous Oxides damage.
	Particulate Matter	$/ton	Economic costs arising from Particulate Matter damage.
	Sulfur Dioxide	$/ton	Economic costs arising from Sulfur Oxides damage.
	Methane (GWP-scalar of CO-2 Costs)	$/ton	Economic costs arising from Methane damage.
	Nitrous Oxide (GWP-scalar of CO-2 Costs)	$/ton	Economic costs arising from Nitrous Oxide damage.
	Annual Growth Rate for Average VMT per Vehicle	***various***	Annual growth rate for average VMT per vehicle.
	Base Year for Average Annual Usage Data (Primary)	model year	Base year for annual growth rate for average VMT per vehicle.
	Growth Rate at Low Fuel Price	percentage	Annual growth rate for average VMT per vehicle, when using low fuel prices.
	Growth Rate at Average Fuel Price	percentage	Annual growth rate for average VMT per vehicle, when using average fuel prices.
	Growth Rate at High Fuel Price	percentage	Annual growth rate for average VMT per vehicle, when using high fuel prices.
	Cost of CO-2	$/metric ton	Economic costs arising from Carbon Dioxide damage, by calendar year; estimates for low, average, high, or very high growth rates are provided.
	CO-2 Discount Rates	percentage	Discount rates to apply to low, average, high, or very high Carbon Dioxide estimates.
	"Gap" between Test and On-Road MPG (by Fuel Type)	percentage	Difference between a vehicle's EPA fuel economy rating and its actual on-road fuel economy.
	Average Refueling Time in Minutes (by Fuel Type)	minutes	Average refueling time a spent by a consumer refueling the vehicle tank or recharging the vehicle electric battery.
	Average Tank Volume Refueled	percentage	Average tank volume refilled during a refueling stop.
	Ownership and Operating Costs		
	Taxes & Fees (% of final vehicle MSRP)	percentage	Average percentage of the vehicle's final MSRP the consumer pays in taxes and fees when purchasing a new vehicle.
	Financing (% of final vehicle MSRP)	percentage	Average percentage of the vehicle's final MSRP the consumer would pay for financing a new vehicle.
	Insurance (% of final vehicle MSRP)	percentage	Average percentage of the vehicle's final MSRP the consumer would pay for insuring a new vehicle.
	Relative Value Loss (% of final vehicle MSRP, pure EVs only)	percentage	Average percentage of the vehicle's final MSRP, which translates into relative value loss to consumer due to decreased operating life of pure electric vehicles.
	Resale Value	percentage	Average percentage of the vehicle's final MSRP the consumer recoups after selling the vehicle.

A.3.5 Fuel Properties

The Fuel Properties worksheet contains estimates of the physical properties of gasoline, diesel, and other types of fuels, as well as certain assumptions about the effects of reduced fuel use on different sources of petroleum feedstocks and on imports of refined fuels. These fuel properties and assumptions about the response of petroleum markets to reduced fuel use are used to calculate the changes in vehicular carbon dioxide emissions as well as in "upstream" emissions (from petroleum extraction and refining and from fuel storage and distribution) that are likely to result from reduced motor fuel use.

Table 19. Fuel Properties Worksheet

Category	Model Characteristic	Units	Definition/Notes
Fuel Properties	Share of Total Assumed Fuel Mix	percentage	Estimated share of total fuel consumption by fuel type.
	Energy Density	BTU/unit	Amount of energy stored in a given system or region of space per unit volume, specified by fuel type.
	Mass Density	grams/unit	Mass per unit volume, specified by fuel type.
	Carbon Content	percentage by weight	Average share of carbon in fuel, specified by fuel type.
	SO-2 Emissions	grams/unit	Sulfur Oxides emissions rate of gasoline and diesel fuels.
	Share of Fuel Savings Leading to Lower Fuel Imports	percentage	Assumed value for share of fuel savings leading to lower fuel imports.
	Share of Fuel Savings Leading to Reduced Domestic Fuel Refining	percentage	Assumed value for share of fuel savings leading to reduced domestic fuel refining.
	Share of Reduced Domestic Refining from Domestic Crude	percentage	Assumed value for share of reduced domestic refining from domestic crude.
	Share of Reduced Domestic Refining from Imported Crude	percentage	Assumed value for share of reduced domestic refining from imported crude.

A.3.6 Upstream Emissions

The Upstream Emissions worksheet contains emission factors for greenhouse gas and criteria pollutant emissions from petroleum extraction and transportation, and from fuel refining, storage, and distribution.

Table 20. Upstream Emissions Worksheet

Category	Model Characteristic	Units	Definition/Notes
Upstream Emissions *(Total Emissions by Stage of Fuel Production and Distribution)*	Petroleum Extraction	grams/mil BTU	Total emissions by stage of fuel production and distribution from petroleum extraction, specified by pollutant and fuel type.
	Petroleum Transportation	grams/mil BTU	Total emissions by stage of fuel production and distribution from petroleum transportation, specified by pollutant and fuel type.
	Petroleum Refining	grams/mil BTU	Total emissions by stage of fuel production and distribution from petroleum refining, specified by pollutant and fuel type.
	Fuel TS&D	grams/mil BTU	Total emissions by stage of fuel production and distribution from refined fuel transportation, storage, and delivery, specified by pollutant and fuel type.
	Subtotals	grams/mil BTU	Subtotals from all stages of fuel production and distribution.

A.3.7 Safety Values

The Safety Values worksheet contains parameters for estimating additional fatalities resulting from decreases in vehicle weight.

Table 21. Safety Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
Safety Values	PC Threshold	lbs.	The boundary between small and large weight effects by safety class.
	LT/SUV Threshold	lbs.	
	CUV/Minivan Threshold	lbs.	
	Change per 100 lbs.	percentage	Change per 100 lbs. below the weight threshold.
	Base per billion miles		Base fatalities per billion miles below the weight threshold.
	Adjustment for new FMVSS		Adjustment for new FMVSS below the weight threshold.
	Monetized Fatalities		
	Cost Value	dollar	Social costs arising from vehicle fatalities.

A.4 Tailpipe Emissions File

The emissions rates file contains vehicular criteria pollutant emission factors specified by vehicle age, fuel type (gasoline, reformulated gasoline, diesel, and ethanol-85), and Mobile6 class (LDV, LDT12, LDT34, and HDV). Covered pollutants include carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NOX), and fine particulate matter (PM2.5, or particulate matter less than 2.5 microns in diameter). Particulate matter includes sulfate particulates, elemental carbon, non-volatile organic carbon compounds, and airborne lead, as well as particulate emissions from brake and tire wear. Because we are concerned with increased emissions from more intensive use of existing vehicles (rather than from a larger vehicle fleet), the emission factors we estimated included only the components associated with vehicle use, and omitted those associated with vehicle storage. Emission components associated with increased vehicle use include exhaust emissions during vehicle start-up and operation, evaporative emissions during vehicle operation, cool-down ("hot soak"), and refueling, and particulate emissions from brake and tire wear.

Table 22. Emissions Rates Worksheet

Category	Model Characteristic	Units	Definition/Notes
	Vehicle Age	age	
Gasoline / Gasoline Rfg Diesel / Ethanol-85	LDV	grams/mile	Vehicle operation emission rate for MOBILE6 LDV class for conventional gasoline, reformulated gasoline, diesel, or ethanol-85 fuel types.
	LDT12	grams/mile	Vehicle operation emission rate for MOBILE6 LDT1 and LDT2 classes for conventional gasoline, reformulated gasoline, diesel, or ethanol-85 fuel types.
	LDT34	grams/mile	Vehicle operation emission rate for MOBILE6 LDT3 and LDT4 classes for conventional gasoline, reformulated gasoline, diesel, or ethanol-85 fuel types.
	HDV	grams/mile	Vehicle operation emission rate for MOBILE6 HDV2b class for conventional gasoline, reformulated gasoline, diesel, or ethanol-85 fuel types.

A.5 Scenarios File

The scenarios file provides one or more worksheets that begin with "SCEN_" and are identified as CAFE program scenarios, which are defined in terms of the design and stringency of the CAFE program. The system numbers these scenarios as 0, 1, 2 …, based on their order of appearance. The first worksheet is assigned to Scenario 0, and is identified as the baseline scenario to which all others are compared. Each scenario defines the CAFE program as it relates to the following "regulatory classes":

Table 23. Regulatory Classes

Reg. Class	Includes
0	Unregulated vehicles
1	Passenger automobiles (domestic)
2	Passenger automobiles (imported)
3	Nonpassenger automobiles

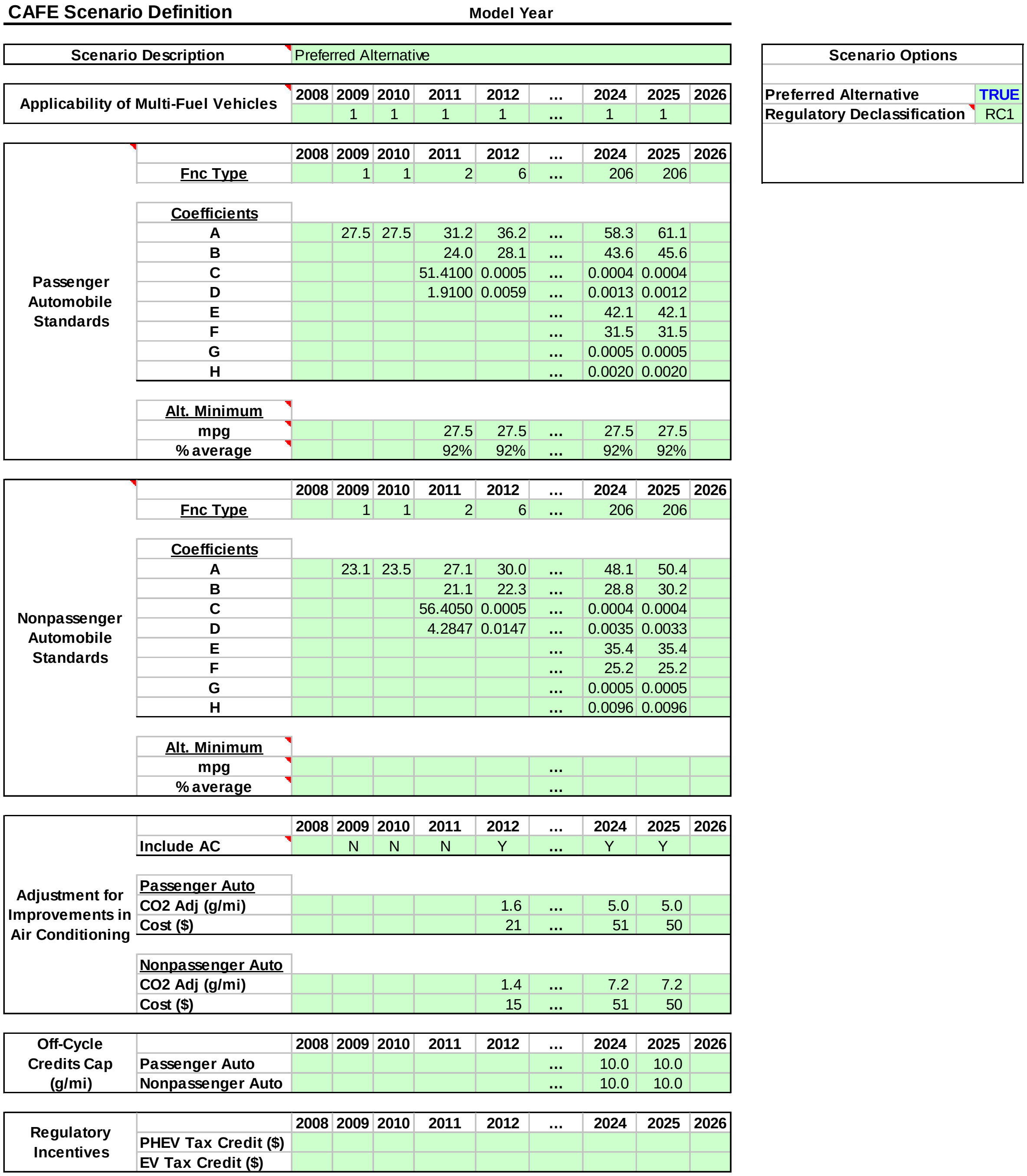
The "Regulatory Class" column on the vehicles worksheet discussed above is used to indicate whether the vehicle is regulated as a passenger or nonpassenger automobile. The vehicle origin is further used to differentiate between regulatory classes 1 and 2 (domestic or imported). Vehicles from one regulatory class may also be reassigned into another via the Regulatory Declassification section of the scenario as shown in Table 24.

Table 24. Regulatory Declassification Codes

Code	Description
<blank>	Specifies that regulatory merging does not apply.
RC1	Specifies that all passenger automobiles (domestic and imported) should be merged into regulatory class 1.
RC3	Specifies that all vehicles should be merged into regulatory class 3.

Table 25 shows an example of a CAFE scenario definition worksheet.

Table 25. Scenario Definition Worksheet (Sample)



CAFE Scenario Definition — Model Year

Scenario Description	
Scenario Description	Preferred Alternative

Scenario Options	
Preferred Alternative	TRUE
Regulatory Declassification	RC1

		2008	2009	2010	2011	2012	...	2024	2025	2026
Applicability of Multi-Fuel Vehicles			1	1	1	1	...	1	1	

		2008	2009	2010	2011	2012	...	2024	2025	2026
Passenger Automobile Standards	Fnc Type		1	1	2	6	...	206	206	
	Coefficients									
	A		27.5	27.5	31.2	36.2	...	58.3	61.1	
	B				24.0	28.1	...	43.6	45.6	
	C				51.4100	0.0005	...	0.0004	0.0004	
	D				1.9100	0.0059	...	0.0013	0.0012	
	E						...	42.1	42.1	
	F						...	31.5	31.5	
	G						...	0.0005	0.0005	
	H						...	0.0020	0.0020	
	Alt. Minimum									
	mpg				27.5	27.5	...	27.5	27.5	
	% average				92%	92%	...	92%	92%	

		2008	2009	2010	2011	2012	...	2024	2025	2026
Nonpassenger Automobile Standards	Fnc Type		1	1	2	6	...	206	206	
	Coefficients									
	A		23.1	23.5	27.1	30.0	...	48.1	50.4	
	B				21.1	22.3	...	28.8	30.2	
	C				56.4050	0.0005	...	0.0004	0.0004	
	D				4.2847	0.0147	...	0.0035	0.0033	
	E						...	35.4	35.4	
	F						...	25.2	25.2	
	G						...	0.0005	0.0005	
	H						...	0.0096	0.0096	
	Alt. Minimum									
	mpg						...			
	% average						...			

		2008	2009	2010	2011	2012	...	2024	2025	2026
Adjustment for Improvements in Air Conditioning	Include AC		N	N	N	Y	...	Y	Y	
	Passenger Auto									
	CO2 Adj (g/mi)					1.6	...	5.0	5.0	
	Cost ($)					21	...	51	50	
	Nonpassenger Auto									
	CO2 Adj (g/mi)					1.4	...	7.2	7.2	
	Cost ($)					15	...	51	50	

		2008	2009	2010	2011	2012	...	2024	2025	2026
Off-Cycle Credits Cap (g/mi)	Passenger Auto						...	10.0	10.0	
	Nonpassenger Auto						...	10.0	10.0	

		2008	2009	2010	2011	2012	...	2024	2025	2026
Regulatory Incentives	PHEV Tax Credit ($)									
	EV Tax Credit ($)									

Each section in Table 25 contains the following:

- ***Scenario Description***: A short name describing the key features of the scenario.
- ***Scenario Options***: Additional scenario specific options:
  - ***Preferred Alternative***: Specifies whether the scenario should be treated as the preferred alternative.

  - ***Regulatory Declassification***: Specifies whether vehicles from one regulatory class should be merged with vehicles from another regulatory class. Table 24 above shows the codes that may be used for regulatory declassification.

- ***Passenger Automobile Standards***: The CAFE functional or flat standards to use during modeling of the scenario. The "Fnc Type" subsection determines the functional form the system will use for the specific scenario. Presently, the supported functional forms are: 1, for flat standards; 2 for a logistic area-based functional form; 6, for a linear area-based functional form, and 206, for a dual-linear area-based functional form. The "Coefficients" subsection contains corresponding coefficient values. The "Alt. Minimum" sub-section applies to non-flat standard scenarios and represents the alternative minimum CAFE standards to apply to manufacturers whose required functional CAFE standard is below a specific minimum (mpg), or less than the specific percentage of the industry average (% average). In the example scenario in Table 25, function type "206" is used for model year 2024, indicating that passenger automobiles should use a dual-linear area-based functional form, with the coefficients specified in fields A through H.

- ***Nonpassenger Automobile Standards***: Same as the Passenger Automobile Standards section above, but applies to nonpassenger automobiles.

- ***Adjustment for Improvements in Air Conditioning***: Provides functionality for including AC adjustments during compliance and effects calculations on a scenario basis. The "Include AC" subsection determines during which model years the AC adjustments should be used for compliance. The "CO2 Adj (g/mi)" and "Cost ($)" values, under the "Passenger Auto" and "Nonpassenger Auto" subsections, specify the AC adjustment factor and the cost of the AC adjustment respectively. For the adjustment factor, a positive value should be used to represent a decrease in vehicle CO-2 emissions, while a negative value should be used to represent an increase in vehicle CO-2 emissions.

- ***Off-Cycle Credits Cap (g/mi)***: Specifies the maximum amount of off-cycle credits that may be accrued by a manufacturer. Credits are accrued and capped separately for passenger automobiles and nonpassenger automobiles.

- ***Regulatory Incentives***: Provides additional regulatory incentives, such as amount of tax credit to a buyer for purchasing a plug-in hybrid/electric vehicle or a pure electric vehicle.

A.6 EIS Parameters File

The EIS parameters file contains additional modeling parameters required to perform supplemental analysis necessary for the Environmental Impact Statement (EIS). The file contains a series of worksheets, the contents of which are summarized below.

A.6.1 Fleet Data and Sales Data

The Fleet Data worksheet provides historic data of vehicles remaining on the road, specified by model year for each vehicle age, for the car and truck fleets. The period of years covered is between 1975 and 2010.

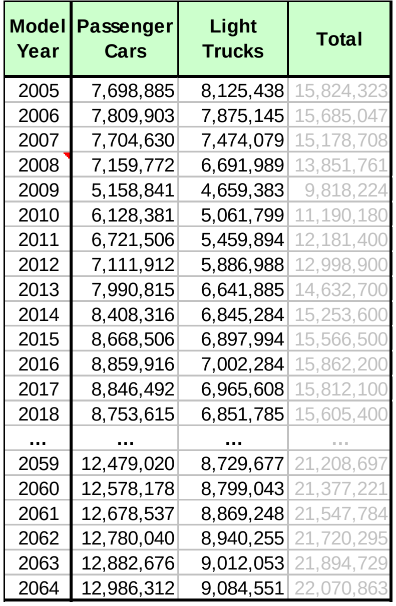
Table 26. Fleet Data Worksheet (Sample)

Vehicle Age	Car Fleet (by Model Year)										
	1975	1976	1977	1978	1979	1980	1981	1982	...	2009	2010
1	7,459,274	9,452,325	10,267,394	10,573,362	10,277,491	8,707,110	8,127,671	7,303,353	...	6,894,305	4,393,208
2	7,395,419	9,371,408	10,110,566	10,358,469	10,119,116	8,712,739	8,141,874	7,332,088	...	7,577,453	5,389,361
3	7,206,478	9,096,899	9,823,405	10,165,079	9,950,999	8,635,812	8,045,038	7,310,447	...	7,171,436	6,848,631
4	6,911,003	8,797,199	9,649,940	10,029,281	9,887,960	8,571,932	8,043,169	7,213,789	...	7,206,951	7,539,262
...	...	...	...	...	...	...	...	...	...	...	...
26	212,919	300,888	392,570	448,988	528,824	338,916	289,038	257,489	...	448,178	791,060
27	187,363	267,571	356,875	401,147	461,134	0	0	0	...	304,201	617,169
28	169,579	268,922	320,266	349,590	0	0	0	0	...	262,313	368,417
29	162,788	245,921	280,102	0	0	0	0	0	...	0	254,821
30	150,873	220,318	0	0	0	0	0	0	...	0	227,745
31	135,272	0	0	0	0	0	0	0	...	0	0
32	0	0	0	0	0	0	0	0	...	0	0
33	0	0	0	0	0	0	0	0	...	0	0
34	0	0	0	0	0	0	0	0	...	0	0
35	0	0	0	0	0	0	0	0	...	0	0
36	0	0	0	0	0	0	0	0	...	0	0
37	0	0	0	0	0	0	0	0	...	0	0
38	0	0	0	0	0	0	0	0	...	0	0
39	0	0	0	0	0	0	0	0	...	0	0
40	0	0	0	0	0	0	0	0	...	0	0

Vehicle Age	Truck Fleet (by Model Year)										
	1975	1976	1977	1978	1979	1980	1981	1982	...	2009	2010
1	1,716,731	2,415,823	2,879,854	3,143,823	3,368,587	1,950,450	1,861,330	1,996,118	...	6,816,660	3,765,784
2	1,739,671	2,448,104	2,858,443	3,269,424	3,415,518	1,907,867	1,864,288	1,986,850	...	7,156,173	6,723,790
3	1,735,045	2,381,056	2,965,957	3,265,480	3,429,755	1,884,684	1,859,372	2,014,784	...	7,478,573	7,146,249
4	1,667,717	2,458,341	2,976,576	3,264,937	3,388,922	1,859,864	1,875,581	1,987,197	...	7,782,816	7,401,816
...	...	...	...	...	...	...	...	...	...	...	...
26	229,689	329,210	415,832	505,596	502,617	246,500	255,923	276,519	...	312,387	450,131
27	197,691	289,805	399,388	452,733	452,792	215,595	223,836	241,850	...	258,017	274,525
28	173,875	270,615	354,133	399,354	395,270	188,206	195,400	211,126	...	213,030	230,865
29	162,660	242,343	320,112	348,306	344,744	164,148	170,423	184,138	...	182,167	191,683
30	145,220	216,331	278,970	303,540	300,436	143,051	148,520	160,472	...	331,042	164,698
31	129,439	188,345	242,881	264,273	261,570	124,545	129,306	139,712	...	274,098	298,226
32	112,706	163,997	211,483	230,110	227,756	108,445	112,591	121,652	...	236,433	241,781
33	97,897	142,448	183,694	199,873	197,829	94,196	97,796	105,667	...	153,881	213,720
34	85,203	123,978	159,876	173,957	172,178	81,982	85,115	91,965	...	91,660	137,364
35	74,048	107,746	138,944	151,181	149,635	71,248	73,972	79,925	...	107,970	81,700
36	64,239	93,473	120,538	131,155	129,813	61,810	64,173	69,337	...	0	97,920
37	0	0	0	0	0	0	0	0	...	0	69,550
38	0	0	0	0	0	0	0	0	...	0	0
39	0	0	0	0	0	0	0	0	...	0	0
40	0	0	0	0	0	0	0	0	...	0	0

The Sales Data worksheet contains projected vehicle production for sale in the U.S. between model years 2005 and 2064. The Sales worksheet is used to estimate additional car and truck fleet values, beyond what is available on the Fleet Data worksheet.

Table 27. Sales Data Worksheet (Sample)



Model Year	Passenger Cars	Light Trucks	Total
2005	7,698,885	8,125,438	15,824,323
2006	7,809,903	7,875,145	15,685,047
2007	7,704,630	7,474,079	15,178,708
2008	7,159,772	6,691,989	13,851,761
2009	5,158,841	4,659,383	9,818,224
2010	6,128,381	5,061,799	11,190,180
2011	6,721,506	5,459,894	12,181,400
2012	7,111,912	5,886,988	12,998,900
2013	7,990,815	6,641,885	14,632,700
2014	8,408,316	6,845,284	15,253,600
2015	8,668,506	6,897,994	15,566,500
2016	8,859,916	7,002,284	15,862,200
2017	8,846,492	6,965,608	15,812,100
2018	8,753,615	6,851,785	15,605,400
...	...	...	...
2059	12,479,020	8,729,677	21,208,697
2060	12,578,178	8,799,043	21,377,221
2061	12,678,537	8,869,248	21,547,784
2062	12,780,040	8,940,255	21,720,295
2063	12,882,676	9,012,053	21,894,729
2064	12,986,312	9,084,551	22,070,863

A.6.2 No CAFE Data

The No CAFE Data worksheet contains estimated fuel economy levels and fuel shares covering the years between 1975 and 2064, assuming the absence of the CAFE program. Data is provided for gasoline and diesel fuel types and is separated by passenger cars and light trucks. The values are flatlined after 1977, all the way to 2064. The fuel shares of additional fuel types (E85, electricity, and hydrogen) are assumed to be 0.

Table 28. No CAFE Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
No CAFE Data	Passenger Cars (FE)	mpg	Historic fuel economy levels for passenger cars, assuming the absence of the CAFE program.
	Passenger Cars (Share)	percentage	Historic fuel shares for passenger cars, assuming the absence of the CAFE program.
	Light Trucks (FE)	mpg	Historic fuel economy levels for light trucks, assuming the absence of the CAFE program.
	Light Trucks (Share)	percentage	Historic fuel shares for light trucks, assuming the absence of the CAFE program.

A.6.3 Overcompliance Data

The Overcompliance Data worksheet contains additional parameters used when considering the effect of voluntary overcompliance. The worksheets contains growth rates by fleet type (passenger cars and light trucks) and fuel type (gasoline, diesel, ethanol-85, electricity, and hydrogen), to estimate additional fuel economy growth beyond the last model year covered during the study period. For this analysis, the last year examined was 2025, and the growth rates are specified for model years between 2026 and 2064. Different growth rates are provided for the baseline alternative and the action alternatives.

Table 29. Overcompliance Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Overcompliance Data	***Baseline Growth Rates for Voluntary Overcompliance***		Growth rates used to estimate additional fuel economy growth beyond the last model year covered during the study period for the baseline scenario.
	Passenger Cars (FE)	percentage	Baseline scenario growth rates for passenger cars.
	Light Trucks (FE)	percentage	Baseline scenario growth rates for light trucks.
	Action Alternatives Growth Rates for Voluntary Overcompliance		Growth rates used to estimate additional fuel economy growth beyond the last model year covered during the study period for the action alternatives.
	Passenger Cars (FE)	percentage	Action alternatives growth rates for passenger cars.
	Light Trucks (FE)	percentage	Action alternatives growth rates for light trucks.

A.7 EIS Tailpipe Emissions

The EIS tailpipe emissions file contains pollutant emission factors necessary for EIS analysis. Emission factors are specified in grams per mile by vehicle age, fuel type (gasoline, diesel, and ethanol-85), and fleet type (LDV and LDT). Different pollutant values are provided for model years covering the period between 1975 and 2011. After 2011, these values are assumed to hold steady. The included pollutants are: acetaldehyde, acrolein, benzene, butadiene, CH4, CO, diesel PM10, formaldehyde, MTBE, N2O, NOx, PM, and VOC.

Table 30. EIS Tailpipe Emissions Worksheet

Category	Model Characteristic	Units	Definition/Notes
	Vehicle Age	age	
Tailpipe Emission Rates (by Model Year)	Gasoline - LDV	grams/mile	Vehicle operation emission rate for passenger cars for gasoline fuel.
	Gasoline - LDT	grams/mile	Vehicle operation emission rate for light trucks for gasoline fuel.
	Diesel - LDV	grams/mile	Vehicle operation emission rate for passenger cars for diesel fuel.
	Diesel - LDT	grams/mile	Vehicle operation emission rate for light trucks for diesel fuel.
	Ethanol-85 - LDV	grams/mile	Vehicle operation emission rate for passenger cars for ethanol-85 fuel.
	Ethanol-85 - LDT	grams/mile	Vehicle operation emission rate for light trucks for ethanol-85 fuel.

Appendix B Model Outputs

The system produces eight output files in comma separate values (CSV) format. The system places all files in the "reports" folder, located in the user selected output path (ex: **C:\cafe\demo-run\demo\reports-csv**). Table 31 lists the available output types and their contents. With this revision of the modeling system, the structure of all outputs generated has changed from earlier versions. The "raw" modeling results are stored as plain text (without any additional formatting), in a "database-like" style. Most of the modeling reports have been extended to include additional information, while some were scaled down to contain only the relevant portions. As discussed earlier, the first scenario appearing in the scenarios file is assigned to Scenario 0 and is treated as the baseline. The action alternatives are then assigned to Scenario 1, 2, and so on, in order of appearance. Unlike in the previous outputs, the CSV reports for the action alternatives do not include relative changes compared to the baseline; only absolute values are reported. To obtain the relative changes, the users may subtract results reported for Scenario 0 from results reported for action alternative scenarios.

Table 31. Output Files

Output File	Contents
Technology Utilization Report	Contains manufacturer-level and industry-wide technology application and penetration rates for each technology, model year, and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
Compliance Report	Contains manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
Societal Effects Report	Contains industry-wide summary of energy and emissions effects for each model year and scenario analyzed. The results are disaggregated by regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
Societal Costs Report	Contains industry-wide summary of consumer and social costs for each model year and scenario analyzed. The results are disaggregated by regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
Annual Societal Effects Report	This output file is similar to the *Societal Effects Report*, except it further disaggregates the results by calendar year.
Annual Societal Costs Report	This output file is similar to the *Societal Costs Report*, except it further disaggregates the results by calendar year.
Vehicles Report	Contains disaggregate vehicle-level summary of compliance model results, providing a detailed view of the final state of each vehicle examined by the model, for each model year and scenario analyzed.
Optimization Report	Contains functional coefficients and CAFE levels (required and achieved) for each iteration that was evaluated during optimization. This output file also contains a brief snapshot of industry-wide results, per iteration, that aided the model in picking the optimum levels for each model year that was optimized.

The remainder of this section discusses the contents of the output files.

B.1 Technology Utilization Report

The *Technology Utilization Report* contains manufacturer-level and industry-wide technology application and penetration rates for each technology. The application rates represent the amount of technology that was applied by the modeling system during analysis while the penetration rates represent the amount of technology that was either on the vehicle initially at the start of the analysis, or applied by the modeling system during analysis. If a technology was present on or applied to a vehicle, but later superseded during the modeling process by another technology (for example, DCP superseding ICP), the superseded technology on that vehicle will not count toward the penetration rate.

When the *Technology Utilization Report* is generated, the modeling system combines the application and penetration rates of some of the discrete technologies into a single entry. This merging occurs only for technology entries that represent the same technology, but are modeled separately given the differences in costs and fuel improvements attributed to different engine sizes. For example, TRBDS1_SD, TRBDS1_MD, and TRBDS1_LD, all represent the same technology, and the application and penetration rates of these three technologies were summed and reported as TRBDS1. Furthermore, some of the technologies which are present in the baseline fleet, but are not explicitly analyzed by the modeling system also appear in the report. This technologies include DSL (standard diesels) and E85 FFV (ethanol-85 flex-fuel vehicles).

The following table lists the contents of the *Technology Utilization Report*.

Table 32. Technology Utilization Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period.
Manufacturer	text	Manufacturers analyzed during the study period. A value of "<Industry>" is used to represent industry-wide results.
Reg-Class	text	The regulatory class for which the application and penetration rates are reported. A value of "<Total>" is used to represent the sum across all regulatory classes.
Technology (abbreviation)	text	The technology for which the application and penetration rates are reported.
App-Rate	number	The application rate of the technology, specified as a proportion of total sales.
Pen-Rate	number	The penetration rate of the technology, specified as a proportion of total sales.

B.2 Compliance Report

The *Compliance Report* contains manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are reported by regulatory class, as well as aggregated for the entire fleet. Most of the metrics, which are reported independently by model year, are further summed (or averaged) over the entire analysis period. The report provides various cost values associated with the rule, represented as “totals” across all vehicle models, as well as “averages” per single vehicle unit. The following table lists the contents of the *Compliance Report*.

Table 33. Compliance Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "Total" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Manufacturer	text	Manufacturers analyzed during the study period. A value of "<Industry>" is used to represent industry-wide results.
Reg-Class	text	The regulatory class for which the compliance results are reported. A value of "Total" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Sales	units	Total production of vehicles for sale for a specific model year, manufacturer, and regulatory class (as well as sum across any of the attributes, where applicable).
k.Labor Hours	hours (k)	Thousands of employment hours associated with the production of vehicle models. (The modeling system applies any employment hours specified in the input file; however, the system reflects no predetermined assumptions regarding the context for these inputs.)
Prelim-Stnd	mpg	Preliminary value of the required CAFE standard (before the "alternative minimum CAFE standard", as outlined in the scenarios input section, is applied).
Standard	mpg	The value of the required CAFE standard.
CAFE (2-cycle)	mpg	The value of the achieved CAFE standard, using a 2-bag test cycle, not including the adjustment for improvements in air conditioning or off-cycle credits.
CAFE	mpg	The value of the achieved CAFE standard, including the adjustment for improvements in air conditioning and off-cycle credits. This value is used for compliance purposes.
Average CW	lbs.	Average curb weight of analyzed vehicles.
Average FP	sq.ft.	Average footprint of analyzed vehicles.
Tech Cost	dollars	Total amount of technology costs accrued by all vehicles for a specific model year, manufacturer, and regulatory class.
Fines	dollars	Total amount of fines paid by a manufacturer for a specific model year and regulatory class.
Reg-Cost	dollars	Total amount of regulatory costs accrued by all vehicles for a specific model year, manufacturer, and regulatory class. The regulatory costs are the sum of technology costs and fines.
Value Loss	dollars	Total loss in value to the consumer due to decreased range of pure electric vehicles.
Rel. Value Loss	dollars	Total relative loss in value to the consumer due to due to decreased operating life of pure electric vehicles.
Maint Cost	dollars	Total maintenance costs accrued due to application of additional technologies.
Repair Cost	dollars	Total repair costs accrued due to application of additional technologies.
Taxes/Fees	dollars	Total amount of taxes & fees paid by the consumers for purchasing new vehicles for a specific model year, manufacturer, and regulatory class.
Financing	dollars	Total amount paid by the consumers for financing new vehicles for a specific model year, manufacturer, and regulatory class.
Insurance	dollars	Total amount paid by the consumers for insuring new vehicles for a specific model year, manufacturer, and regulatory class.
Total Consumer Costs	dollars	The total consumer costs accumulated by the manufacturer for a specific model year and regulatory class. The consumer costs are the sum of: technology costs, fines, taxes & fees, financing costs, insurance costs, maintenance costs, repair costs, loss of value, and relative loss of value.
Total Social Costs	dollars	The total social costs accumulated by the manufacturer for a specific model year and regulatory class. The social costs are the sum of: technology costs, maintenance costs, repair costs, loss of value, and relative loss of value.
Avg Tech Cost	dollars	Average technology costs per single vehicle unit.
Avg Fines	dollars	Average fines paid per single vehicle unit.
Avg Reg-Cost	dollars	Average regulatory costs per single vehicle unit.
Avg Value Loss	dollars	Average loss in value per single vehicle unit.
Avg Rel. Value Loss	dollars	Average relative loss in value per single vehicle unit.
Avg Maint Cost	dollars	Average maintenance costs per single vehicle unit.
Avg Repair Cost	dollars	Average repair costs per single vehicle unit.
Avg Taxes/Fees	dollars	Average taxes & fees per single vehicle unit.
Avg Financing	dollars	Average financing costs per single vehicle unit.
Avg Insurance	dollars	Average insurance costs per single vehicle unit.
Avg Consumer Costs	dollars	Average consumer costs per single vehicle unit.
Avg Social Costs	dollars	Average social costs per single vehicle unit.
Credits Earned	vehicle-mpg	Total credits accumulated by the manufacturer for a specific model year and regulatory class. Manufacturers earn one compliance credit for each tenth of an mpg that its achieved value of CAFE standard is above the required value of the CAFE standard (*i.e., CreditsEarned = MAX(ROUND(AchievedCAFE, 1) - RequiredCAFE, 0) * 10*).
Credits Out	vehicle-mpg	Total credits transferred out of a specific regulatory class (such as from domestic passenger automobiles to light trucks) or carried forward from a previous model year.
Credits In	vehicle-mpg	Total credits transferred into a specific regulatory class or carried forward into the present model year.

B.3 Societal Effects Report and Societal Costs Report

The *Societal Effects Report* contains industry-wide summary of energy and emissions effects, while the *Societal Costs Report* contains corresponding industry-wide summary of consumer and social costs for each model year and scenario analyzed. The results are reported by regulatory class, as well as aggregated for the entire fleet. Most of the metrics, which are reported independently by model year, are further summed (or averaged) over the entire analysis period.

The *Societal Effects Report* also disaggregates energy and emissions effects by fuel type, as well as providing aggregate totals across all fuels. The report contains calculated levels of energy consumed by fuel type in MBTU, thousands of gallons, megawatt hours, and thousands cubic feet during the full useful life of all vehicles sold in each model year. For gasoline, diesel, and ethanol-85 fuel types, fuel consumption is specified in gallons of appropriate fuel. For electricity and hydrogen, fuel consumption is specified in gasoline equivalent gallons. Full useful life travel (in thousands of miles) and average fuel economy levels are also presented to provide a basis for comparison. The rated fuel economy levels reported are not comparable to the value of achieved CAFE standard shown in the compliance report. The values contained in the Societal Effects Report are computed as total VMT divided by total gallons (with the effect of the on-road gap backed out), and do not incorporate some of the compliance credits.

The *Societal Effects Report* also presents estimates of full fuel cycle carbon dioxide and criteria pollutant emissions by fuel type. As shown in Table 34 below, carbon dioxide emissions are reported in million metric tons of carbon-equivalent emissions (one metric ton of carbon dioxide is equivalent to 12/44 of a metric ton of carbon), and all criteria pollutants are reported in short tons (one ton equals 2,000 pounds). Furthermore, to account for global warming potential of non-CO_2 gasses, methane and nitrous oxide emissions are also presented in million metric tons.

The *Societal Costs Report* contains monetized consumer and social costs including fuel expenditures, travel and refueling value, economic and external costs arising from additional vehicle use, as well as owner and societal costs associated with emissions damage. In all cases, these costs are calculated for the fleet of vehicles sold in each model year over their full useful lives, discounted using the rate specified in the benefits model parameters file, and reported in thousands of constant year-2010 dollars. Chapter Three, Section 6 of the primary text discusses these types of costs and benefits in greater detail, and Appendix A (Model Inputs) discusses corresponding input assumptions.

Table 34 below lists the full contents of the *Societal Effects Report* and Table 35 lists the full contents of the *Societal Costs Report*.

Table 34. Societal Effects Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "Total" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Reg-Class	text	The regulatory class for which the societal effects are reported. A value of "Total" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Fuel Type	text	The fuel type for which the societal effects are reported. A value of "Total" is used to represent the sums (or averages) across all fuel types for some of the outputs, where applicable.
Sales	units	Total production of vehicles for sale for a specific model year, regulatory class, and fuel type (as well as sum across any of the attributes, where applicable).
kVMT	miles (k)	Thousands of miles traveled by all vehicles over their lifetime in a specific model year and for a specific regulatory class and fuel type.
MBTU	MBTU	Energy used by all vehicles over their lifetime in a specific model year and for a specific regulatory class and fuel type.
kGallons	gallons (k)	Amount of gallons of liquid fuel consumed, or amount of gasoline equivalent gallons of fuel consumed (for electric fuel type), by all vehicles over their lifetime in a specific model year and for a specific regulatory class and fuel type.
mW-h	mW-h	Amount of electricity consumed by all plug-in hybrid/electric vehicles or pure-electric vehicles over their lifetime in a specific model year and for a specific regulatory class. This value is only applicable when fuel type is "Electricity" or "Total".
Mcf	Mcf	Amount of hydrogen fuel consumed by all fuel-cell vehicles over their lifetime in a specific model year and for a specific regulatory class. This value is only applicable when fuel type is "Hydrogen" or "Total".
Rated FE	mpg	The average fuel economy rating of vehicles.
On-road FE	mpg	The average on-road fuel economy rating of vehicles.
CO-2 (mmT)	mmT	Amount of Carbon Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory class, and fuel type.
CO (tons)	tons	Amount of Carbon Monoxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory class, and fuel type.
VOC (tons)	tons	Amount of Volatile Organic Compounds emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory class, and fuel type.
NOx (tons)	tons	Amount of Nitrogen Oxides emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory class, and fuel type.
PM (tons)	tons	Amount of Particulate Matter emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory class, and fuel type.
SOx (tons)	tons	Amount of Sulfur Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory class, and fuel type.
CH4 (mmT)	mmT	Amount of Methane emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory class, and fuel type.
N2O (mmT)	mmT	Amount of Nitrous Oxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory class, and fuel type.
Fatals PC	units	Changes in fatalities, for the Passenger Car safety class, resulting from reduction in vehicle curb weight, aggregated over the lifetime of all vehicles for a specific model year and regulatory class. A negative number indicates a reduction in fatalities, while a positive number indicates an increase in fatalities.
Fatals CM	units	Changes in fatalities, for the CUV/Minivan safety class, resulting from reduction in vehicle curb weight, aggregated over the lifetime of all vehicles for a specific model year and regulatory class. A negative number indicates a reduction in fatalities, while a positive number indicates an increase in fatalities.
Fatals LT	units	Changes in fatalities, for the Light Truck/SUV safety class, resulting from reduction in vehicle curb weight, aggregated over the lifetime of all vehicles for a specific model year and regulatory class. A negative number indicates a reduction in fatalities, while a positive number indicates an increase in fatalities.

Table 35. Societal Costs Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "Total" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Reg-Class	text	The regulatory class for which the societal costs are reported. A value of "Total" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Disc-Rate	number	Social discount rate applied to future benefits. A value of 0 indicates undiscounted costs.
Pre-Tax Fuel Cost	dollars (k)	Total pre-tax fuel expenditures accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
Fuel Tax Cost	dollars (k)	Total fuel tax revenues accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
Drive Surplus	dollars (k)	Benefits from the additional driving that results from improved fuel economy, accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
Refuel Surplus	dollars (k)	Benefits from reduced refueling frequency due to the extended vehicle range and improved fuel economy, accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
Market Externalities	dollars (k)	Economic costs of oil imports not accounted for by price, accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
Congestion Costs	dollars (k)	Congestion costs from additional vehicle use, accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
Accident Costs	dollars (k)	Accident costs from additional vehicle use, accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
Noise Costs	dollars (k)	Noise costs from additional vehicle use, accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
Fatality Costs	dollars (k)	Cost from additional fatalities resulting from reduction in vehicle curb weight, accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
CO-2 Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Dioxide damage, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
CO Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Monoxide damage, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
VOC Damage Costs	dollars (k)	Owner and societal costs arising from Volatile Organic Compounds damage, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
NOx Damage Costs	dollars (k)	Owner and societal costs arising from Nitrogen Oxides damage, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
PM Damage Costs	dollars (k)	Owner and societal costs arising from Particulate Matter damage, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
SOx Damage Costs	dollars (k)	Owner and societal costs arising from Sulfur Dioxide damage, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
CH4 Damage Costs	dollars (k)	Owner and societal costs arising from Methane damage, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
N2O Damage Costs	dollars (k)	Owner and societal costs arising from Nitrous Oxide damage, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
Retail Fuel Costs	dollars (k)	Total retail fuel expenditures (pre-tax fuel cost + fuel tax cost) accumulated across all vehicles over their lifetime in a specific model year and for a specific regulatory class.
Total Consumer Costs	dollars (k)	Total consumer costs accumulated by the industry for a specific model year and regulatory class. The consumer costs are the sum of: retail fuel costs, drive surplus, and refueling surplus.
Total Social Costs	dollars (k)	Total social costs accumulated by the industry for a specific model year and regulatory class. The social costs are the sum of: pre-tax fuel costs, drive surplus, refueling surplus, market externalities, congestion costs, accident costs, noise costs, fatality costs, and emissions damage costs (CO2, CO, VOC, NOx, PM, SOx, CH4, and N2O).

B.4 Annual Societal Effects Report and Annual Societal Costs Report

The *Annual Societal Effects Report* and the *Annual Societal Costs Report* contain similar results as the *Societal Effects Report* and the *Societal Costs Report*, except these outputs further disaggregate the results by calendar year. Table 36 lists the full contents of the *Annual Societal Effects Report* and Table 37 lists the full contents of the *Annual Societal Costs Report*.

Table 36. Annual Societal Effects Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "Total" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Calendar Year	calendar year	Calendar years analyzed for the effects calculations. Each calendar year corresponds to vehicle's vintage. A value of "Total" is used to represent the sums (or averages) across all calendar years for some of the outputs, where applicable.
Reg-Class	text	The regulatory class for which the societal effects are reported. A value of "Total" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
kVMT	miles (k)	Thousands of miles traveled by all vehicles in a specific model year and calendar year, and for a specific regulatory class.
MBTU	MBTU	Energy used by all vehicles in a specific model year and calendar year, and for a specific regulatory class.
kGallons	gallons (k)	Amount of gallons of liquid fuel consumed, or amount of gasoline equivalent gallons of fuel consumed (for electric fuel type), by all vehicles in a specific model year and calendar year, and for a specific regulatory class.
mW-h	mW-h	Amount of electricity consumed by all plug-in hybrid/electric vehicles or pure-electric vehicles in a specific model year and calendar year, and for a specific regulatory class. This value is only applicable when fuel type is "Electricity" or "Total".
Mcf	Mcf	Amount of hydrogen fuel consumed by all fuel-cell vehicles in a specific model year and calendar year, and for a specific regulatory class. This value is only applicable when fuel type is "Hydrogen" or "Total".
CO-2 (mmT)	mmT	Amount of Carbon Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
CO (tons)	tons	Amount of Carbon Monoxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
VOC (tons)	tons	Amount of Volatile Organic Compounds emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
NOx (tons)	tons	Amount of Nitrogen Oxides emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
PM (tons)	tons	Amount of Particulate Matter emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
SOx (tons)	tons	Amount of Sulfur Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
CH4 (mmT)	mmT	Amount of Methane emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
N2O (mmT)	mmT	Amount of Nitrous Oxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
Fatalities	units	Changes in fatalities, from all safety classes, resulting from reduction in vehicle curb weight, aggregated over the lifetime of all vehicles for a specific model year and regulatory class. A negative number indicates a reduction in fatalities, while a positive number indicates an increase in fatalities.

Table 37. Annual Societal Costs Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "Total" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Calendar Year	calendar year	Calendar years analyzed for the effects calculations. Each calendar year corresponds to vehicle's vintage. A value of "Total" is used to represent the sums (or averages) across all calendar years for some of the outputs, where applicable.
Reg-Class	text	The regulatory class for which the societal effects are reported. A value of "Total" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Disc-Rate	number	Social discount rate applied to future benefits. A value of 0 indicates undiscounted costs.
Pre-Tax Fuel Cost	dollars (k)	Total pre-tax fuel expenditures accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
Fuel Tax Cost	dollars (k)	Total fuel tax revenues accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
Drive Surplus	dollars (k)	Benefits from the additional driving that results from improved fuel economy, accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
Refuel Surplus	dollars (k)	Benefits from reduced refueling frequency due to the extended vehicle range and improved fuel economy, accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
Market Externalities	dollars (k)	Economic costs of oil imports not accounted for by price, accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
Congestion Costs	dollars (k)	Congestion costs from additional vehicle use, accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
Accident Costs	dollars (k)	Accident costs from additional vehicle use, accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
Noise Costs	dollars (k)	Noise costs from additional vehicle use, accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
Fatality Costs	dollars (k)	Cost from additional fatalities resulting from reduction in vehicle curb weight, accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
CO-2 Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Dioxide damage, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
CO Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Monoxide damage, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
VOC Damage Costs	dollars (k)	Owner and societal costs arising from Volatile Organic Compounds damage, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
NOx Damage Costs	dollars (k)	Owner and societal costs arising from Nitrogen Oxides damage, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
PM Damage Costs	dollars (k)	Owner and societal costs arising from Particulate Matter damage, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
SOx Damage Costs	dollars (k)	Owner and societal costs arising from Sulfur Dioxide damage, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
CH4 Damage Costs	dollars (k)	Owner and societal costs arising from Methane damage, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
N2O Damage Costs	dollars (k)	Owner and societal costs arising from Nitrous Oxide damage, aggregated for all vehicles in a specific model year, calendar year, and regulatory class.
Retail Fuel Costs	dollars (k)	Total retail fuel expenditures (pre-tax fuel cost + fuel tax cost) accumulated across all vehicles in a specific model year and calendar year, and for a specific regulatory class.
Total Consumer Costs	dollars (k)	Total consumer costs accumulated by the industry for a specific model year, calendar year, and regulatory class. The consumer costs are the sum of: retail fuel costs, drive surplus, and refueling surplus.
Total Social Costs	dollars (k)	Total social costs accumulated by the industry for a specific model year, calendar year, and regulatory class. The social costs are the sum of: pre-tax fuel costs, drive surplus, refueling surplus, market externalities, congestion costs, accident costs, noise costs, fatality costs, and emissions damage costs (CO2, CO, VOC, NOx, PM, SOx, CH4, and N2O).

B.5 Vehicles Report

The *Vehicles Report* contains disaggregate vehicle-level summary of compliance model results, providing a detailed view of the final state of each vehicle examined by the model, for each model year and scenario analyzed. The report includes basic vehicle characteristics (such as vehicle code, manufacturer, engine and transmission used, curb weight, footprint, and sales volumes), fuel economy information (before and after the analysis), final technology utilization, and cost metrics associated with application of additional technology.

The vehicle's fuel economy ratings prior to the start of the analysis as well as at the end of each compliance model year are presented. The fuel economy values are specified per fuel type (wherever applicable) in addition to an overall value, which used for compliance purposes. For multi-fuel vehicles, the multiple fuel economy ratings are combined according to the statutory requirements. For flex-fuel vehicles (those that operate on gasoline and ethanol-85), only the gasoline fuel economy rating is considered for compliance. For plug-in hybrid/electric vehicles (PHEVs operating on gasoline and electricity), the overall fuel economy rating is harmonically averaged based on the share of each fuel type. The vehicle's fuel share indicates the amount of miles driven by the vehicle on each fuel type. For vehicles operating on a single fuel (*e.g.*, gasoline, diesel, or electricity), the fuel share for that fuel type only is specified. For vehicles operating on multiple fuels (FFVs and PHEVs), the fuel shares are specified for gasoline and ethanol-85 or for gasoline and electricity.

The *Vehicles Report* provides initial and final sales volumes as well as initial and final MSRPs. The initial sales and MSRP represent the starting values as obtained from the input file, and do not reflect changes associated with the modeling analysis. The final sales volumes are specified by model year and will typically match the initial values, unless modeling options for sales mixing are selected (such as the Dynamic Fleet Share Model). The final MSRPs are specified by model year as well, and incorporate additional costs arising from technology application or fine payment.

Due to its size, the contents of the *Vehicles Report* are split among several tables. Table 38, Table 39, Table 40, and Table 41 below list the full contents of the *Vehicles Report*.

Table 38. Vehicles Report (1)

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period.
Manufacturer	text	Manufacturers analyzed during the study period.
Veh Index	integer	Unique index assigned to each vehicle by the modeling system during runtime.
Veh Code	integer	Index of the vehicle (unique per manufacturer), as read from the input file.
Model	text	Vehicle model. This field is used by the modeling system to group similar vehicles together when applying technologies from the "aerodynamics" group.
Name Plate	text	Vehicle nameplate.
Platform	text	Reserved for future use.
Eng Code	integer	Index of the engine used by a vehicle. If the modeling system splits an engine (due to different redesign schedules or other conflicts of multiple vehicles), the value in this field would show a new engine code, with the original in parentheses; for example: "12 (3)".
Eng Fuel	text	Fuel used by the engine. Available options are: G for gasoline, D for diesel, G+E85 for gasoline/ethanol-85 flex fuel vehicles.
Eng Type	text	Brief information about the engine, including engine configuration, number of cylinders, and engine displacement.
Eng HP	horse-power	Engine horsepower.
Trn Code	integer	Index of the transmission used by a vehicle. If the modeling system splits an transmission (due to different redesign schedules or other conflicts of multiple vehicles), the value in this field would show a new transmission code, with the original in parentheses; for example: "45 (6)".
Trn Type	text	Brief information about the transmission, including the transmission type (A=automatic, M=manual, CVT=continuously variable transmission, AMT=automated manual transmission, DCT=dual-clutch transmission) and number of gears (if applicable).

Table 39. Vehicles Report (2)

Column	Units	Contents
FE Initial (Gas)	mpg	Vehicle's initial fuel economy rating when operating on a specific fuel type. This represents the starting value as read from the input file.
FE Initial (Dsl)		
FE Initial (E85)		
FE Initial (Elc)		
FE Initial (Hgn)		
FE Initial	mpg	Vehicle's overall initial fuel economy rating. For FFVs (gasoline/ethanol-85), only the gasoline component is considered; for PHEVs (gasoline/electricity), the fuel economy rating is harmonically averaged based on the share of each fuel type.
FS Initial (Gas)	ratio	Vehicle's initial fuel share, indicating the amount of miles driven by the vehicle on each fuel type. This represents the starting value as read from the input file.
FS Initial (Dsl)		
FS Initial (E85)		
FS Initial (Elc)		
FS Initial (Hgn)		
Fuel Initial	text	Fuel types initially used by the vehicle. Available options are: G for gasoline, D for diesel, G+E85 for gasoline/ethanol-85 flex fuel vehicles, G+E for plug-in hybrid/electric vehicles, E for electric vehicles.
FE (Gas)	mpg	Vehicle's fuel economy rating when operating on a specific fuel type, in a specific model year, taking into account the effect of technology additions made by the modeling system. This value does not include adjustment for improvements in air conditioning or off-cycle credits.
FE (Dsl)		
FE (E85)		
FE (Elc)		
FE (Hgn)		
FE	mpg	Vehicle's overall fuel economy rating in a specific model year, taking into account the effect of technology additions made by the modeling system. For FFVs (gasoline/ethanol-85), only the gasoline component is considered; for PHEVs (gasoline/electricity), the fuel economy rating is harmonically averaged based on the share of each fuel type. This value does not include adjustment for improvements in air conditioning or off-cycle credits.
Delta FE AC (Gas)	mpg	Amount of fuel economy gain attributed to the adjustment for improvements in air conditioning for a specific fuel type, in a specific model year.
Delta FE AC (Dsl)		
Delta FE AC (E85)		
Delta FE AC (Elc)		
Delta FE AC (Hgn)		
Delta FE AC	mpg	Overall amount of fuel economy gain attributed to the adjustment for improvements in air conditioning in a specific model year.
Delta FE Off-Cycle (Gas)	mpg	Amount of fuel economy gain attributed to the off-cycle credits for a specific fuel type, in a specific model year.
Delta FE Off-Cycle (Dsl)		
Delta FE Off-Cycle (E85)		
Delta FE Off-Cycle (Elc)		
Delta FE Off-Cycle (Hgn)		
Delta FE Off-Cycle	mpg	Overall amount of fuel economy gain attributed to the off-cycle credits in a specific model year.
FE Adj (Gas)	mpg	Vehicle's fuel economy rating when operating on a specific fuel type, in a specific model year, taking into account the effect of technology additions made by the modeling system, adjusted for improvements in air conditioning and off-cycle credits.
FE Adj (Dsl)		
FE Adj (E85)		
FE Adj (Elc)		
FE Adj (Hgn)		
FE Adj	mpg	Vehicle's overall fuel economy rating in a specific model year, taking into account the effect of technology additions made by the modeling system, adjusted for improvements in air conditioning and off-cycle credits. For FFVs (gasoline/ethanol-85), only the gasoline component is considered; for PHEVs (gasoline/electricity), the fuel economy rating is harmonically averaged based on the share of each fuel type. This value is used for compliance purposes.
FS (Gas)	ratio	Vehicle's fuel share in a specific model year.
FS (Dsl)		
FS (E85)		
FS (Elc)		
FS (Hgn)		
Fuel	text	Fuel types used by the vehicle in a specific model year. Available options are: G for gasoline, D for diesel, G+E85 for gasoline/ethanol-85 flex fuel vehicles, G+E for plug-in hybrid/electric vehicles, E for electric vehicles.

Table 40. Vehicles Report (3)

Column	Units	Contents
Reg Class	text	Vehicle's regulatory class (DomesticAuto, ImprotedAuto, or LightTruck).
Tech Class	text	Vehicle's technology class (used for technology selection and application).
Mobile6 Class	text	Vehicle's Mobile6 class (used for some of the effects calculations).
Safety Class	text	Vehicle's safety class (PC=Passenger Car, CM=CUV/Minivan, LT=Light Truck/SUV; used for safety calculations).
Redesign State	text	Vehicle's redesign state, whether the vehicle is at redesign (being redesigned in the current model year) or "in shadow" of redesign (was redesigned within the past 4 years or will be redesigned within the next 4 years).
Refresh State	text	Vehicle's refresh state, whether the vehicle is at refresh (being refreshed in the current model year) or "in shadow" of refresh (was refreshed in the past year or will be refreshed in the next year).
Sales Initial	units	Vehicle's production volumes in a specific model year. This represents the starting value as read from the input file.
Sales Final	units	Vehicle's final production volumes in a specific model year. If modeling options for sales mixing are used (such as the Dynamic Fleet Share Model), this value will differ from the initial production volumes; otherwise, this value will be the same the initial one.
MSRP Initial	dollars	Vehicle's initial MSRP value in a specific model year. This represents the starting value as read from the input file.
MSRP Final	dollars	Vehicle's final MSRP value in a specific model year, including additional costs arising from technology application or fine payment.
k.Labor Hours	hours (k)	Thousands of employment hours associated with the production of the vehicle models in a specific model year.
CW Initial	lbs.	Vehicle's initial curb weight. This represents the starting value as read from the input file.
CW Final	lbs.	Vehicle's final curb weight in a specific model year, taking into account any mass reduction technology applied by the modeling system.
Footprint	sq.ft.	Vehicle's initial footprint. This represents the starting value as read from the input file. The vehicle's footprint does not change during the analysis.
Tech Cost	dollars	Unit costs accumulated by the vehicle model from technology application in a specific model year.
Price Increase	dollars	Increase in vehicle price accumulated by the vehicle model from technology application and fine payment in a specific model year.
Tax Credit	dollars	
Value Loss	dollars	Loss in value to the consumer due to decreased range of pure electric vehicles. This value does not apply if the vehicle is not an EV.
Rel. Value Loss	dollars	Relative loss in value to the consumer due to due to decreased operating life of pure electric vehicles. This value does not apply if the vehicle is not an EV.
Maint Cost	dollars	Unit maintenance costs accumulated by the vehicle model from technology application in a specific model year.
Repair Cost	dollars	Unit repair costs accumulated by the vehicle model from technology application in a specific model year.
Taxes/Fees	dollars	Taxes & fees paid by the consumers for purchasing a new vehicle model in a specific model year.
Financing	dollars	Financing costs paid by the consumers for purchasing a new vehicle model in a specific model year.
Insurance	dollars	Insurance costs paid by the consumers for purchasing a new vehicle model in a specific model year.

Table 41. Vehicles Report (4)

Column	Units	Contents
LUB1	text	The utilization of technologies on a vehicle model in a specific model year. The following define the utilization codes used by the modeling system: U = technology was initially in use on a base vehicle before modeling began A = technology was applied to a vehicle by the modeling system US = technology was in use on a base vehicle, but was later superseded when another technology was applied by the modeling system AS = technology was applied to a vehicle by the modeling system, but was later superseded when another technology was applied PA = technology has exceed its phase-in threshold in the current model year, however, it was still applied by the modeling system in order to satisfy backfilling constraints of another technology P = technology has exceed its phase-in threshold in the current model year, and thus was not applied by the modeling system X = technology is not available for application on a vehicle in the current model year <blank> = technology is available for application on a vehicle in the current model year, but the modeling system has not yet applied it
EFR1		
LUB2_EFR2		
CCPS		
DVVLS		
DEACS		
ICP		
DCP		
DVVLD		
CVVL		
DEACD		
SGDI		
DEACO		
VVA		
SGDIO		
TRBDS1_SD		
TRBDS1_MD		
TRBDS1_LD		
TRBDS2_SD		
TRBDS2_MD		
TRBDS2_LD		
CEGR1_SD		
CEGR1_MD		
CEGR1_LD		
CEGR2_SD		
CEGR2_MD		
CEGR2_LD		
ADSL_SD		
ADSL_MD		
ADSL_LD		
6MAN	text	(same as above)
HETRANSM		
IATC		
NAUTO		
DCT		
8SPD		
HETRANS		
SHFTOPT		
EPS	text	(same as above)
IACC1		
IACC2		
MHEV		
ISG		
SHEV1		
SHEV1_2		
SHEV2		
PHEV1		
PHEV2		
EV1		
EV2		
EV3		
EV4		
FCV		
MR1	text	(same as above)
MR2		
MR3		
MR4		
MR5		
ROLL1		
ROLL2		
ROLL3		
LDB		
SAX		
AERO1		
AERO2		

B.6 Optimization Report

0 (below) discusses use of the model to estimate the “optimal” stringency of CAFE standards. This operating mode involves incrementally increasing the stringency of the standards over a specific range, and estimating corresponding costs, fuel savings, and benefits at each iteration. The *Optimization Report* contains functional coefficients and CAFE levels (required and achieved) for each iteration that was evaluated during optimization. This output file also contains a brief snapshot of industry-wide results, per iteration, that aided the model in determining the optimum levels for each model year that was optimized. The following table lists the contents of the *Optimization Report*.

Table 42. Optimization Report

Column	Units	Contents
Model Year	model year	Model years analyzed during the study period. Only the model years that were evaluated as part of optimization modeling are reported.
Iteration	integer	Index of the optimization iteration (unique per model year).
Is Optimal	text	A value of "Y" indicates if a specific iteration was selected as the optimal for a specific model year. Each model year contains only one optimal solution.
Coef-A	mpg	The value of the A- through H-coefficients of the functional form evaluated for a specific optimization iteration.
Coef-B	mpg	
Coef-C	gpm	
Coef-D	gpm	
Coef-E	mpg	
Coef-F	mpg	
Coef-G	gpm	
Coef-H	gpm	
Standard	mpg	The value of the required CAFE standard (resulting from corresponding functional form coefficients) evaluated for a specific optimization iteration.
CAFE	mpg	The value of the achieved CAFE standard resulting from the functional form coefficients of a specific optimization iteration.
Total Social Costs	dollars (m)	Total social costs resulting from the functional form coefficients of a specific optimization iteration.
Total Social Benefits	dollars (m)	Total undiscounted social benefits resulting from the functional form coefficients of a specific optimization iteration.
Disc Social Benefits	dollars (m)	Total discounted social benefits resulting from the functional form coefficients of a specific optimization iteration.
Net Benefits (m$)	dollars (m)	Total net benefits (discounted social benefits - total social costs) resulting from the functional form coefficients of a specific optimization iteration.
Fuel Savings (m-gal)	gallons (m)	Total fuel savings resulting from the functional form coefficients of a specific optimization iteration.

Appendix C   “Optimization” of CAFE Standards

The modeling system contains algorithms that may be used to “optimize” the average stringency (that is, the average required fuel economy) of an attribute-based system by estimating the stringency at which a given condition is met. “Optimizing” the stringency, in the current modeling system, is done either by estimating the stringency level at which net societal benefits are maximized (maximum net benefits), or by finding the level where the absolute value of net benefits is minimized, after the maximum has occurred (total cost equals total benefits).[30] Optimization of CAFE Standards may be set up and run using directions provided in Appendix E below.

Using the functional form defined in the scenarios file, the optimized stringency for either the passenger car or light truck fleet is determined for the entire industry, and for each year, by adjusting the entire function at a user-specified increment, for a given number of iterations above and below the initial shape.[31] To ensure the correct “carry-over” of technology costs and improvements, the model years are optimized sequentially. At the end of each model year, the system re-runs the entire passenger car or light truck fleet using the optimized stringency, then carries the costs and improvements into the next year.

With the varying functional form, the stringency is slightly altered between new iterations (or trials). As the system examines each trial, it performs typical compliance modeling. At the end of each iteration, the model calculates and saves the final incremental technology costs, discounted social benefits, fuel savings, and net benefits for each manufacturer and industry overall. Once all iterations have been processed, the modeling system calculates the stringency by finding the first iteration that satisfies the net-benefit-maximizing or absolute-value-of-net-benefit-minimizing criterion.

Below, Figure 8 illustrates how the model maximizes net benefits. The plot on the left shows curves specifying fuel economy targets for three iterations (*i.e.*, stringency levels) examined under a sample optimization. For each of these iterations, colored points in the plot on the right show the corresponding stringency (in terms of average required fuel economy) and the calculated net benefits (in $m). The black line in the plot on the right shows stringency and net benefits for all other iterations included in the optimization. In this example, the least stringent of the three highlighted iterations, shown in red, produces net benefits of about $2,700m at a stringency of 31.2 mpg. As stringency increases, net benefits reach a peak or maximum, shown in green, of about $3,100m at a stringency of 31.7 mpg. The corresponding curve is shown in green in the plot on the left. As stringency increases beyond this point, more expensive

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[30] Use of the term “optimize” was first applied in this model in reference to the concept of estimating the “socially optimal” stringency—that is, the stringency producing the greatest increase in benefits relative to the increase in costs, where both benefits and costs are measured on a societal basis, excluding economic transfers such as fuel taxes and civil penalties. This approach involves maximizing net benefits. Considering public comments, NHTSA also required the availability to examine stringencies at which total costs equal total benefits (or, within the scope of available technologies, most nearly equal). As currently used, the term “optimize” refers to either approach.

[31] The model currently optimizes stringency for only one fleet (*i.e.*, passenger car or light truck) in a single model run.

technologies are required, such that net benefits decrease. By the point stringency reaches 31.2 mpg, shown in blue, net benefits fall to about $2,800m.

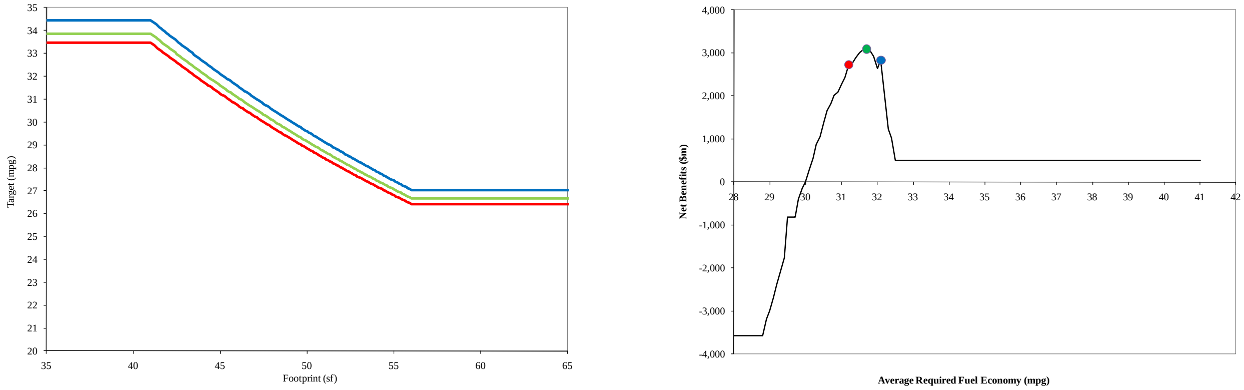

Figure 8. Maximizing Net Benefits

This example also illustrates a scenario in which net benefits stop decreasing before total costs equal total benefits (when total costs equal total benefits, net benefits equal zero). In this example, all available technologies are exhausted when stringency reaches 32.5 mpg, at which point net benefits are about $500m. Once technologies are exhausted, no additional cost or benefits will be realized – the manufacturer's fleet will remain static. Above this stringency, civil penalties are incurred. However, as economic transfers, civil penalties are not counted as costs to society. Therefore, net benefits do not change as stringency increases beyond 32.5 mpg.

The last step of the modeling process is to use the optimized standard (*i.e.*, the standard defined by the user-specified shape and then shifted vertically by the model to produce the optimized stringency) to obtain the corresponding fleet (*i.e.*, the fleet that reflects estimated manufacturer responses at the optimized stringency) for the model year. As under regular (*i.e.*, non-optimizing) modeling exercises, this step is necessary to properly carry over added technologies from one model year to the next.

As originally designed, the model only performed optimization by accounting for each manufacturer separately, and then using the industry-wide sum of manufacturer-specific results to estimate optimal stringency. In the current version, the model also provides an optional setting to merge the fleet (*i.e.*, combine the vehicles of all individual manufacturers into a single group) throughout the optimization process. As explained below, under some circumstances, this option can provide more stable optima than when accounting for each manufacturer separately. The effect of this setting is illustrated below for a hypothetical fleet involving two manufacturers: "OEM1," a "laggard" which produces a fleet of vehicles with generally low baseline fuel economy relative to fuel economy targets; and "OEM2," a "front runner" which produces a fleet of vehicles with generally high baseline fuel economy relative to fuel economy targets. Typically, a manufacturer with a "laggard" fleet will experience application of technologies to its fleet at a lower stringency than that of a manufacturer with a more fuel efficient fleet. This will result in a different shape net benefits curve, as well as a different placement of the peak of maximum net benefits.

Below, Figure 9 shows net benefits (attributable separately to OEM1 and OEM2) on the y axis, with stringency (in terms of the average required fuel economy) on the x axis. As stringency increases (moving from left to right on the chart), OEM1, shown in orange, begins to be impacted by new standards when the average stringency (*i.e.*, the average fuel economy required of the industry) reaches 29.0 mpg.[32] For OEM1, net benefits increase as stringency increases past 29.0 mpg, peak when stringency reaches 31.9 mpg, decline as stringency continues to increase, and stabilize when stringency increases beyond past 32.8 mpg, at which point OEM1 exhausts all available technology applications. For OEM2, shown in blue, net benefits do not begin to increase until stringency increases past 34.3 mpg. Subsequently, net benefits attributable to OEM2 peak when stringency reaches 40.1 mpg, decline as stringency continues to increase, and stabilize when stringency increases beyond past 41.2 mpg, at which point OEM2 exhausts all available technology applications.

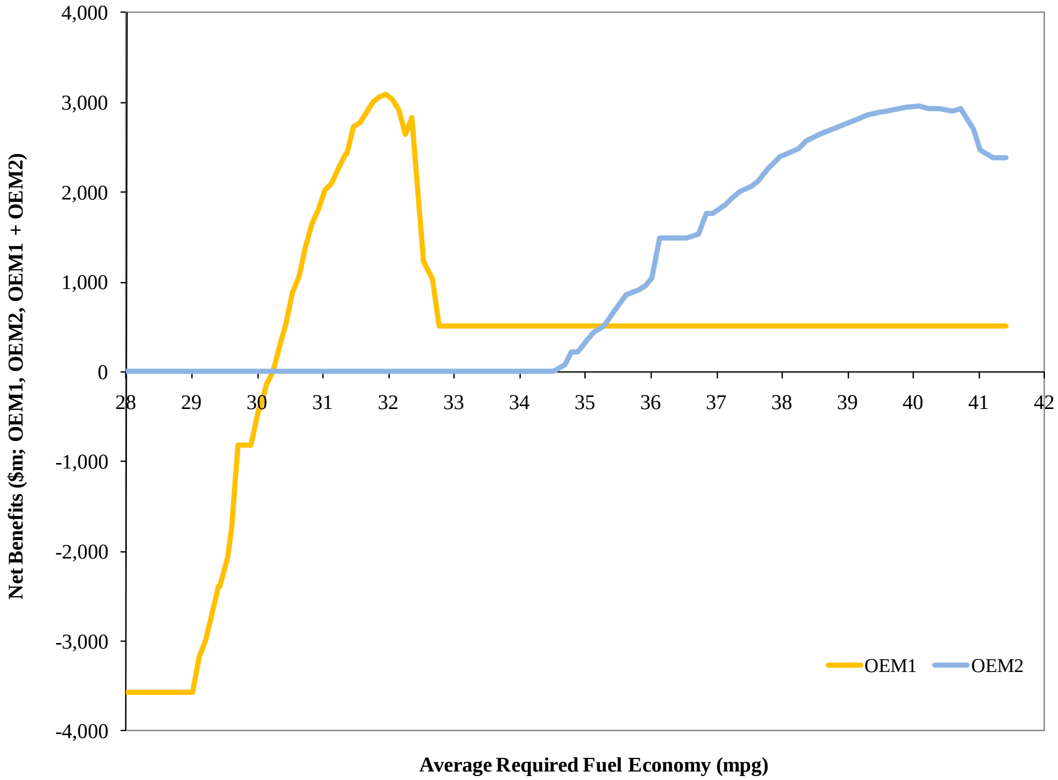

Figure 9. Net Benefits versus Stringency for Hypothetical 2-Manufacturer Fleet

Figure 10 shows the corresponding total net benefits for the industry (*i.e.*, the sum of net benefits attributable to both OEM1 and OEM2) as a dashed line superimposed on the net benefits attributable separately to OEM1 and OEM2. In this example, the significant difference between OEM1 and OEM2 in terms of baseline performance as compared to targets causes the total net benefits for the industry to exhibit two distinct peaks, one at 32.8 mpg and one at 40.1 mpg.

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[32] At stringencies of about 29.0-30.2 mpg, net benefits attributable to OEM1 are negative. This indicates the market forecast for OEM1 fell short of the baseline standards, and that for OEM1, standards of 29.0-30.2 mpg (again, in terms of average fuel economy required of the industry) would require technology beyond that required under the market forecast for OEM1, but not as much as would be required under the baseline standards.

Below 34.3 mpg, OEM2 is unaffected, such that results for OEM1 account for all of the net benefits for the industry. Above 34.3 mpg, the net benefits attributable to OEM2 are augmented by approximately $500m in net benefits attributable to OEM1 once OEM1 has exhausted available technologies (at 32.8 mpg).[33] In this example, relative sales volumes are such that the "OEM2 peak" at 40.1 mpg is dominant. However, if OEM1's market share had been somewhat greater than in this example, the "OEM1" peak at 32.8 mpg would have been dominant.

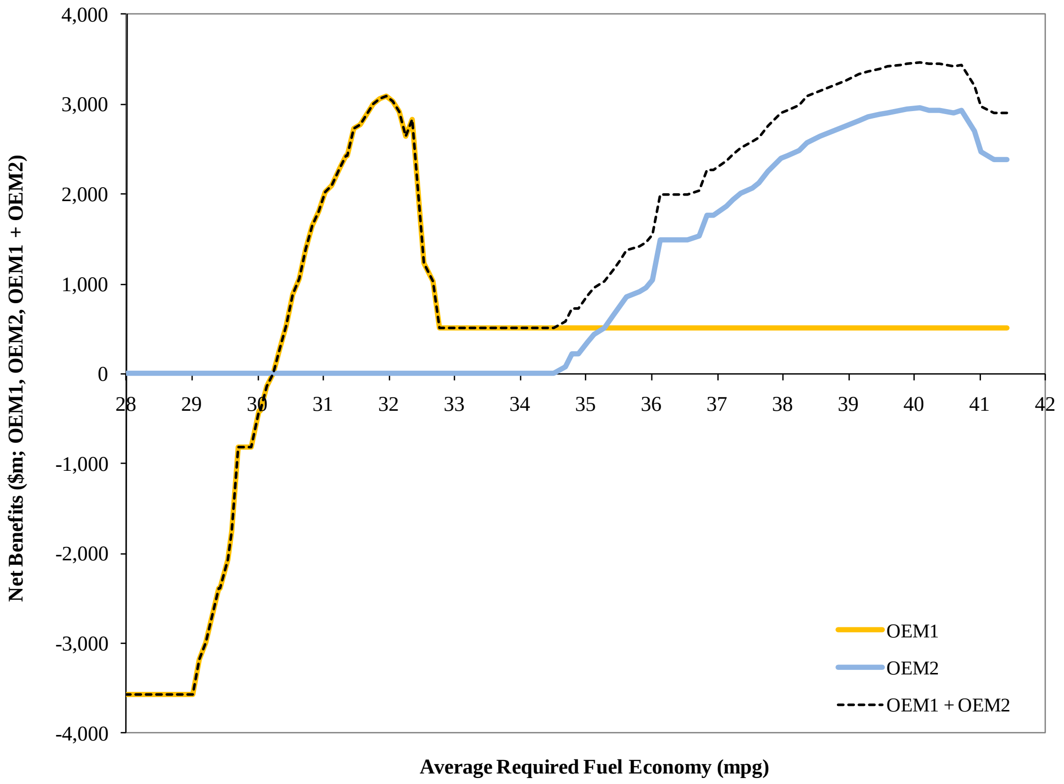

Figure 10. Sum of Net Benefits Attributable to OEM1 and OEM2

For the same hypothetical fleet, Figure 11 demonstrates the effect of selecting the "merged fleet" setting when running the model. With distinctions between OEM1 and OEM2 removed, the baseline average fuel economy of the merged fleet exceed are 30.2 mpg and technologies are not required until average stringency reaches 30.3 mpg. This higher average fuel economy is because the relatively high performance of OEM2's fleet balances the relatively low performance of OEM1's fleet. Net benefits subsequently increase, peak at 33.8 mpg, and then decline (except for a slight secondary peak at 34.2 mpg) until all technology options are exhausted when stringency reaches 34.4 mpg.

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[33] If a manufacturer exhausts available technologies without achieving compliance with a given standard, the model calculates the resultant civil penalties. However, because civil penalties are economic transfers, the model does not add these to estimated costs; therefore, the plot of net benefits attributed to an individual manufacturer becomes flat at stringencies beyond the point where the manufacturer exhausts available technology options.

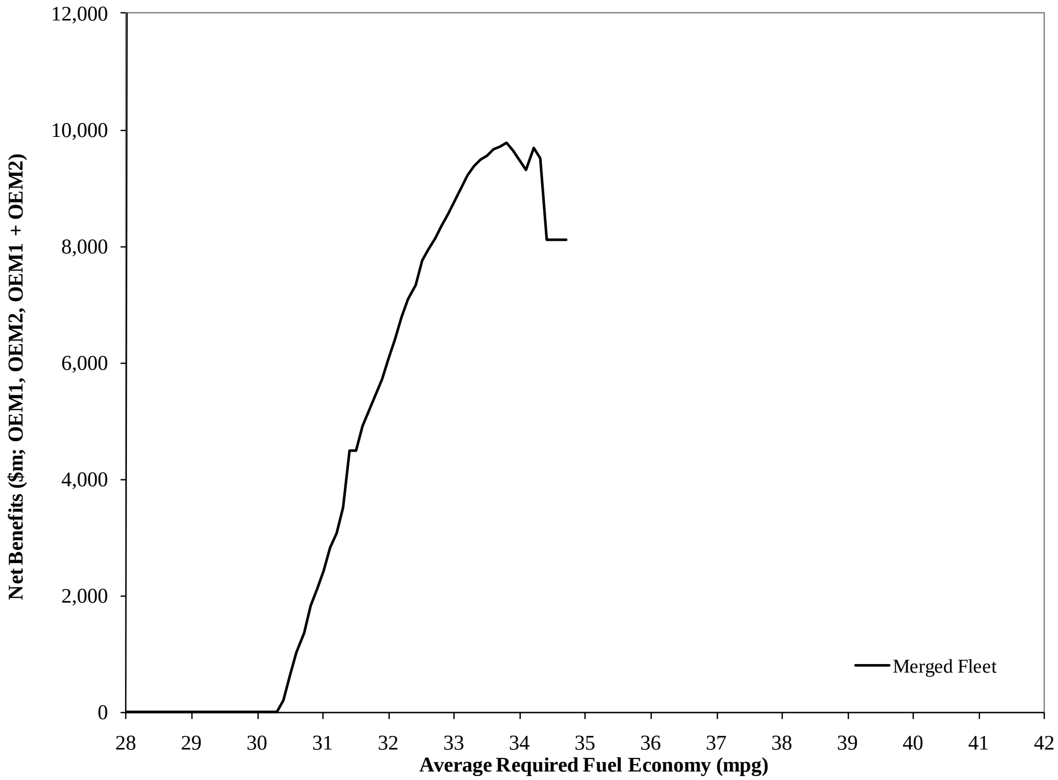

Figure 11. Net Benefits for Hypothetical Merged Fleet

Figure 12 compares the net benefits obtained with the merged fleet to those obtained for the underlying individual manufacturers, and for the industry as represented maintaining the distinction between the two manufacturers. Without merging the fleet, the model obtains a net benefits plot that has two widely separated peaks. Because the relative heights of these peaks could be impacted differently by relatively modest changes in model inputs (including manufacturers' market shares and sometimes other inputs), these widely separated peaks lead to unstable (albeit correctly calculated) results. For example, relatively modest changes in model inputs such as manufacturer sales volumes or economic factors (*e.g.*, discount rate, rebound effect, fuel price) can change which peak is dominant, thereby causing a significant change in estimated optimized stringency. The merged fleet produces a much more stable peak that falls between the two peaks obtained without applying this option.

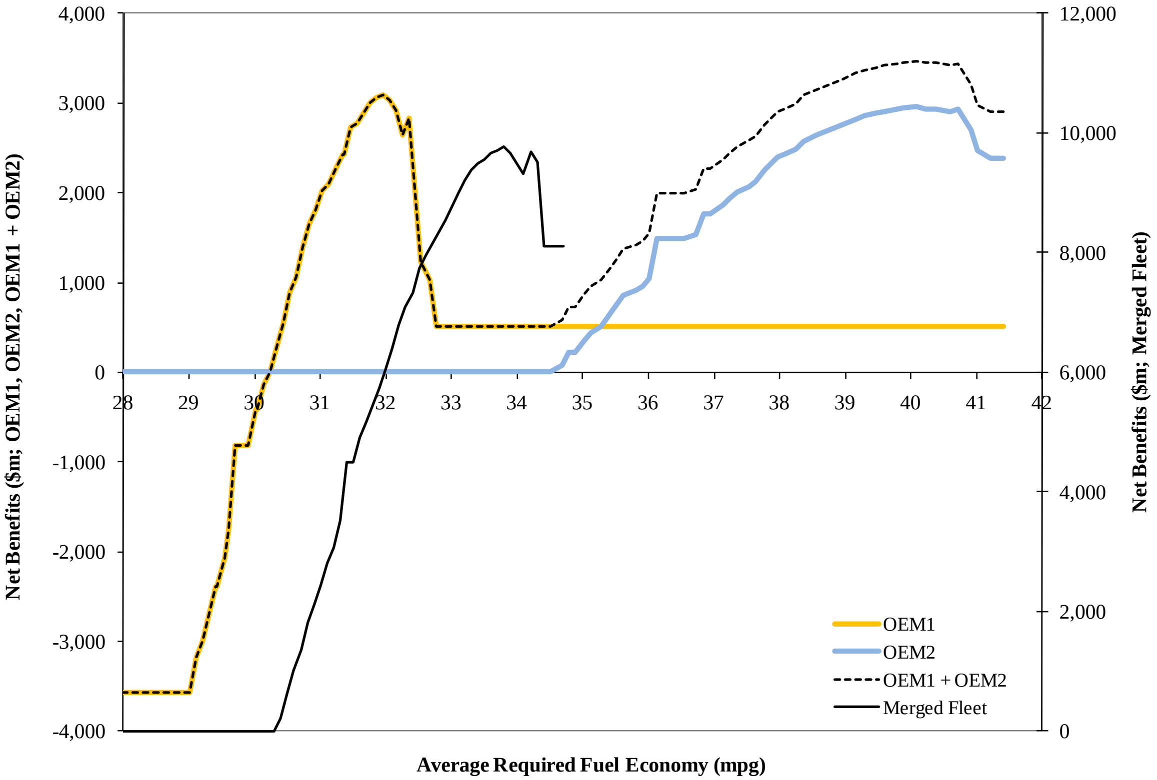

Figure 12. Comparison of Net Benefits with and without Merging of Fleet

Appendix D Monte Carlo Analysis

Probabilistic uncertainty analysis (for example, Monte-Carlo simulation) may be performed, such that all included scenarios are examined under varying technology costs and fuel consumption effects, pretax fuel prices, post-compliance payback periods, rebound effect, price shock costs, and mileage schedules. Monte-Carlo analysis may be set up and run using directions provided in the CAFE Model Software Manual document. While the modeling system could potentially be set up to analyze multiple alternative scenarios within a single run, given the resource restrictions associated with multiyear modeling, as well as time constraints placed on the development of the CAFE Model, at present the system only supports one alternative scenario per individual run. Multiple modeling instances, however, may be set up to evaluate additional alternatives.

The results of the analysis are located in the output folder selected during modeling. During Monte-Carlo simulation, the CSV outputs that are typically produced with regular compliance or optimization modeling are not generated. Instead, plain text Monte-Carlo log files can be found under the “MC-logs” subdirectory. As with regular modeling runs, however, the per-scenario logs are numbered in order of appearance, starting at 0, with the first scenario (Sn0) being the baseline to which all others are compared. The following files are generated at the end of the Monte-Carlo simulation:

- ***MC_trials.csv***: Contains Monte-Carlo trials used as input to the analysis. The contents of this file are summarized in Table 43 below.
- ***MC_tech_costs.csv***: Specifies the sales-weighted average technology costs for each technology, adjusted by the randomized cost scales from the **MC_trials.csv** file. The average costs for a technology are computed across all vehicle technology classes that were used during modeling as follows:

  $$TECHCOST_t = \left(\frac{\sum_{i,MY} \left(SALES_i \times COST_{i,t} \right)}{\sum_{i,MY} SALES_i} \right) \times SCALE_t$$

  where $SALES_i$ represent the sales of vehicle *i*, $COST_{i,t}$ is the base (unadjusted) cost of technology *t* as it applies to vehicle *i*, and $SCALE_t$ is the randomized value specifying the amount by which to scale the technology cost of technology *t*.
- ***MC_tech_fcs.csv***: Specifies the sales-weighted average technology fuel consumption improvements for each technology, adjusted by the randomized fuel consumption scales from the **MC_trials.csv** file. The average fuel consumption improvements for a technology are computed across all vehicle technology classes that were used during modeling as follows:

  $$TECHFC_t = \left(\frac{\sum_{i,MY} \left(SALES_i \times FC_{i,t} \right)}{\sum_{i,MY} SALES_i} \right) \times SCALE_t$$

where $SALES_i$ represent the sales of vehicle i, $FC_{i,t}$ is the base (unadjusted) fuel consumption improvement of technology t as it applies to vehicle i, and $SCALE_t$ is the randomized value specifying the amount by which to scale the technology fuel consumption improvement of technology t.

- ***MC_Sn*_data.csv***: Includes the results of pseudo-randomly generated Monte-Carlo trials for all scenarios. The log file for the results of the baseline scenario (Sn0) provides the totals accrued during that scenario. The log file for the results of the non-baseline scenario (Sn1) contains changes compared to the baseline. The contents of the file are summarized in Table 46 below.

D.1 Monte-Carlo Input Sampling

In the previous versions of the CAFE Model, the sampling of trials for Monte-Carlo analysis was performed internally by the modeling system. With the current revision, the Monte-Carlo trials are generated externally and are fed into the system in the form of an input file. The “MC trials” file is provided as part of the current rulemaking analysis, and may be obtained to perform additional modeling by users. Alternatively, users wishing to experiment with various distributions and sampling techniques may generate their own trials, provided the resulting input file is congruent with the original used for the analysis. The sampling procedure employed for generating the Monte-Carlo trials is outlined below.

The CAFE model requires entries for each of the variables in Table 43 (below) for every trial, as well as the set of input files necessary to produce a normal run (i.e., those specifying technology and fleet inputs, economic assumptions, regulatory scenarios, etc.). For the “MC trials” file that was used in the final analysis of the 2017–2025 CAFE program, a number of different distributions and technology groupings were used to produce the set of trials. A detailed description of the distributions used and the technology groups can be found in chapter XII of the NHTSA Regulatory Impact Analysis for the 2017–2025 CAFE standards.

Table 43. Monte-Carlo Input Data

Column	Contents
Index	Unique index of the trial.
FleetShare	Additional constant sampled from the distribution of residuals in the statistical relationship that defines the Dynamic Fleet Share Model and dynamically adjusts the PC/LT fleet share.
FuelPriceEstimates	Seed value to use for calculating the fuel prices.
PaybackPeriod_OC	Randomized value of the post-compliance payback period that manufacturers use with voluntary overcompliance.
ReboundEffect	Randomized value of the rebound effect.
PriceShockCost	Randomized value of the price shock cost.
MilesCars0	Randomly sampled seed value for the annual miles driven by passenger automobiles in "age 0", where the VMT for the remaining ages will be computed from this seed.
MilesAllLTs0	Randomly sampled seed value for the annual miles driven by all light trucks (vans, SUVs, and pickups) in "age 0", where the VMT for the remaining ages will be computed from this seed.
Cost_[Technology]	Randomized value specifying the amount by which to scale the technology costs for each technology.
FC_[Technology]	Randomized value specifying the amount by which to scale the technology fuel consumption improvement for each technology.

The FleetShare uncertainty is sampled from the distribution of residuals of an empirical model that estimates the share of new passenger cars as a function of fuel prices and other factors. The residuals themselves are small and approximately normally distributed about zero. Users who wish to omit this variable should simply substitute a value of zero in each run, or draw random samples from the trials file used in the analysis of the final rule. The FuelPriceEstimates variable is drawn from a uniform distribution on [0, 1]. Each unique draw is used by the CAFE model to generate a time series of fuel prices for that trial. The PaybackPeriod_OC is drawn from a Poisson distribution with a lambda value of 0.85. The CAFE model expects discrete (rather than continuous) values for this variable, so users should either use discrete distributions or modify their samples accordingly. The ReboundEffect is sampled from a beta distribution, then rescaled and shifted to produce values that are non-positive, and between 0 and -0.35. The PriceShockCost is drawn from a normal distribution intended to represent the range of values produced by Paul Leiby of the Oak Ridge National Laboratory. The midpoint of the range represents the mean of the normal distribution, and each endpoint is two standard deviations away from the mean. The two mileage accumulation variables (MilesCars0 and MilesAllLTs0) are smapled from normal distributions with means of 13,215 and 14,757, and standard deviations of 108 miles and 129 miles, respectively[34].

Technology costs and effectiveness are sampled in groups, though not the same groups. It is also the case that technologies within a single group may have different cost distributions, although the grouping ensures that all technologies within a group are at similar quantiles of their respective distributions. Table 44 shows the unique cost distribution associated with each technology, as well as the group in which it is sampled for the Monte Carlo draws. In order to create the values that are passed to the CAFE model, a randomly sampled quantile (essentially just a uniform random number between zero and one) is generated for each group, for each draw. Then each of these is transformed by taking the value at the corresponding quantile of the beta distribution associated with each cost uncertainty. That value is then scaled by the width of the range between the "low index" and "high index", and then shifted by adding the "low index". These transformed values are then passed to the CAFE model, which treats them as scalars on the value of the technology cost in the technologies input file. The quantile of each beta distribution is the same for every group, for every draw, but the actual values passed to the model vary based on the shape of the underlying beta distribution specific to each technology.

Table 44. Technology Cost Sampling Groups and Distributions

		Beta Parameters		Index Values		
Technology	**Tech Group**	**α Shape Parameter**	**β Shape Parameter**	**Low Index**	**Mode Index**	**High Index**
Low Friction Lubricants - Level 1	1	1.8	3.14	0.6806	1	1.8484
Engine Friction Reduction - Level 1	1	1.8	3.14	0.9619	1	1.1013
Low Friction Lubricants and Engine Friction Reduction - Level 2	1	1.8	3.14	0.8726	1	1.3384
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	1	1.8	3.14	0.9046	1	1.2533
Discrete Variable Valve Lift (DVVL) on SOHC	1	1.8	3.14	0.811	1	1.502
Cylinder Deactivation on SOHC	1	1.8	3.14	-2.287	1	9.7305
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	1	1.8	3.14	0.9046	1	1.2533
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	1	1.8	3.14	0.8713	1	1.3418
Discrete Variable Valve Lift (DVVL) on DOHC	1	1.8	3.14	0.811	1	1.502
Continuously Variable Valve Lift (CVVL)	1	1.8	3.14	0.9378	1	1.1653
Cylinder Deactivation on DOHC	1	1.8	3.14	-2.287	1	9.7305
Stoichiometric Gasoline Direct Injection (GDI)	1	1.8	3.14	0.8767	1	1.3274
Cylinder Deactivation on OHV	1	1.8	3.14	0.5069	1	2.3098
Variable Valve Actuation - CCP and DVVL on OHV	1	1.8	3.14	0.9809	1	1.0508

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[34] The sample used in the final rule includes a process that averages in the usage characteristics of new fleet vehicles, which are typically used more intensively than household vehicles. Entries for the two l=mileage varibales in the trials will differ from the distributions described above for this reason.

Stoichiometric Gasoline Direct Injection (GDI) on OHV	1	3.14	1.8	0.793	1	1.0779
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - SD	2	3.14	1.8	0.7632	1	1.0892
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - MD	2	3.14	1.8	-10.82	1	5.451
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - LD	2	3.14	1.8	0.8452	1	1.0583
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - SD	2	1.8	3.14	0.536	1	2.2327
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - MD	2	1.8	3.14	0.8767	1	1.3274
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - LD	2	1.8	3.14	0.8767	1	1.3274
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - SD	2	1.8	3.14	0.8767	1	1.3274
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - MD	2	1.8	3.14	0.8767	1	1.3274
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - LD	2	1.8	3.14	0.8767	1	1.3274
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - SD	2	1.8	3.14	0.8909	1	1.2898
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - MD	2	1.8	3.14	0.8909	1	1.2898
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - LD	2	3.14	1.8	1.1501	1	0.9435
Advanced Diesel - Small Displacement	2	1.8	3.14	0.9404	1	1.1584
Advanced Diesel - Medium Displacement	2	3.14	1.8	0.9899	1	1.0038
Advanced Diesel - Large Displacement	2	1.8	3.14	0.9658	1	1.0909
6-Speed Manual/Improved Internals	3	1.8	3.14	0.8415	1	1.4209
High Efficiency Gearbox (Manual)	3	1.8	3.14	0.8726	1	1.3384
Improved Auto. Trans. Controls/Externals	3	1.8	3.14	0.8415	1	1.4209
6-Speed Trans with Improved Internals (Auto)	3	1.8	3.14	4.6303	1	-8.6431
6-speed DCT	3	3.14	1.8	1.0138	1	0.9948
8-Speed Trans (Auto or DCT)	3	1.8	3.14	0.8767	1	1.3274
High Efficiency Gearbox (Auto or DCT)	3	1.8	3.14	0.8726	1	1.3384
Shift Optimizer	3	1.8	3.14	0.8726	1	1.3384
Electric Power Steering	4	1.8	3.14	0.7987	1	1.5348
Improved Accessories - Level 1	4	1.8	3.14	0.7698	1	1.6115
Improved Accessories - Level 2	4	3.14	1.8	0.9813	1	1.0071
12V Micro-Hybrid (Stop-Start)	4	1.8	3.14	0.3081	1	2.8379
Integrated Starter Generator	5	1.8	3.14	0.7295	1	1.7185
Strong Hybrid - Level 1	5	3.14	1.8	-0.801	1	1.6782
Conversion from SHEV1 to SHEV2	5	1.8	3.14	0.8805	1	1.3174
Strong Hybrid - Level 2	5	3.14	1.8	-0.757	1	1.6616
Plug-in Hybrid - 30 mi range	5	3.14	1.8	0.5384	1	1.1738
Plug-in Hybrid						
Electric Vehicle (Early Adopter) - 75 mile range	5	3.14	1.8	1	1	1
Electric Vehicle (Early Adopter) - 100 mile range						
Electric Vehicle (Early Adopter) - 150 mile range						
Electric Vehicle (Broad Market) - 150 mile range	5	3.14	1.8	1	1	1
Fuel Cell Vehicle						
Mass Reduction - Level 1	6	1.8	3.14	-15.01	1	43.521
Mass Reduction - Level 2	6	1.8	3.14	-1.276	1	7.0453
Mass Reduction - Level 3	6	1.8	3.14	0.0199	1	3.6035
Mass Reduction - Level 4	6	1.8	3.14	0.5377	1	2.2279
Mass Reduction - Level 5	6	1.8	3.14	0.711	1	1.7676
Low Rolling Resistance Tires - Level 1	1	1.8	3.14	-0.45	1	4.8517
Low Rolling Resistance Tires - Level 2	1	3.14	1.8	0.7204	1	1.1053
Low Rolling Resistance Tires - Level 3						
Low Drag Brakes	1	1.8	3.14	0.8726	1	1.3384
Secondary Axle Disconnect	1	1.8	3.14	0.8415	1	1.4209
Aero Drag Reduction, Level 1	1	1.8	3.14	0.7502	1	1.6636
Aero Drag Reduction, Level 2	6	1.8	3.14	0.7977	1	1.5373

The uncertainty for technology effectiveness is sampled in a similar way to the cost uncertainty, with the only significant difference being the introduction of multiple types of distributions. While all of the cost uncertainties are described by beta distributions (of several shapes), effectiveness uses both beta and normal distributions. The beta distributions are sampled (and translated) in the same manner described above, while the normal distributions are sampled in a less complicated way. Each draw merely uses the sampled value of the group's quantile (a uniform random number between zero and one) to select an appropriate value from the normal distribution (i.e., the one occurs at that quantile). Table 45 describes the grouping scheme associated with the incremental improvement from adding new fuel economy technology, as well as the probability distributions associated with the amount of improvement achieved by the additional of each technology.

Table 45. Technology Effectiveness Sampling Groups and Distributions

			Normal Dist Parameters	Beta Parameters		Index Values		
Technology	**Tech Group**	**Distribution Type**	**Std Dev (in 0:1 range)**	**α Shape Parameter**	**β Shape Parameter**	**Low Index**	**Mode Index**	**High Index**
Low Friction Lubricants - Level 1	1	Beta		1.2	1.0549956	0.6623	1	1.09285
Engine Friction Reduction - Level 1	1	Beta		1.2	1.0549956	0.4877	1	1.14087
Low Friction Lubricants and Engine Friction Reduction - Level 2	1	Beta		1.1	1.4108074	0.7598	1	1.98687
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	1	Normal	0.145					
Discrete Variable Valve Lift (DVVL) on SOHC	1	Normal	0.29					
Cylinder Deactivation on SOHC	1	Normal	0.29					
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	1	Normal	0.145					
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	1	Normal	0.29					
Discrete Variable Valve Lift (DVVL) on DOHC	1	Normal	0.29					
Continuously Variable Valve Lift (CVVL)	1	Normal	0.29					
Cylinder Deactivation on DOHC	1	Normal	0.29					
Stoichiometric Gasoline Direct Injection (GDI)	1	Normal	0.29					
Cylinder Deactivation on OHV	1	Normal	0.29					
Variable Valve Actuation - CCP and DVVL on OHV	1	Normal	0.29					
Stoichiometric Gasoline Direct Injection (GDI) on OHV	1	Normal	0.29					
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - SD	2	Normal	0.29					
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - MD	2	Normal	0.29					
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - LD	2	Normal	0.29					
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - SD	2	Normal	0.29					
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - MD	2	Normal	0.29					
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - LD	2	Normal	0.29					
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - SD	2	Normal	0.29					
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - MD	2	Normal	0.29					
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - LD	2	Normal	0.29					
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - SD	2	Normal	0.29					
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - MD	2	Normal	0.29					
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - LD	2	Normal	0.29					
Advanced Diesel - Small Displacement	2	Beta		1.1	1.4108074	0.746	1	2.04325
Advanced Diesel - Medium Displacement	2	Beta		1.1	1.4108074	0.746	1	2.04325
Advanced Diesel - Large Displacement	2	Beta		1.1	1.4108074	0.8831	1	1.48027
6-Speed Manual/Improved Internals	3	Normal	0.145					
High Efficiency Gearbox (Manual)	3	Normal	0.145					
Improved Auto. Trans. Controls/Externals	3	Normal	0.145					
6-Speed Trans with Improved Internals (Auto)	3	Normal	0.145					
6-speed DCT	3	Normal	0.29					
8-Speed Trans (Auto or DCT)	3	Normal	0.29					
High Efficiency Gearbox (Auto or DCT)	3	Normal	0.145					
Shift Optimizer	3	Normal	0.145					
Electric Power Steering	3	Beta		1.1	1.4108074	0.8248	1	1.71969
Improved Accessories - Level 1	3	Beta		1.2	1.0549956	0.7284	1	1.07468
Improved Accessories - Level 2	3	Beta		1.2	1.0549956	0.1343	1	1.23804
12V Micro-Hybrid (Stop-Start)	3	Beta		1.1	1.4108074	0.8387	1	1.66283
Integrated Starter Generator	4	Beta		1.1	1.4108074	0.9138	1	1.35425
Strong Hybrid - Level 1	4	Beta		1.2	1.0549956	-0.5208	1	1.4182
Conversion from SHEV1 to SHEV2	4	Beta		1.1	1.4108074	0.9069	1	1.38236
Strong Hybrid - Level 2	4	Beta		1.2	1.0549956	-2.9104	1	2.07527
Plug-in Hybrid - 30 mi range	4	Normal	0.435					
Plug-in Hybrid								
Electric Vehicle (Early Adopter) - 75 mile range	4		0.435					
Electric Vehicle (Early Adopter) - 100 mile range								
Electric Vehicle (Early Adopter) - 150 mile range								
Electric Vehicle (Broad Market) - 150 mile range	4		0.435					
Fuel Cell Vehicle								
Mass Reduction - Level 1	3	Normal	0.145					
Mass Reduction - Level 2	3	Normal	0.145					
Mass Reduction - Level 3		Normal	0.145					
Mass Reduction - Level 4		Normal	0.29					
Mass Reduction - Level 5		Normal	0.29					
Low Rolling Resistance Tires - Level 1	1	Beta		1.1	1.4108074	0.9353	1	1.26581
Low Rolling Resistance Tires - Level 2	1	Beta		1.2	1.0549956	0.7836	1	1.05949
Low Rolling Resistance Tires - Level 3								
Low Drag Brakes	1	Beta		1.1	1.4108074	0.8938	1	1.43641
Secondary Axle Disconnect	1	Normal	0.145					
Aero Drag Reduction, Level 1	1	Beta		1.2	1.0549956	0.5676	1	1.11891
Aero Drag Reduction, Level 2	3	Beta		1.1	1.4108074	0.8794	1	1.49534

D.2 Monte-Carlo Output Data

The modeling system produced two data outputs as part of the Monte-Carlo analysis: MC_Sn0_data.csv and MC_Sn1_data.csv. The former contains results of the baseline scenario

(Sn0), which are specified as the totals accrued during analysis of the baseline, while the latter contains results of the alternative scenario (Sn1), which are presented as incremental changes over the baseline. In both output files, results are provided for each model year analyzed (where the years span multiple columns), separated into the PC and the LT fleets (according to the regulatory classification of vehicles), as well as aggregated across the entire industry (combining PC and LT fleets). Some of the outputs reported do not apply to the baseline scenario. In particular, since the "net benefits" and the "benefit:cost ratios" are the direct results of improvements realized in the alternative scenario over the baseline scenario, these values would appear as "0" in the baseline's output file (MC_Sn0_data.csv).

The following table lists the full contents of the *Monte-Carlo Output Data* file.

Table 46. Monte-Carlo Output Data

Column	Contents
Index	Unique index of the trial.
Sales_PC_[MY]	Total sales volumes for the PC fleet in each model year.
Sales_LT_[MY]	Total sales volumes for the LT fleet in each model year.
Sales_[MY]	Total sales volumes for the entire industry (PC and LT fleets) in each model year.
PCShare_[MY]	Passenger automobile share of the total industry sales. The PC shares presented in the outputs are computed based on the regulatory classification of vehicles. Conversely, for the Dynamic Fleet Share Model, the modeling system computes PC shares based on the style of the vehicles.
TechCosts_PC_[MY]	Total technology costs accumulated by the PC fleet in each model year.
TechCosts_LT_[MY]	Total technology costs accumulated by the LT fleet in each model year.
TechCosts_[MY]	Total technology costs accumulated by the entire industry (PC and LT fleets) in each model year.
Fines_PC_[MY]	Total fines owed resulting from undercompliance by the PC fleet in each model year.
Fines_LT_[MY]	Total fines owed resulting from undercompliance by the LT fleet in each model year.
Fines_[MY]	Total fines owed resulting from undercompliance by the entire industry (PC and LT fleets) in each model year.
SocialCosts_PC_[MY]	Total social costs accumulated by the PC fleet in each model year.
SocialCosts_LT_[MY]	Total social costs accumulated by the LT fleet in each model year.
SocialCosts_[MY]	Total social costs accumulated by the entire industry (PC and LT fleets) in each model year.
SocialBenefits_PC_[MY]	Discounted social benefits accumulated by the PC fleet in each model year.
SocialBenefits_LT_[MY]	Discounted social benefits accumulated by the LT fleet in each model year.
SocialBenefits_[MY]	Discounted social benefits accumulated by the entire industry (PC and LT fleets) in each model year.
NetBenefits_PC_[MY]	Net benefits attributed to the PC fleet in each model year.
NetBenefits_LT_[MY]	Net benefits attributed to the LT fleet in each model year.
NetBenefits_[MY]	Net benefits attributed to the entire industry (PC and LT fleets) in each model year.
AdditionalVMT_PC_[MY]	Total additional vehicle miles traveled by the PC fleet in each model year.
AdditionalVMT_LT_[MY]	Total additional vehicle miles traveled by the LT fleet in each model year.
AdditionalVMT_[MY]	Total additional vehicle miles traveled by the entire industry (PC and LT fleets) in each model year.
FuelSavings_PC_[MY]	Fuel savings (in dollars) accumulated by the PC fleet in each model year.
FuelSavings_LT_[MY]	Fuel savings (in dollars) accumulated by the LT fleet in each model year.
FuelSavings_[MY]	Fuel savings (in dollars) accumulated by the entire industry (PC and LT fleets) in each model year.
FuelSavingsGal_PC_[MY]	Fuel savings (in gallons) accumulated by the PC fleet in each model year.
FuelSavingsGal_LT_[MY]	Fuel savings (in gallons) accumulated by the LT fleet in each model year.
FuelSavingsGal_[MY]	Fuel savings (in gallons) accumulated by the entire industry (PC and LT fleets) in each model year.
BCRatio_PC_[MY]	Ratio of social benefits to total technology costs for the PC fleet in each model year.
BCRatio_LT_[MY]	Ratio of social benefits to total technology costs for the LT fleet in each model year.
BCRatio_[MY]	Ratio of social benefits to total technology costs for the entire indusry (PC and LT fleets) in each model year.

Appendix E CAFE Model Software Manual

E.1 Warnings

This software was developed for analysis by U.S. Department of Transportation staff of potential fuel economy requirements.

This software uses input files containing detailed information regarding vehicles manufactured for sale in the United States and creates output files containing similarly detailed information regarding such vehicles. If input files containing information in any way (*e.g.*, based on entitlement under 5 U.S.C 552 to confidential treatment) protected from disclosure to the public are used, some output files created by this software must also be protected from disclosure to the public.

E.2 Notice

The CAFE Model software is a U.S. government work not subject to copyright pursuant to 17 USC 105; however, some of the third-party works used by the software are subject to usage agreements, as described below.

The button controls in the application toolbar of the CAFE Model use images from the Glaze Icon Set (version 0.4.6, released on 3/06/2006) obtained from http://www.notmart.org. All icons and/or images within the Glaze Icon Set are distributed under the GNU Lesser General Public License (LGPL), version 2.1. The version 2.1 of the GNU LGPL may be obtained from http://www.gnu.org/licenses/old-licenses/lgpl-2.1.html.

Some of the compiled or object code used by the CAFE Model was obtained from third-party sources. Specifically, the code for randomizing the forecast data for the average fuel prices, which is executed as part of the CAFE Model's uncertainty analysis, makes use of the inverse of the beta cumulative probability density function contained within the Meta.Numerics library (in particular, the InverseLeftProbability method of the BetaDistribution class is used). The Meta.Numerics library (version 2.0.0, released on 4/06/2011) was obtained from http://www.meta-numerics.net and is distributed under the Microsoft Public License (Ms-PL). The latest version of the Ms-PL may be obtained from http://www.microsoft.com/en-us/openness/licenses.aspx.

If users of the CAFE model have any questions about this notice, please contact the current administrators of the CAFE Model project.

E.3 Installation and System Requirements

The CAFE Compliance and Effects Modeling System (abbreviated: CAFE Model) runs on IBM-compatible computers using the Microsoft® Windows operating system. Although the software does not have strict hardware requirements, beyond what is needed to run the operating system, a 1 GHz or faster Intel compatible processor, with at least 2 GB of physical memory (RAM) is strongly recommended. The software has been developed and tested on computers using Windows XP/7 and Windows Server 2003/2008, but may operate properly on machines using older versions of Windows (*e.g.*, Windows 2000), or newer versions (*e.g.*, Windows 8), as long as a compatible Microsoft® .NET Framework is installed.

The CAFE Model software uses Microsoft® Excel to read input files needed for modeling. As such, Excel must be installed on the system. The software also uses the Microsoft® .NET Framework, version 3.5. If the Framework is not already present, it must be installed. Instructions for downloading and installing the .NET framework are available on the Internet at http://www.microsoft.com/download/en/details.aspx?id=22.

Based on the characteristics of machines used in the development of this software, the following table provides a summary of system requirements:

Table 47. CAFE Model System Requirements

Intel compatible processor (1 GHz or faster recommended)
512 MB RAM (2 GB recommended)
10 MB hard drive space for installation (additional disk space will be required during runtime)
Microsoft® Windows XP/Vista/7 Microsoft® Windows Server 2003/2008
Microsoft® .NET Framework 3.5
Microsoft® Office 2003 or later

Once the system requirements have been met, the latest version of the CAFE Model may be obtained by contacting NHTSA or Volpe Center staff.

The current version of the software is packaged in a way that does not require installation. To operate the model, place the “CAFE Model.exe” file on the desktop and execute it[35].

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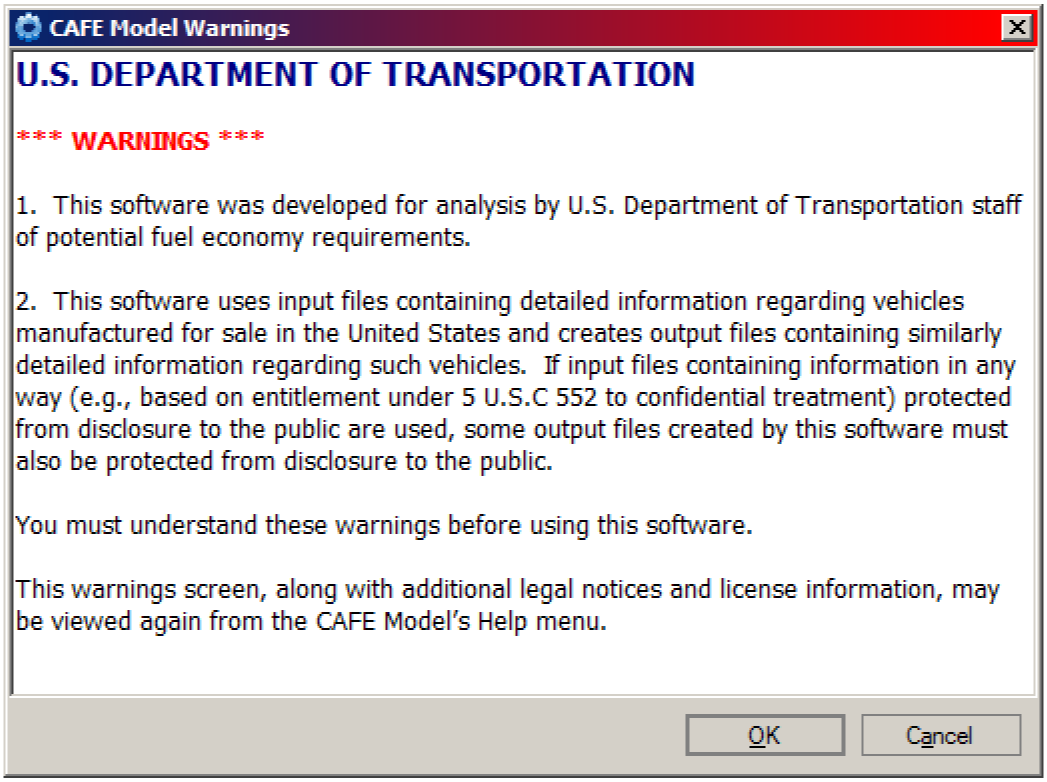
[35] The CAFE Model files provided may be in a zip archive, which will need to be extracted using a zip utility such as WinZip (www.winzip.com) or 7Zip (www.7-zip.org).

E.4 CAFE Model Graphical User Interface

The CAFE Model Graphical User Interface (GUI) provides users with a set of tools necessary to set up and run multiple modeling test scenarios, which are commonly referred to as CAFE Model sessions. Each CAFE Model session can be configured independently, each with its own set of model inputs and settings. Once configured, the session may be saved for future runs, or executed immediately.[36] When the model runs, the system displays the progress of the compliance modeling process in each session's window.

The model GUI consists of two primary screens: the main **CAFE Model** window and the **Modeling Settings** window. The **CAFE Model** window is used for managing the modeling sessions, while the **Modeling Settings** window is used to configure them.

To run the modeling system, click on the **CAFE Model** executable file located on the desktop. When the application launches, a **Warnings** dialog box is displayed (Figure 13). The user must read and understand the warnings listed prior to using the modeling system.



U.S. DEPARTMENT OF TRANSPORTATION

*** WARNINGS ***

1. This software was developed for analysis by U.S. Department of Transportation staff of potential fuel economy requirements.

2. This software uses input files containing detailed information regarding vehicles manufactured for sale in the United States and creates output files containing similarly detailed information regarding such vehicles. If input files containing information in any way (e.g., based on entitlement under 5 U.S.C 552 to confidential treatment) protected from disclosure to the public are used, some output files created by this software must also be protected from disclosure to the public.

You must understand these warnings before using this software.

This warnings screen, along with additional legal notices and license information, may be viewed again from the CAFE Model's Help menu.

Figure 13. Warnings Dialog Box

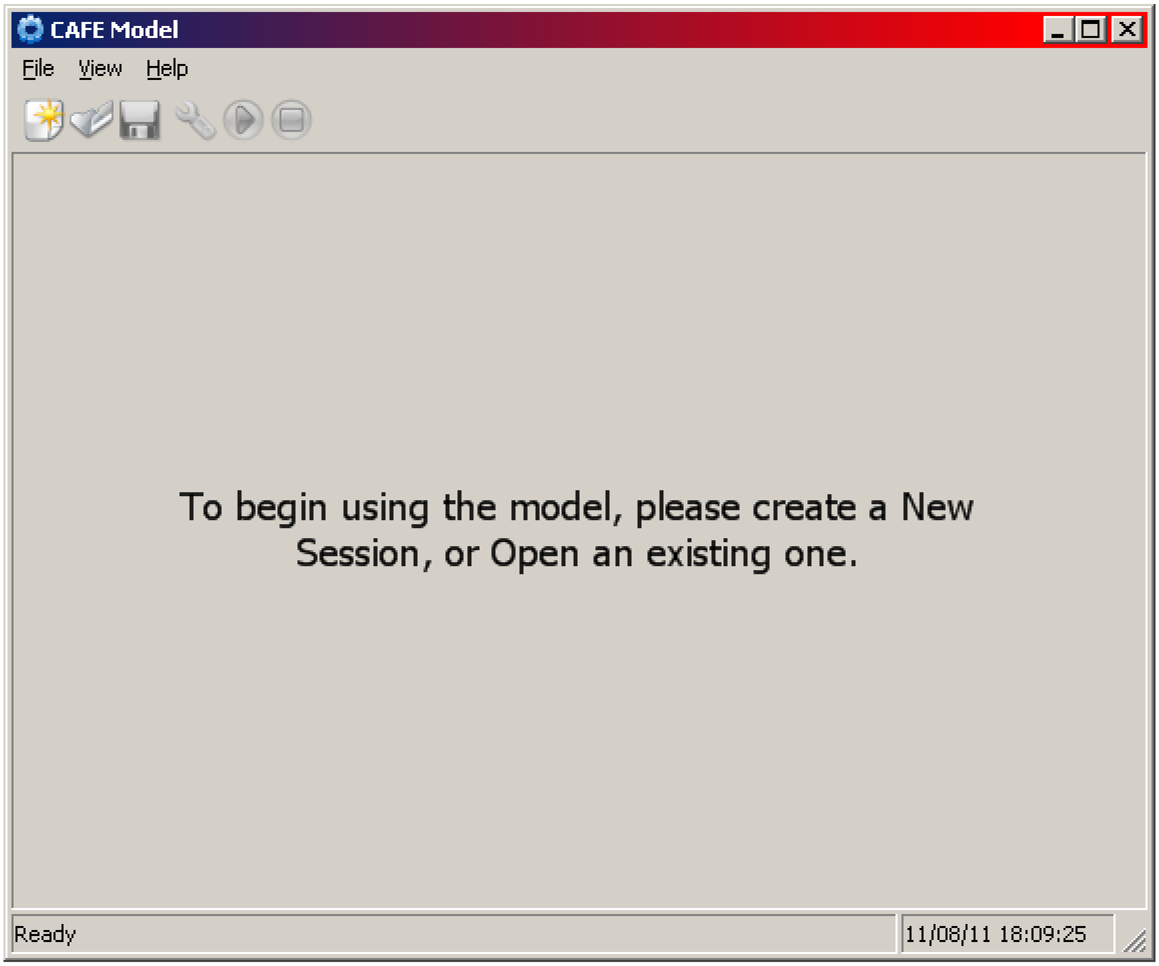
After clicking the **OK** button in the **Warnings** dialog box, the main **CAFE Model** window, described below, opens.

---

[36] It is recommended that users save the sessions prior to running them in order to assign a meaningful title to each session.

E.4.1 CAFE Model Window

The main **CAFE Model** window (Figure 14) is used to create, configure, and manage CAFE modeling sessions. The main window also controls the model operation, allowing users to start and stop modeling simulation.



To begin using the model, please create a New Session, or Open an existing one.

Ready

11/08/11 18:09:25

Figure 14. CAFE Model Window

When the model first starts up, most of the menu items and toolbar icons are disabled, until a new session is created, or an existing one is opened.

The model GUI is operated using a simple, easy to use file-menu (Figure 15), with most commonly used shortcuts also available on the model toolbar (Figure 16). For user convenience, most of the menu entries may also be controlled using keyboard shortcuts.

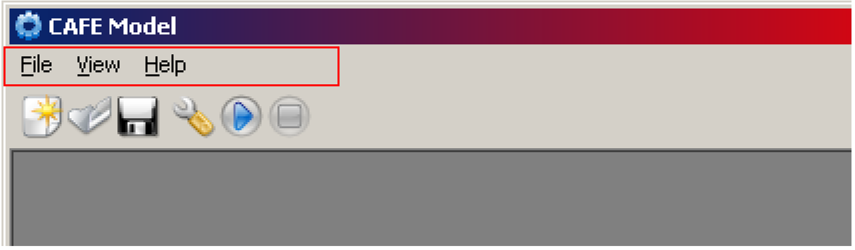


Figure 15. CAFE Model File Menu

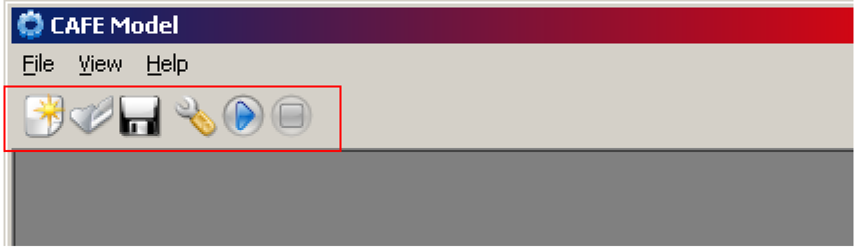


Figure 16. CAFE Model Toolbar

Some of the most commonly used file menus are:

- ***File*** > ***New Session***: Creates a new *CAFE Model Session* and displays the **Modeling Settings** window to the user.
- ***File*** > ***Open Session***: Opens an existing *CAFE Model Session*.
- ***File*** > ***Close Session***: Closes the active *CAFE Model Session*.
- ***File*** > ***Save Session***: Saves the active *CAFE Model Session*.
- ***File*** > ***Start Modeling***: Begins the modeling process for the active *CAFE Model Session*.
- ***File*** > ***Stop Modeling***: Suspends the modeling process of the active *CAFE Model Session*.
- ***File*** > ***Exit***: Exits the **CAFE Model**. If any of the modeling sessions are still opened, they will be closed prior to exiting the model.
- ***View*** > ***Modeling Settings***: Displays the **Modeling Settings** window, where all modeling options and settings may be configured.
- ***View*** > ***Optimization Settings***: Displays the **Manage Optimization** window, where additional options for Optimization modeling can be configured.
- ***View*** > ***Monte-Carlo Settings***: Displays the **Manage Monte-Carlo** window, where additional options for Monte-Carlo modeling can be configured.
- ***View*** > ***Output Location***: Opens the Windows Explorer and browses to the location where the output files and reports of the active session are saved.

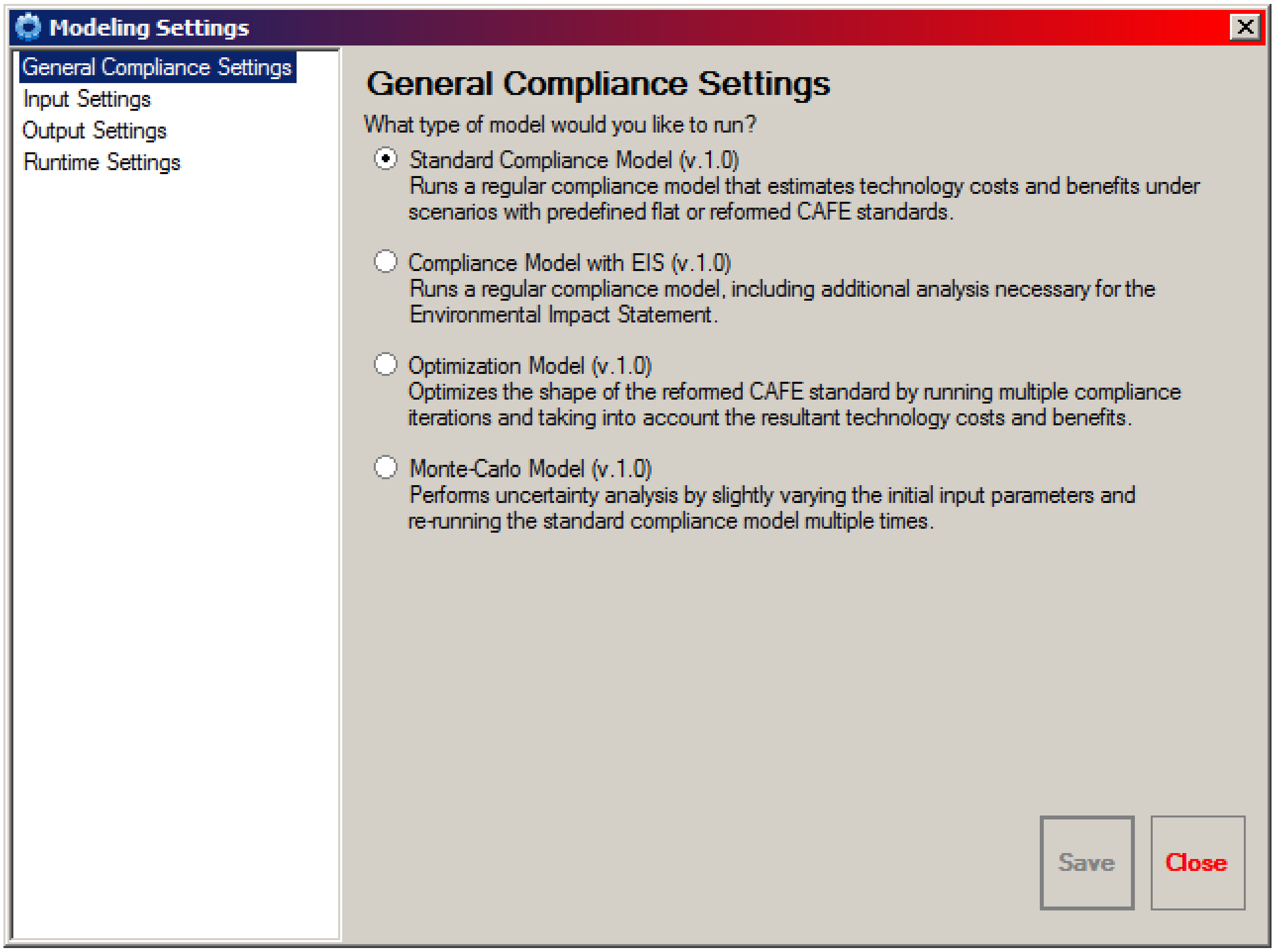
E.4.2 Modeling Settings Window

The **Modeling Settings** window contains multiple panels for configuring all of the runtime options available to the model. The user can operate this window to set up a new session, or modifying an existing one, before starting the modeling process. Each of the available configuration panels is outlined in the sections below.

E.4.2.1 General Compliance Settings Panel

The **General Compliance Settings** panel (Figure 17) is used to specify what type of modeling the user would like to run. Each model is tailored to different type of analysis, using its own set of assumptions and configuration settings. Presently, four model types are available:

- ***Standard Compliance Model***: The *Standard Compliance Model* is the default mode of operation for the CAFE modeling system. This model type is used to evaluate technology costs and benefits in response to the required CAFE standards defined in the modeling scenarios.
- ***Compliance Model with EIS***: This model type is similar to the *Standard Compliance Model*, except additional analysis necessary for the Environmental Impact Statement is performed.
- ***Optimization Model***: This model type should be used to perform analysis for optimizing the shape of the required CAFE standard.
- ***Monte-Carlo Model***: The *Monte-Carlo Model* is a specialized CAFE modeling type, which is used for running customized Monte-Carlo simulations necessary for uncertainty analysis.



General Compliance Settings

What type of model would you like to run?

● Standard Compliance Model (v.1.0)
Runs a regular compliance model that estimates technology costs and benefits under scenarios with predefined flat or reformed CAFE standards.

○ Compliance Model with EIS (v.1.0)
Runs a regular compliance model, including additional analysis necessary for the Environmental Impact Statement.

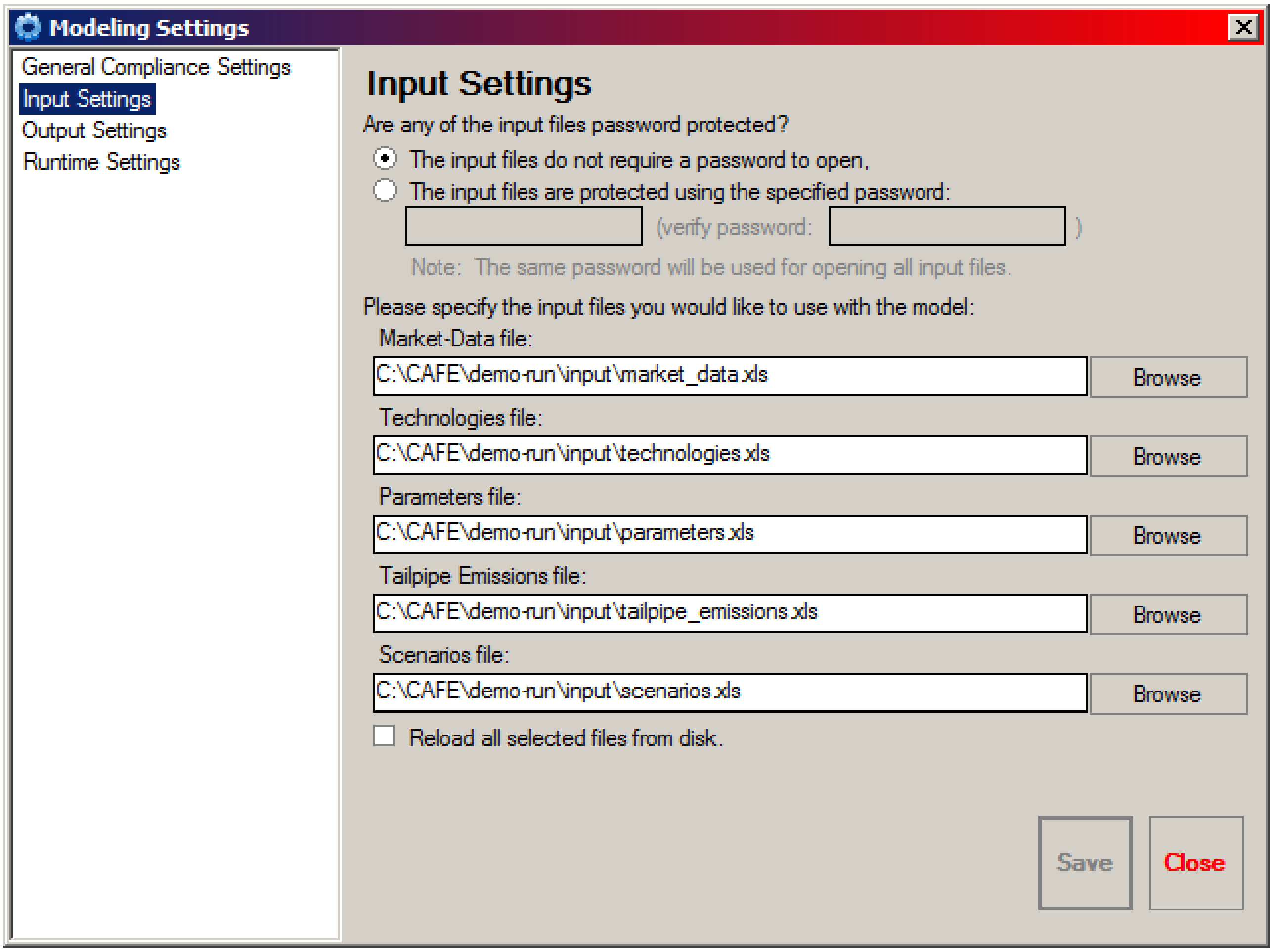
○ Optimization Model (v.1.0)
Optimizes the shape of the reformed CAFE standard by running multiple compliance iterations and taking into account the resultant technology costs and benefits.

○ Monte-Carlo Model (v.1.0)
Performs uncertainty analysis by slightly varying the initial input parameters and re-running the standard compliance model multiple times.

Figure 17. General Compliance Settings Panel

E.4.2.2 Input Settings Panel

On the **Input Settings** panel (Figure 18), the user can select the input data files for use with the modeling system. To protect Confidential Business Information (CBI), some of the input files may be password protected. The system, therefore, provides an option for users to enter an input password prior to loading such files.



Input Settings

Are any of the input files password protected?

● The input files do not require a password to open.

○ The input files are protected using the specified password:

(verify password:)

Note: The same password will be used for opening all input files.

Please specify the input files you would like to use with the model:

Market-Data file: C:\CAFE\demo-run\input\market_data.xls

Technologies file: C:\CAFE\demo-run\input\technologies.xls

Parameters file: C:\CAFE\demo-run\input\parameters.xls

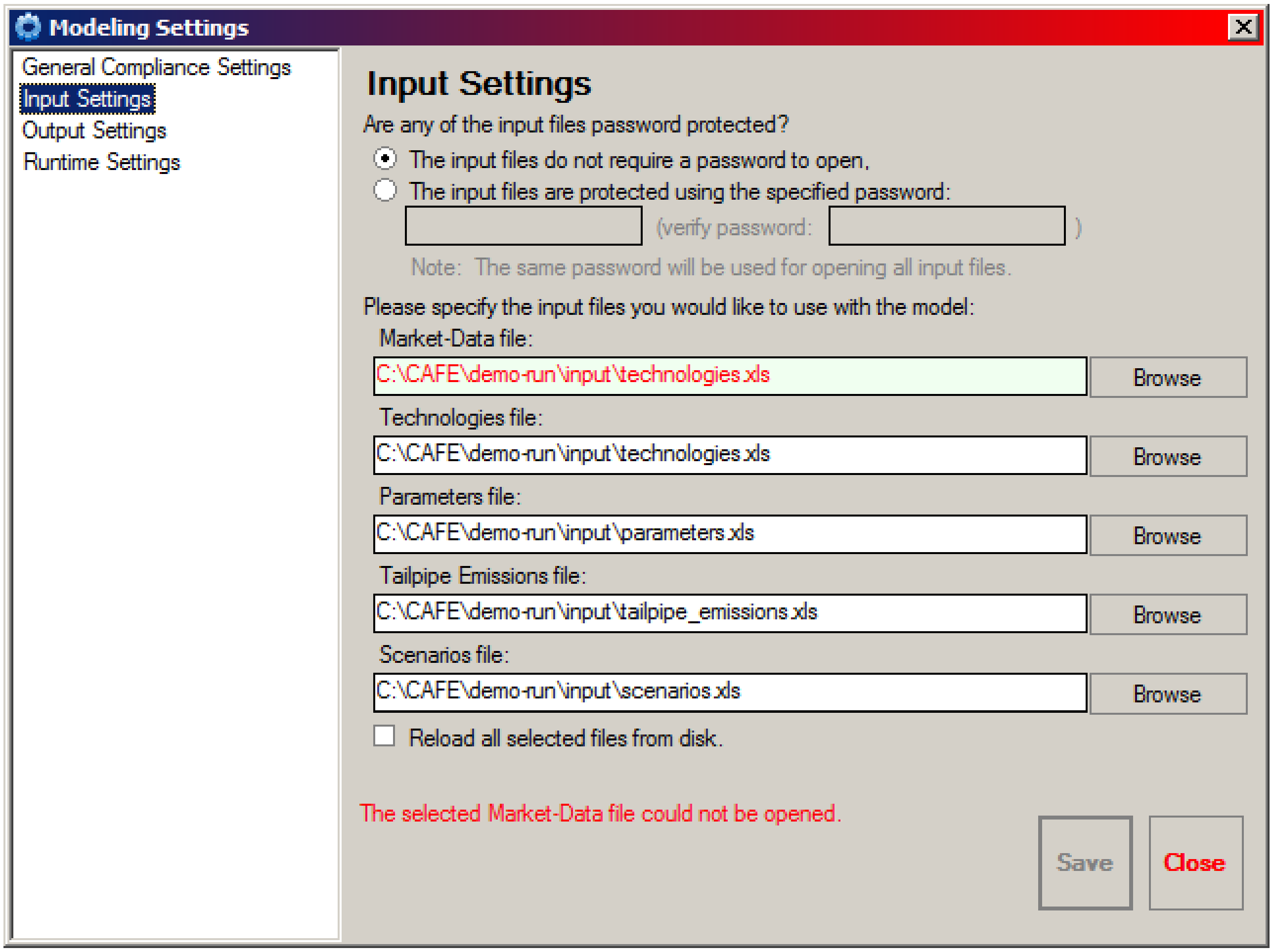
Tailpipe Emissions file: C:\CAFE\demo-run\input\tailpipe_emissions.xls

Scenarios file: C:\CAFE\demo-run\input\scenarios.xls

☐ Reload all selected files from disk.

Figure 18. Input Settings Panel (1)

When selecting input files, the model will attempt to verify if an appropriate file was used. If incorrect file path is entered, an error message will be displayed (Figure 19).



Input Settings

Are any of the input files password protected?

● The input files do not require a password to open.

○ The input files are protected using the specified password:

(verify password:)

Note: The same password will be used for opening all input files.

Please specify the input files you would like to use with the model:

Market-Data file: C:\CAFE\demo-run\input\technologies.xls

Technologies file: C:\CAFE\demo-run\input\technologies.xls

Parameters file: C:\CAFE\demo-run\input\parameters.xls

Tailpipe Emissions file: C:\CAFE\demo-run\input\tailpipe_emissions.xls

Scenarios file: C:\CAFE\demo-run\input\scenarios.xls

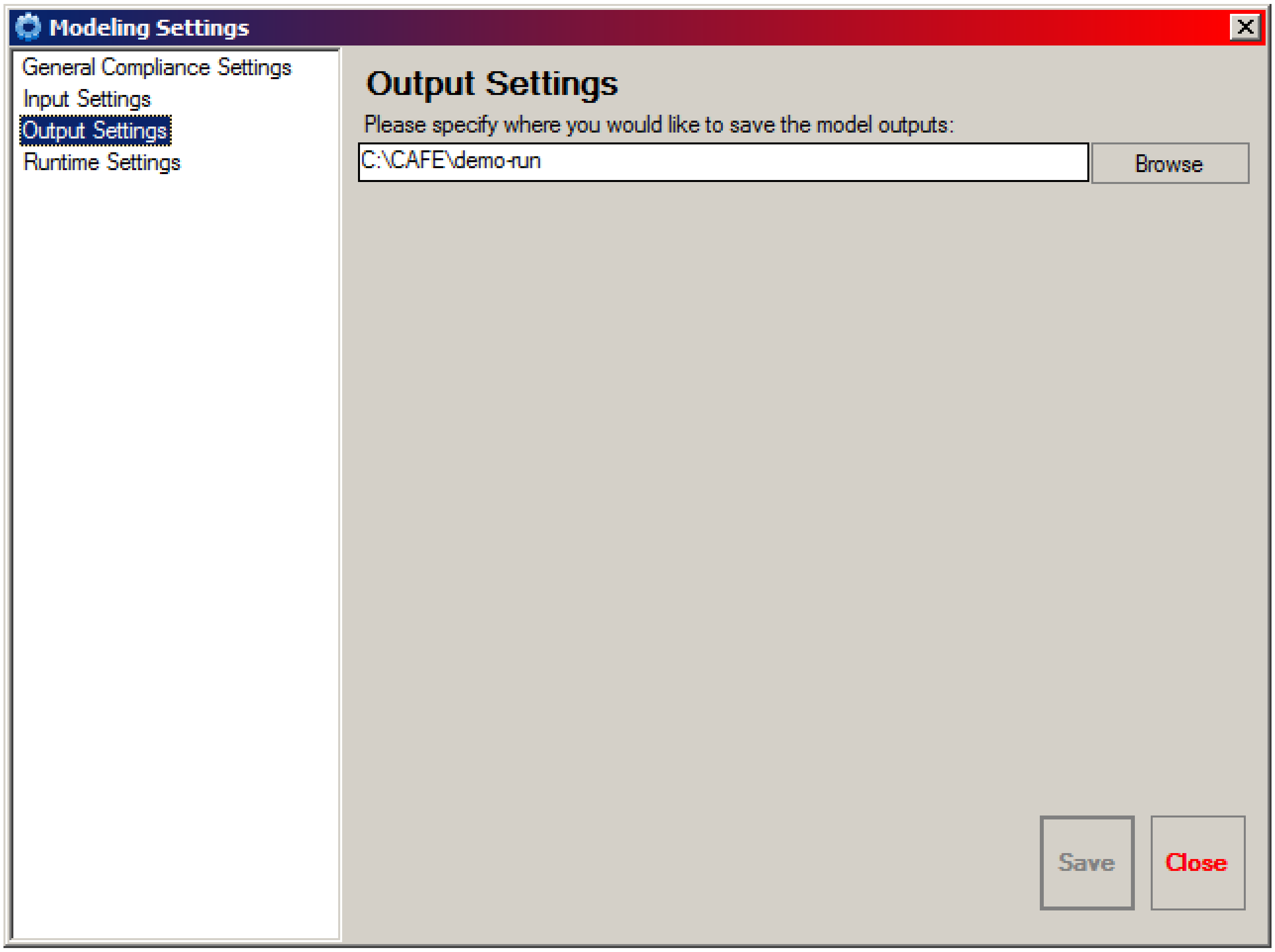
☐ Reload all selected files from disk.

The selected Market-Data file could not be opened.

Figure 19. Input Settings Panel (2)

E.4.2.3 Output Settings Panel

The **Output Settings** panel (Figure 20) is used to configure the location where modeling results will be saved.



Output Settings

Please specify where you would like to save the model outputs:

C:\CAFE\demo-run

Figure 20. Output Settings Panel

The modeling system automatically generates the following eight output files (in CSV format) during runtime:

- ***Technology Utilization Report***: Provides manufacturer-level and industry-wide technology application and penetration rates for each technology, model year, and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
- ***Compliance Report***: Provides manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
- ***Societal Effects Report***: Provides industry-wide summary of energy and emissions effects for each model year and scenario analyzed. The results are disaggregated by regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
- ***Societal Costs Report***: Provides industry-wide summary of consumer and social costs for each model year and scenario analyzed. The results are disaggregated by regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
- ***Annual Societal Effects Report***: This output file is similar to the *Societal Effects Report*, except it further disaggregates the results by calendar year.
- ***Annual Societal Costs Report***: This output file is similar to the *Societal Costs Report*, except it further disaggregates the results by calendar year.
- ***Vehicles Report***: Provides a detailed view of the final state of each vehicle examined by the model, for each model year and scenario analyzed.
- ***Optimization Report***: Provides functional coefficients and CAFE levels (required and achieved) for each iteration that was evaluated during optimization. This output file also contains a brief snapshot of industry-wide results, per iteration, that aided the model in picking the optimum levels for each model year that was optimized. **Note**: the *Optimization Report* is only generated when the *Optimization Model* is run.

E.4.2.4 Runtime Settings Panel

The **Runtime Settings** panel (Figure 21) provides additional modeling options to further customize the model behavior, beyond what is available in the input files:

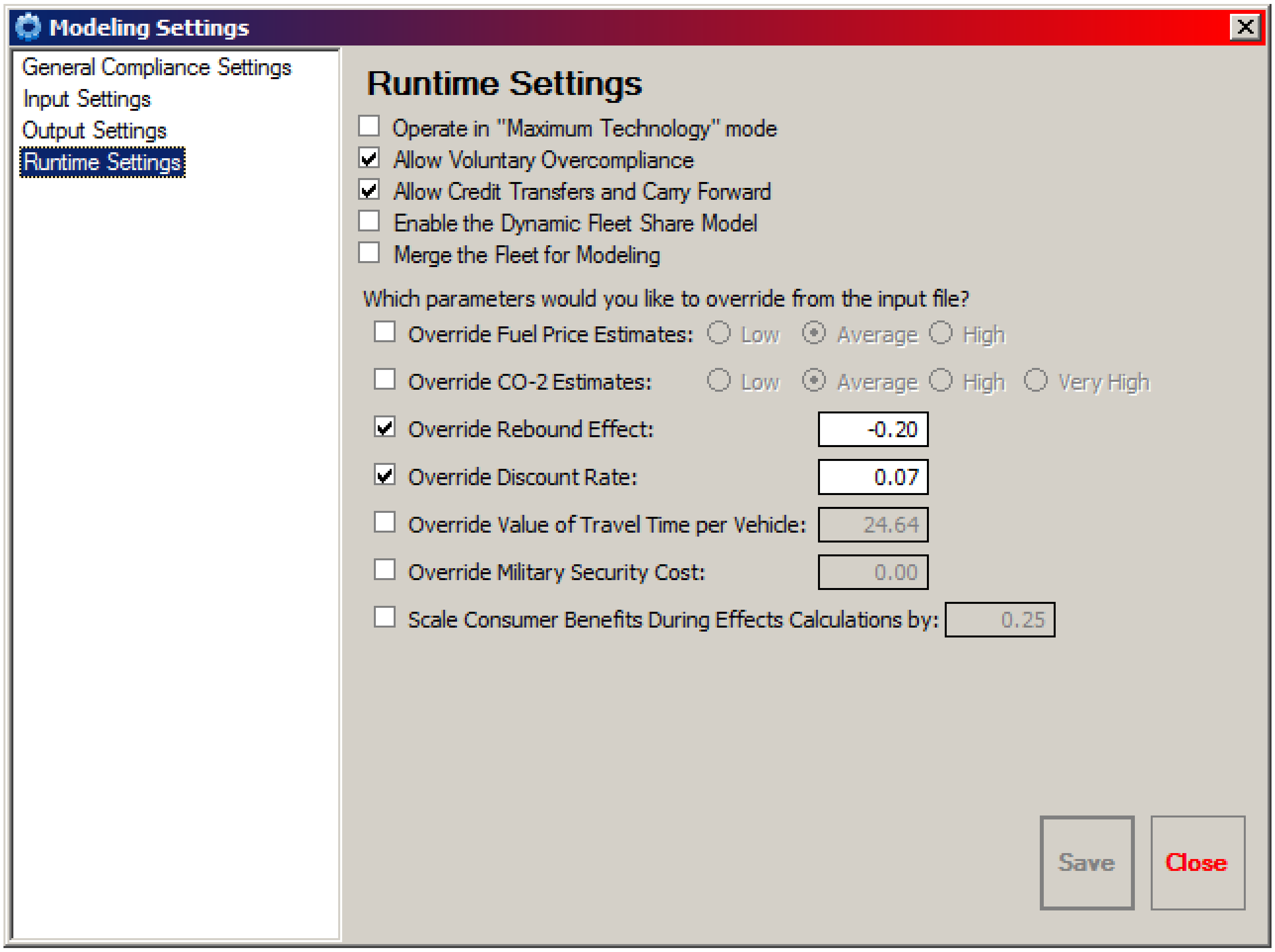
- ***Operate in "Maximum Technology" mode***: Specifies that the model should operate in "maximum technology" mode, where each manufacturer is assumed to be unwilling to pay CAFE fines, all vehicle refresh and redesign schedules are ignored, and all technologies are available for application immediately and without being subject to phase-in constraints.
- ***Allow Voluntary Overcompliance***: Specifies that the model should continue to apply technologies after reaching compliance during a given model year, as long as the application of additional technologies is cost effective.

- ***Allow Credit Transfers and Carry Forward***: Specifies whether the model should be able to transfer credits between fleets (PC and LT) within the same manufacturer and model year, and whether the model should be able to carry past credits forward for up to five years within the same fleet and manufacturer.
- ***Enable the Dynamic Fleet Share Model***: Specifies whether the model should dynamically adjust the model year's PC/LT fleet share based on achieved CAFE levels from the previous year, the PC share from the previous year, and the current year's fuel prices.
- ***Merge the Fleet for Modeling***: Specifies whether to merge the entire industry into a single large manufacturer before beginning the modeling process.

Some of the options loaded from a parameters input file may be overridden using the **Runtime Settings** panel as well. If an "override" option is checked off (not selected), a default value from the input file is used. If an override option is checked on (selected), that value will be used in place of what was loaded from the parameters file. In Figure 21 below, the options for overriding the rebound effect and the discount rate are selected, and set to 20% and 7% respectively.

The following options from the parameters file may be overridden:

- ***Override Fuel Price Estimates***: Specifies whether to use the low, average, or high fuel price estimates from the parameters input file. By default, average fuel price estimates are used.
- ***Override CO2 Estimates***: Specifies whether to use low, average, high, or very-high carbon dioxide cost estimates from the parameters input file. By default, average CO2 cost estimates are used.
- ***Override Rebound Effect***: Overrides the *Rebound Effect* value read in from the parameters file with a user defined value. Valid values are between -1.00 and 1.00.
- ***Override Discount Rate***: Overrides the *Discount Rate* value read in from the parameters file with a user defined value. Valid values are between 0.00 and 1.00.
- ***Override Value of Travel Time per Vehicle***: Overrides the *Value of Travel Time per Vehicle* value read in from the parameters file with a user defined value.
- ***Override Military Security Cost***: Overrides the *Military Security* component of economic costs read in from the parameters file with a user defined value.
- ***Scale Consumer Benefits During Effects Calculations***: Specifies whether the model should scale the private consumer benefits by a specific percentage during the effects calculations. Valid values are between 0.00 and 1.00.



Runtime Settings

☐ Operate in "Maximum Technology" mode
☑ Allow Voluntary Overcompliance
☑ Allow Credit Transfers and Carry Forward
☐ Enable the Dynamic Fleet Share Model
☐ Merge the Fleet for Modeling

Which parameters would you like to override from the input file?

☐ Override Fuel Price Estimates: ○ Low ● Average ○ High
☐ Override CO-2 Estimates: ○ Low ● Average ○ High ○ Very High
☑ Override Rebound Effect: -0.20
☑ Override Discount Rate: 0.07
☐ Override Value of Travel Time per Vehicle: 24.64
☐ Override Military Security Cost: 0.00
☐ Scale Consumer Benefits During Effects Calculations by: 0.25

Figure 21. Parameters Overrides Panel

E.4.3 Manage Optimization Window

The **Manage Optimization** window (Figure 22) provides additional options necessary for configuring the system for optimization modeling.

The first set of options determines the type of optimization – that is, which fleet the model should optimize:

- ***Cars***: Forces the modeling system to optimize vehicles regulated as passenger automobiles only. If the market data input file contains any vehicles regulated as light trucks, the value of CAFE standard for those vehicles will be kept at a constant rate throughout optimization.
- ***Trucks***: Forces the modeling system to optimize vehicles regulated as light trucks only. If the market data input file contains any vehicles regulated as passenger automobiles, the value of CAFE standard for those vehicles will be kept at a constant rate throughout optimization.
- ***Auto-detect***: Allows the model to automatically determine whether to optimize passenger automobiles or light trucks. This option is useful if the market data input file contains only one class of vehicles (*e.g.*, cars-only or trucks-only). If the market data file includes a mixed fleet of vehicles (passenger autos and light trucks), this option should not be used.

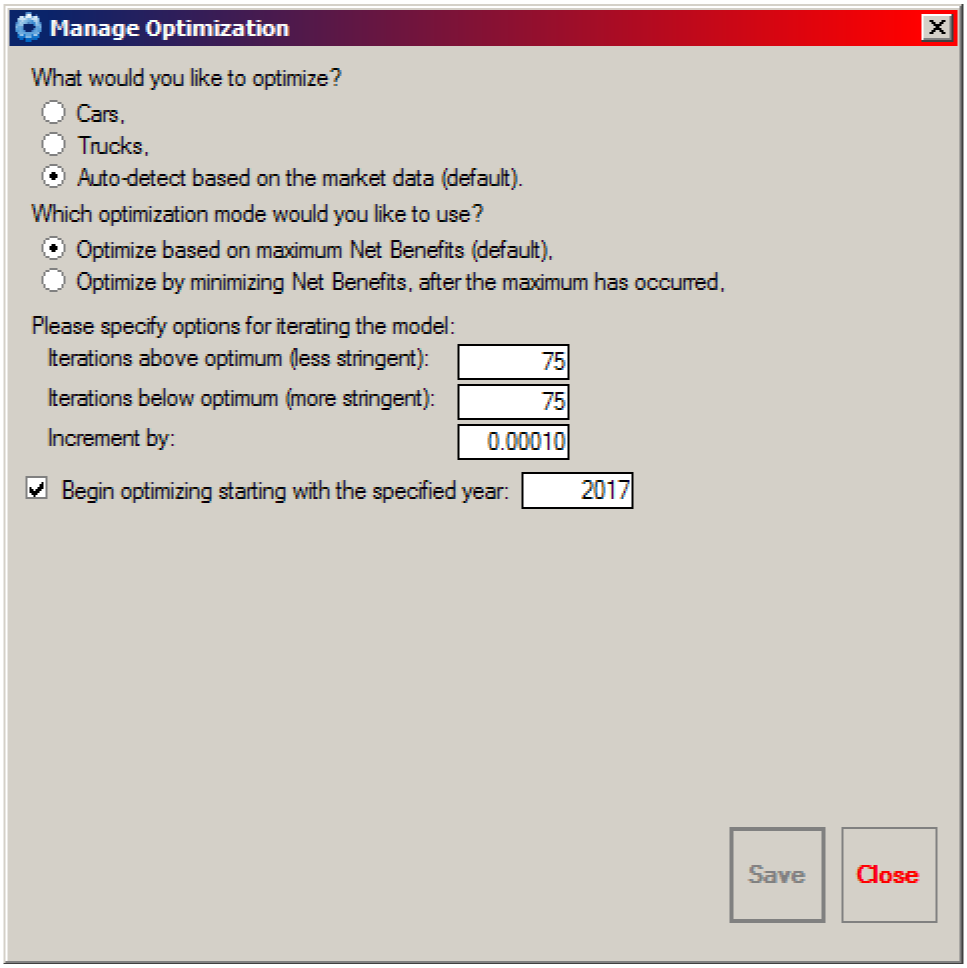
The next set of options determines the optimization mode the model should use when identifying the optimum value of the CAFE standard:

- ***Optimize based on maximum Net Benefits***: Specifies that the optimization model should optimize the value of CAFE standard based on the difference between the discounted social benefits and technology costs, by maximizing that difference.
- ***Optimize by minimizing Net Benefits, after the maximum has occurred***: Specifies that the optimization model should optimize the value of CAFE standard based on the difference between the discounted social benefits and technology costs, by finding the lowest positive difference after the maximum difference has occurred.

Additional optimization options are:

- ***Iterations above optimum***: Indicates the number of iterations to examine above the initially calibrated shape of the target function, by moving the function upwards in GPM space. Raising the function produces a less stringent value of CAFE standard. Valid values are between 0 and 1000.
- ***Iterations below optimum***: Indicates the number of iterations to examine below the initially calibrated shape of the target function, by pushing the function downwards in GPM space. Lowering the function produces a more stringent value of CAFE standard. Valid values are between 0 and 1000.
- ***Increment by***: Specifies the value by which to increment the target function in GPM space. Valid values are between 0.00001 and 0.1.

- ***Begin optimizing starting with the specified year***: Specifies the first model year to optimize.



What would you like to optimize?

○ Cars,
○ Trucks,
● Auto-detect based on the market data (default).

Which optimization mode would you like to use?

● Optimize based on maximum Net Benefits (default),
○ Optimize by minimizing Net Benefits, after the maximum has occured,

Please specify options for iterating the model:

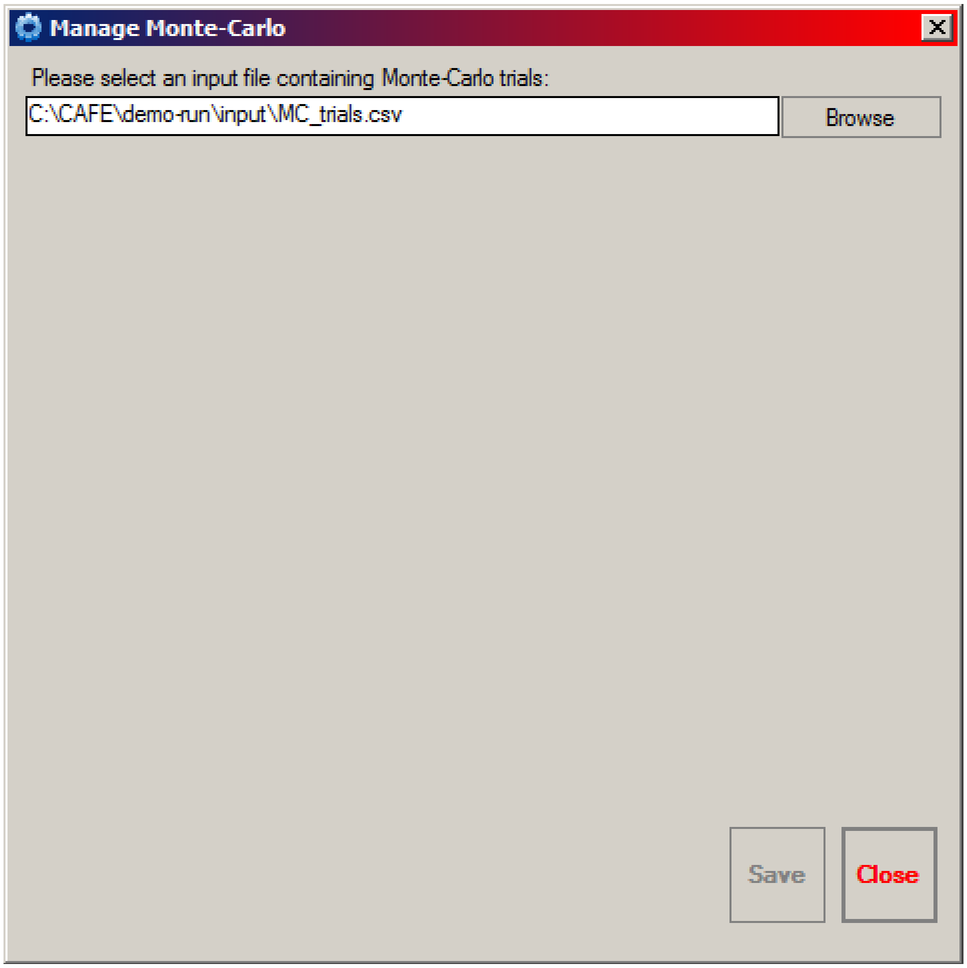
Iterations above optimum (less stringent): 75
Iterations below optimum (more stringent): 75
Increment by: 0.00010

☑ Begin optimizing starting with the specified year: 2017

Figure 22. Manage Optimization Window

E.4.4 Manage Monte-Carlo Window

The **Manage Monte-Carlo** window (Figure 23) provides additional options necessary for configuring the system for Monte-Carlo modeling. During modeling, the system will use an input file specified here, containing trials to use for analysis. Upon completion of the modeling process, the system will automatically generate Monte-Carlo log files.



Please select an input file containing Monte-Carlo trials:
C:\CAFE\demo-run\input\MC_trials.csv

Figure 23. Monte-Carlo Model Settings Panel

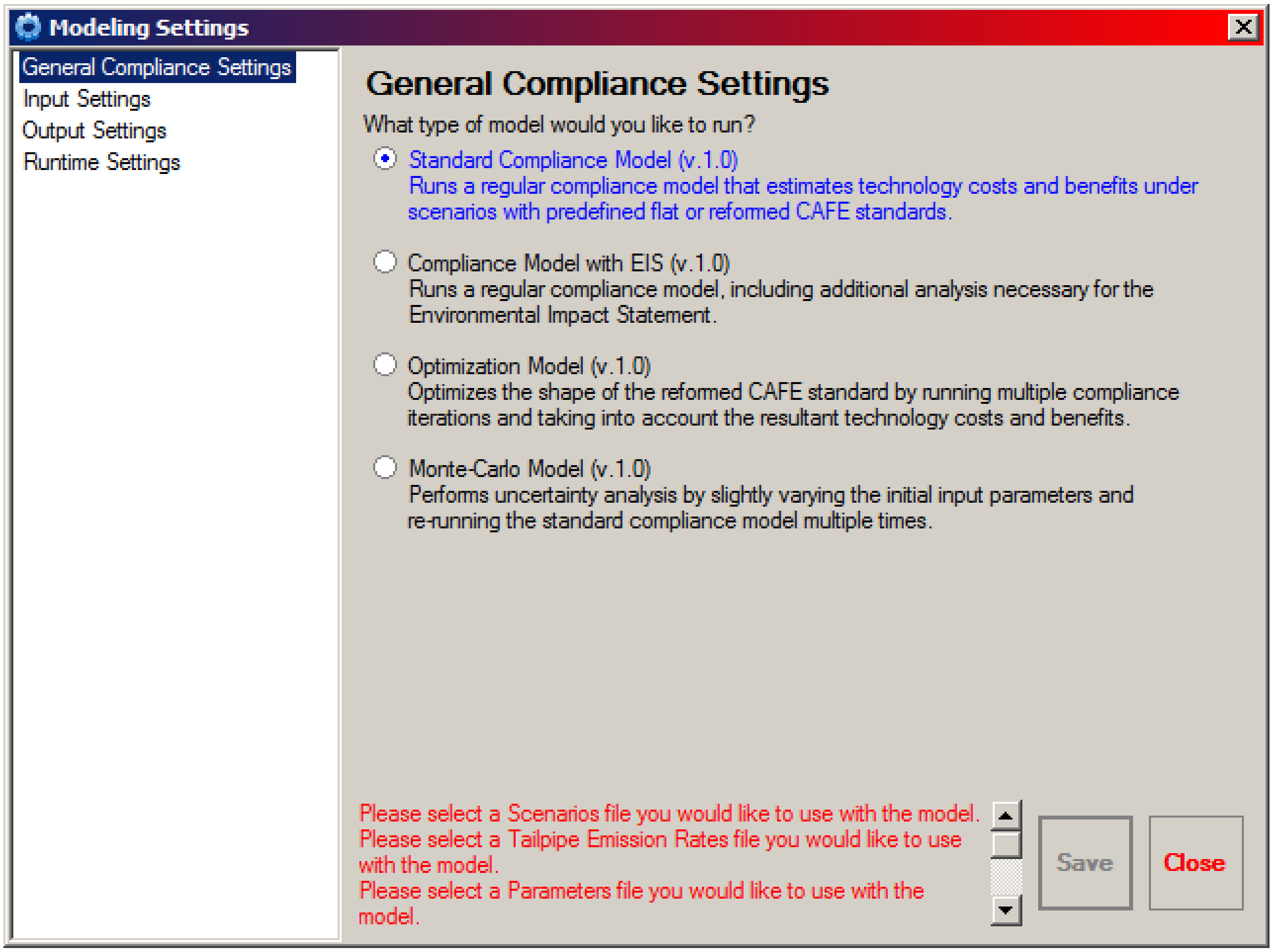
E.5 CAFE Model Usage Examples

This section provides examples for configuring and running the CAFE Model sessions using various model types.

E.5.1 Example 1 – Configuring for Standard Compliance Modeling

This example demonstrates the steps necessary for configuring the modeling system to perform a regular *Compliance Model* run.

- Run the CAFE Model by clicking on the **CAFE Model** executable located on the desktop. Read through the **Warnings** dialog box, and then click the **OK** button.
- Select **File** > **New Session** to create a new modeling session. The **Modeling Settings** window appears. Note the errors at the bottom of the window; these indicate that the input files have not been selected.
- On the **General Compliance Settings** panel, select the *Standard Compliance Model* as shown in Figure 24 below.



General Compliance Settings

What type of model would you like to run?

● Standard Compliance Model (v.1.0)
Runs a regular compliance model that estimates technology costs and benefits under scenarios with predefined flat or reformed CAFE standards.

○ Compliance Model with EIS (v.1.0)
Runs a regular compliance model, including additional analysis necessary for the Environmental Impact Statement.

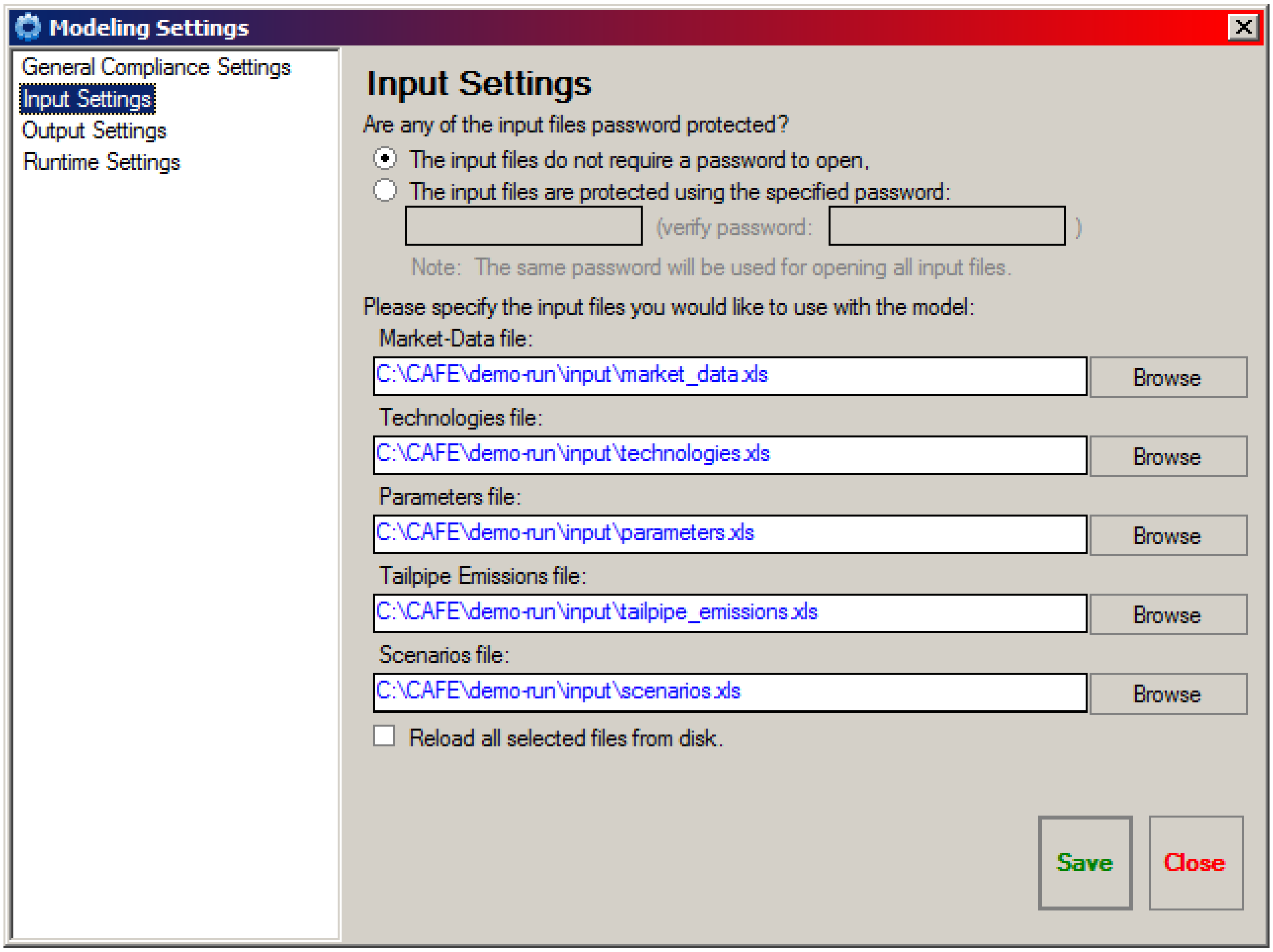
○ Optimization Model (v.1.0)
Optimizes the shape of the reformed CAFE standard by running multiple compliance iterations and taking into account the resultant technology costs and benefits.

○ Monte-Carlo Model (v.1.0)
Performs uncertainty analysis by slightly varying the initial input parameters and re-running the standard compliance model multiple times.

Please select a Scenarios file you would like to use with the model.
Please select a Tailpipe Emission Rates file you would like to use with the model.
Please select a Parameters file you would like to use with the model.

Figure 24. Select Standard Compliance Model

- Click on the **Input Settings** panel to select the input files to use for modeling (Figure 25). Note that once all the input files have been selected appropriately, the error messages disappear.



Input Settings

Are any of the input files password protected?

● The input files do not require a password to open.

○ The input files are protected using the specified password:

(verify password:)

Note: The same password will be used for opening all input files.

Please specify the input files you would like to use with the model:

Market-Data file: C:\CAFE\demo-run\input\market_data.xls

Technologies file: C:\CAFE\demo-run\input\technologies.xls

Parameters file: C:\CAFE\demo-run\input\parameters.xls

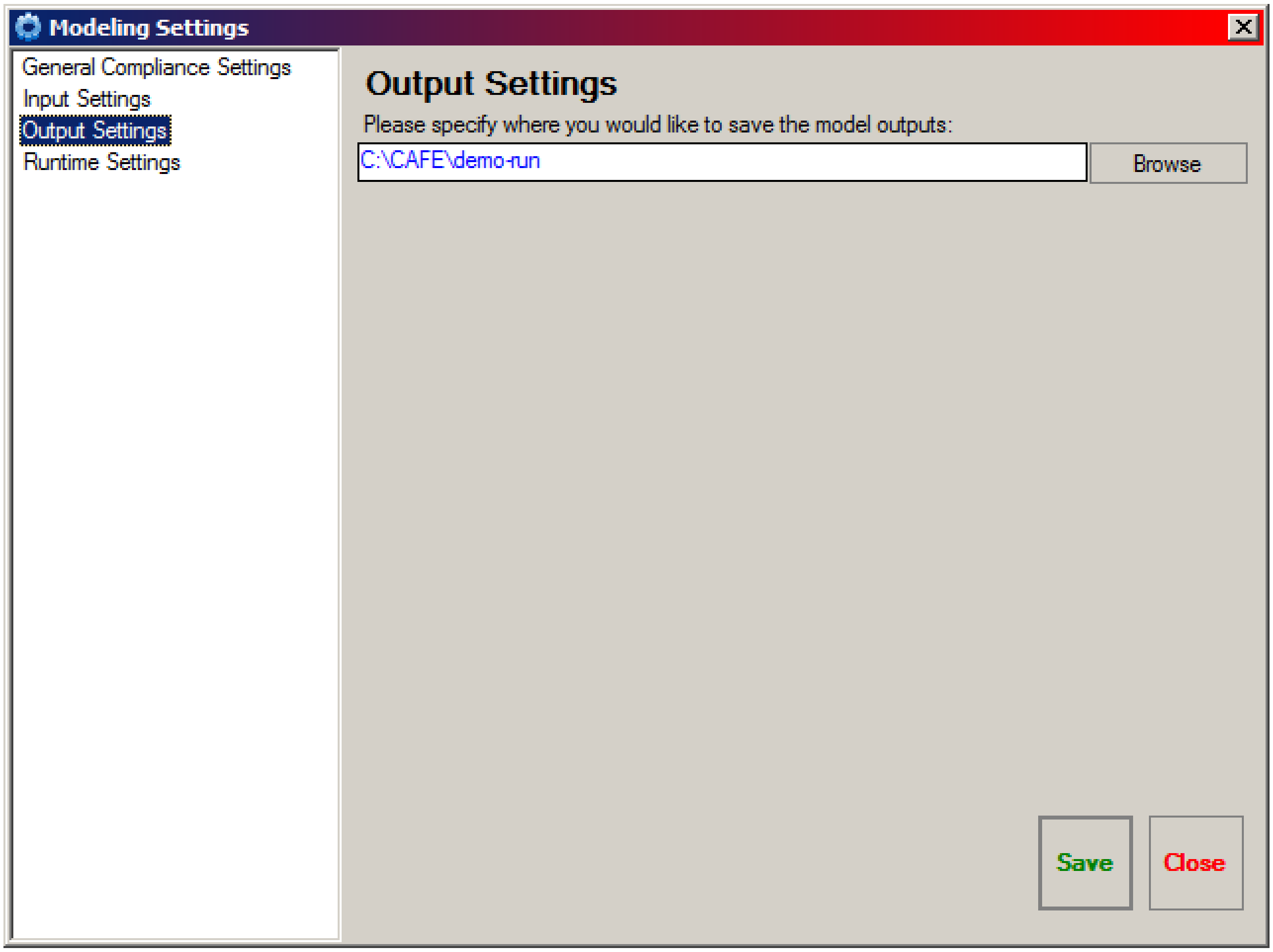
Tailpipe Emissions file: C:\CAFE\demo-run\input\tailpipe_emissions.xls

Scenarios file: C:\CAFE\demo-run\input\scenarios.xls

☐ Reload all selected files from disk.

Figure 25. Select Input Files

- On the **Output Settings** panel, select the location for output files (Figure 26).



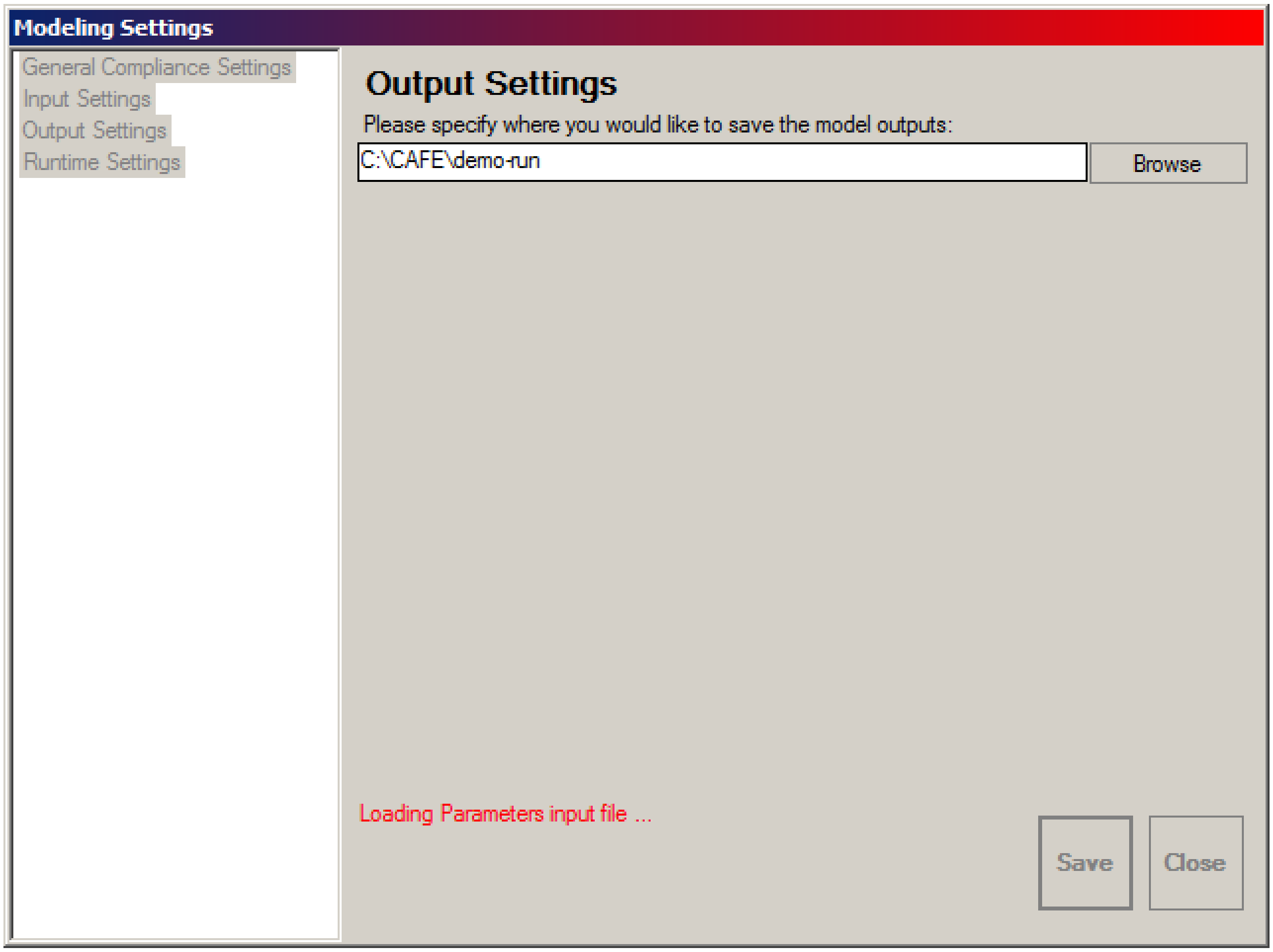
Output Settings

Please specify where you would like to save the model outputs:

C:\CAFE\demo-run

Figure 26. Select Output Location

- The **Runtime Settings** panel is not used for this exercise.
- Click the **Save** button to save the modeling settings and load the input files (Figure 27).



Output Settings

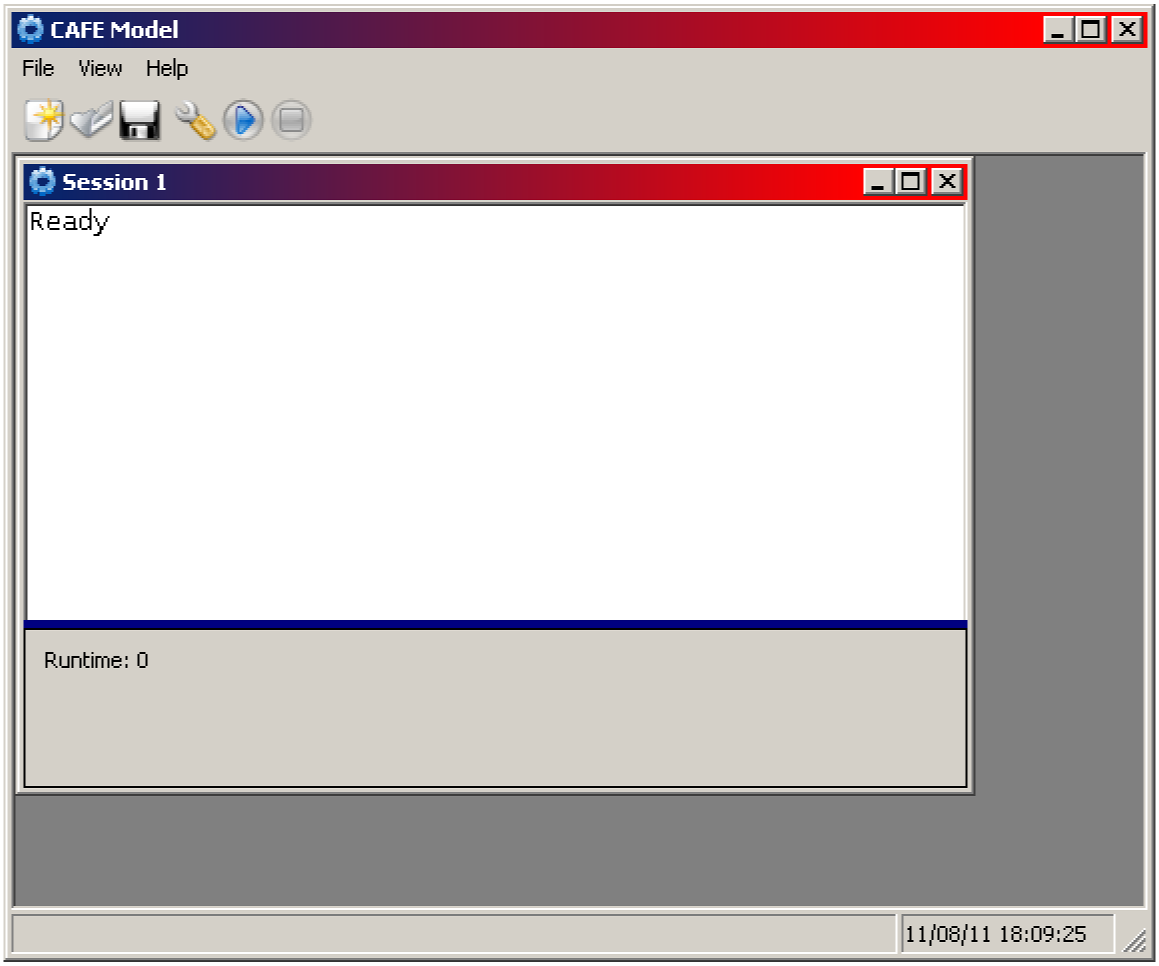
Please specify where you would like to save the model outputs:

C:\CAFE\demo-run

Loading Parameters input file ...

Figure 27. Save Modeling Settings

- Once loading completes, click the **Close** button to return the main **CAFE Model** window. A new *Compliance Model* session, titled “Session 1” has now been created (Figure 28).



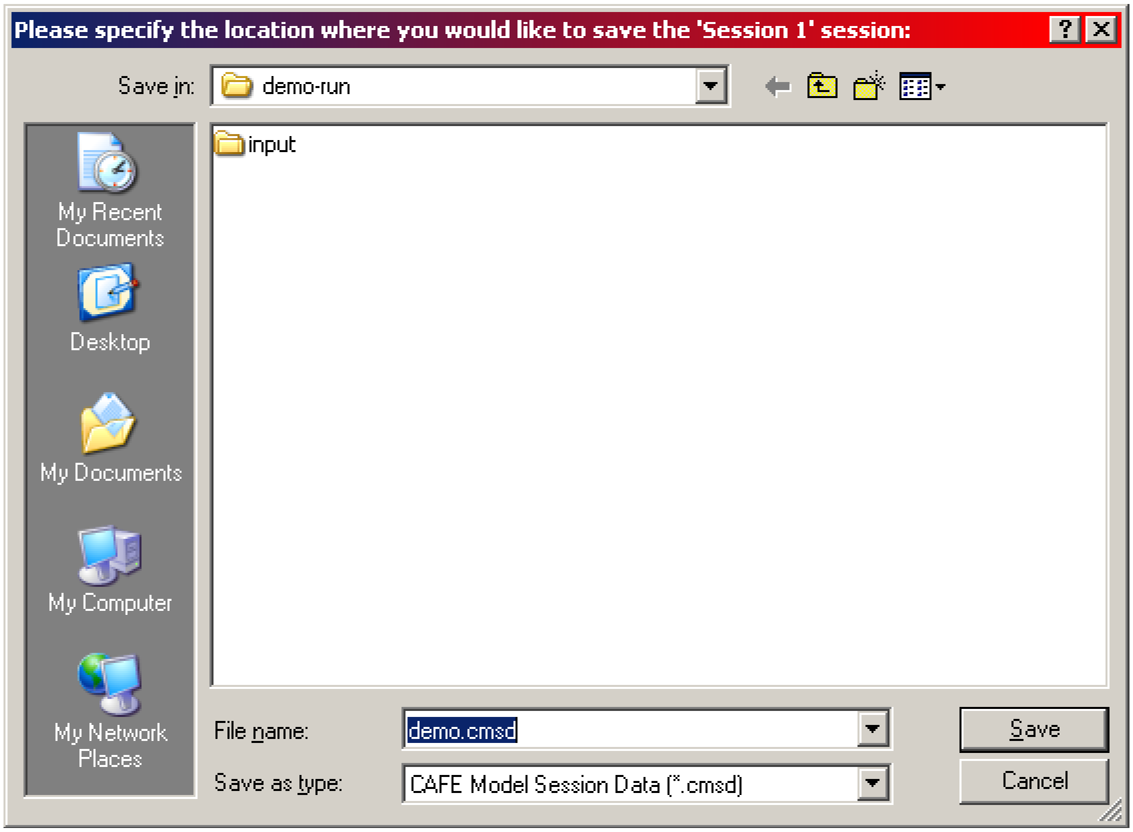
Ready

Runtime: 0

11/08/11 18:09:25

Figure 28. New Compliance Model Session Created

- Save the new session by selecting **File > Save Session As...**. Enter "demo.cmsd" in the dialog box that appears, and click the **Save** button (Figure 29).



Please specify the location where you would like to save the 'Session 1' session:

Save in: demo-run

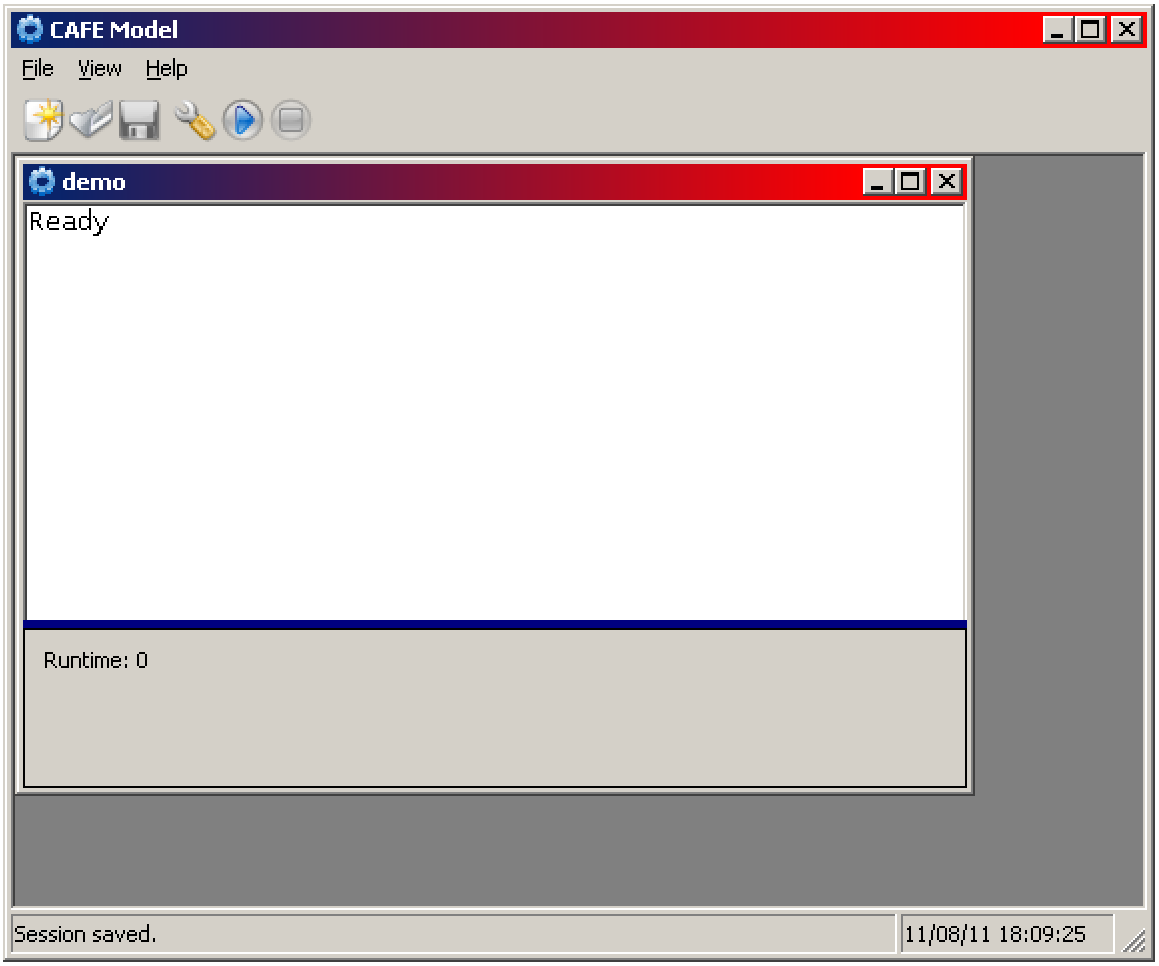
input

File name: demo.cmsd

Save as type: CAFE Model Session Data (*.cmsd)

Figure 29. Save New Session

- After the session has been saved, notice the title of the session has changed to “demo” (Figure 30).



Ready

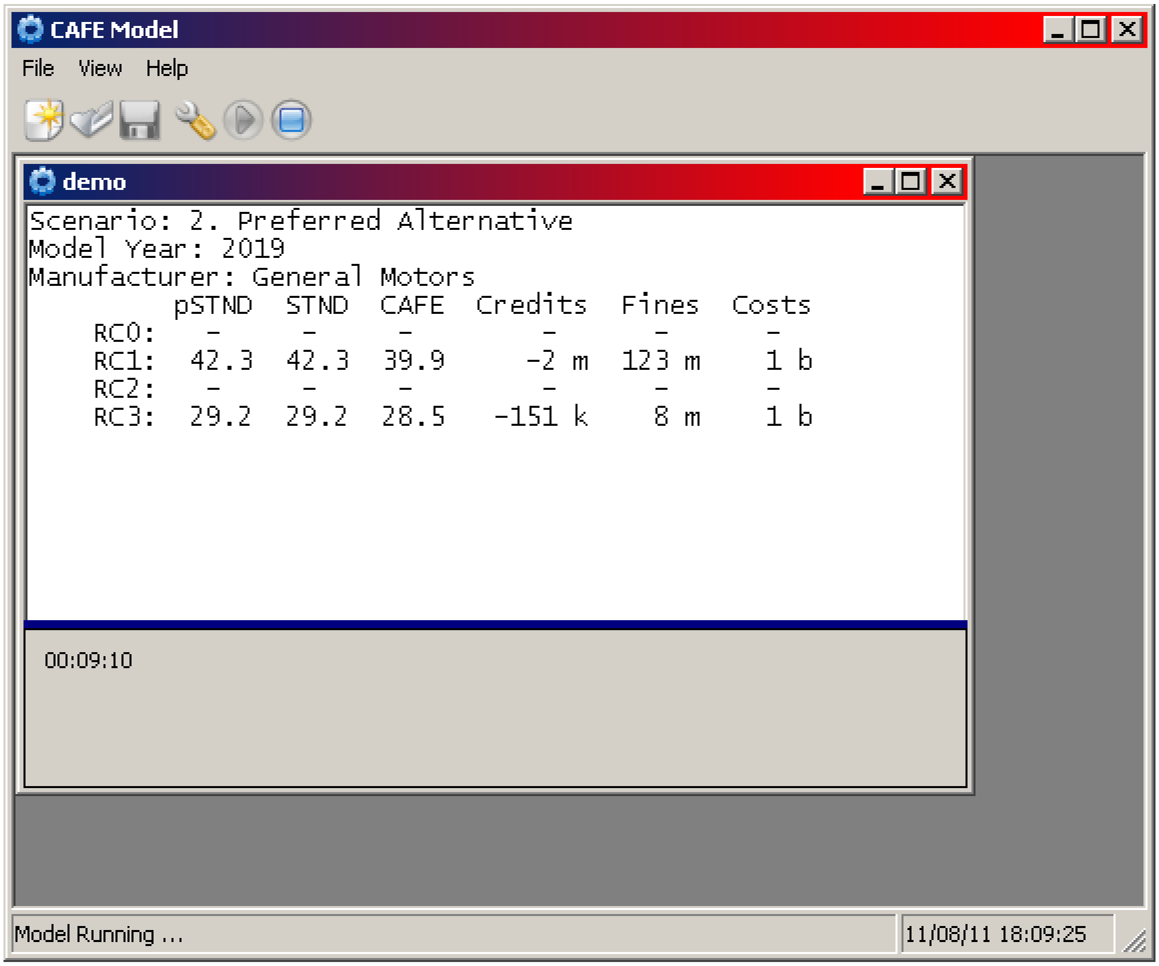
Runtime: 0

Session saved.

11/08/11 18:09:25

Figure 30. “demo” Session Saved

- Select **File** > **Start Modeling** to start the compliance modeling process. As the model runs, the progress of the *Compliance Model* is displayed in the session window (Figure 31).



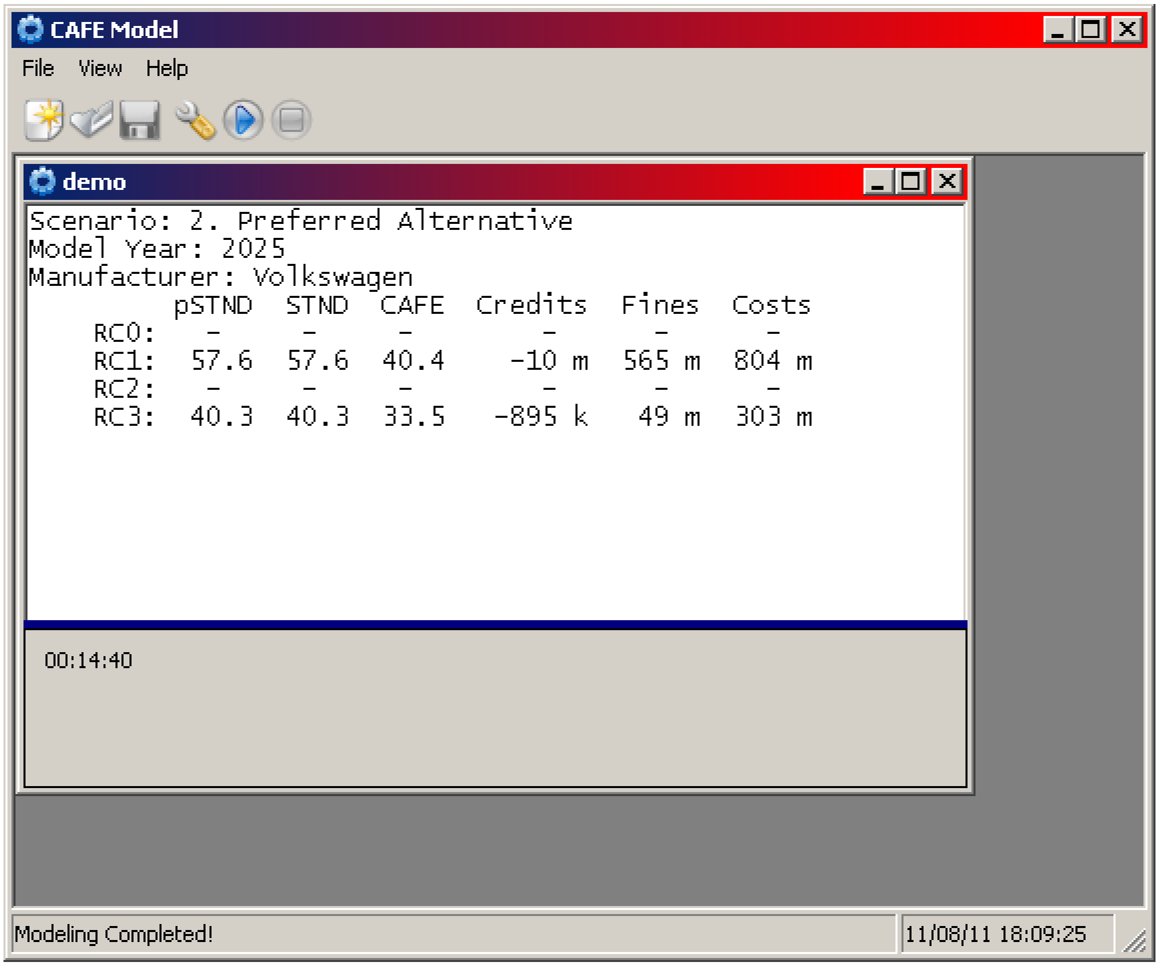
```
Scenario: 2. Preferred Alternative
Model Year: 2019
Manufacturer: General Motors
         pSTND  STND  CAFE  Credits  Fines  Costs
    RC0:   -     -     -         -     -      -
    RC1:  42.3  42.3  39.9     -2 m  123 m    1 b
    RC2:   -     -     -         -     -      -
    RC3:  29.2  29.2  28.5   -151 k    8 m    1 b
```

```
00:09:10
```

```
Model Running ...    11/08/11 18:09:25
```

Figure 31. Modeling Progress from the Compliance Model

- After modeling has completed, the “Modeling Completed!” message appears at the bottom of the main **CAFE Model** window (Figure 32).



```
Scenario: 2. Preferred Alternative
Model Year: 2025
Manufacturer: Volkswagen
           pSTND   STND   CAFE   Credits   Fines   Costs
    RC0:     -       -      -        -       -       -
    RC1:   57.6    57.6   40.4    -10 m    565 m   804 m
    RC2:     -       -      -        -       -       -
    RC3:   40.3    40.3   33.5   -895 k     49 m   303 m
```

00:14:40

Modeling Completed!

11/08/11 18:09:25

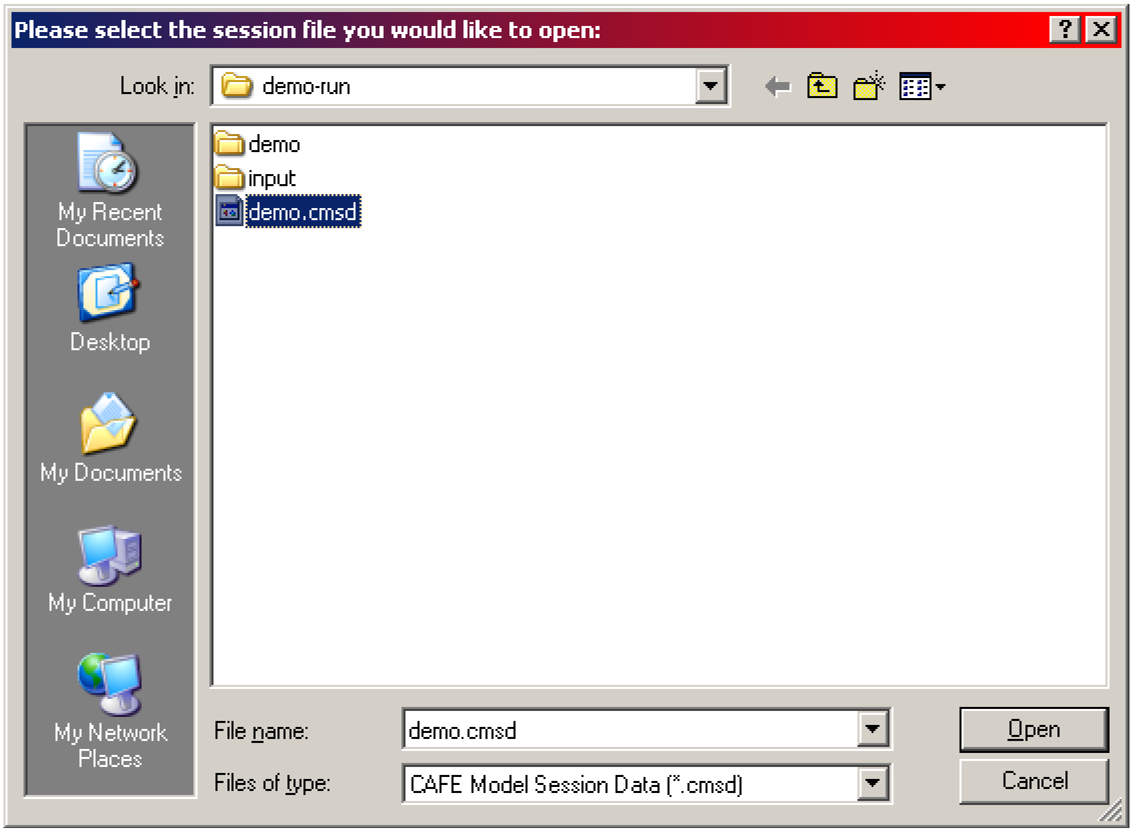
Figure 32. Compliance Model Completed

- Select **View** > **Output Location** to open Windows Explorer and browse to the location where model outputs for the “demo” session are saved.
- Exit the session by selecting **File** > **Close Session**.
- Exit the **CAFE Model** by selecting **File** > **Exit**, or proceed to the next example.

E.5.2 Example 2 – Configuring for Optimization Modeling

This example demonstrates how the take an existing session created in Example 1 – Configuring for Standard Compliance Modeling, and modify it to run the *Optimization Model*.

- Run the CAFE Model by clicking on the **CAFE Model** executable located on the desktop. Read through the **Warnings** dialog box, and then click the **OK** button.
- Select **File** > **Open Session** to open an existing modeling session. Select "demo.cmsd" in the dialog box that appears, and click the **Open** button (Figure 33).



Please select the session file you would like to open:

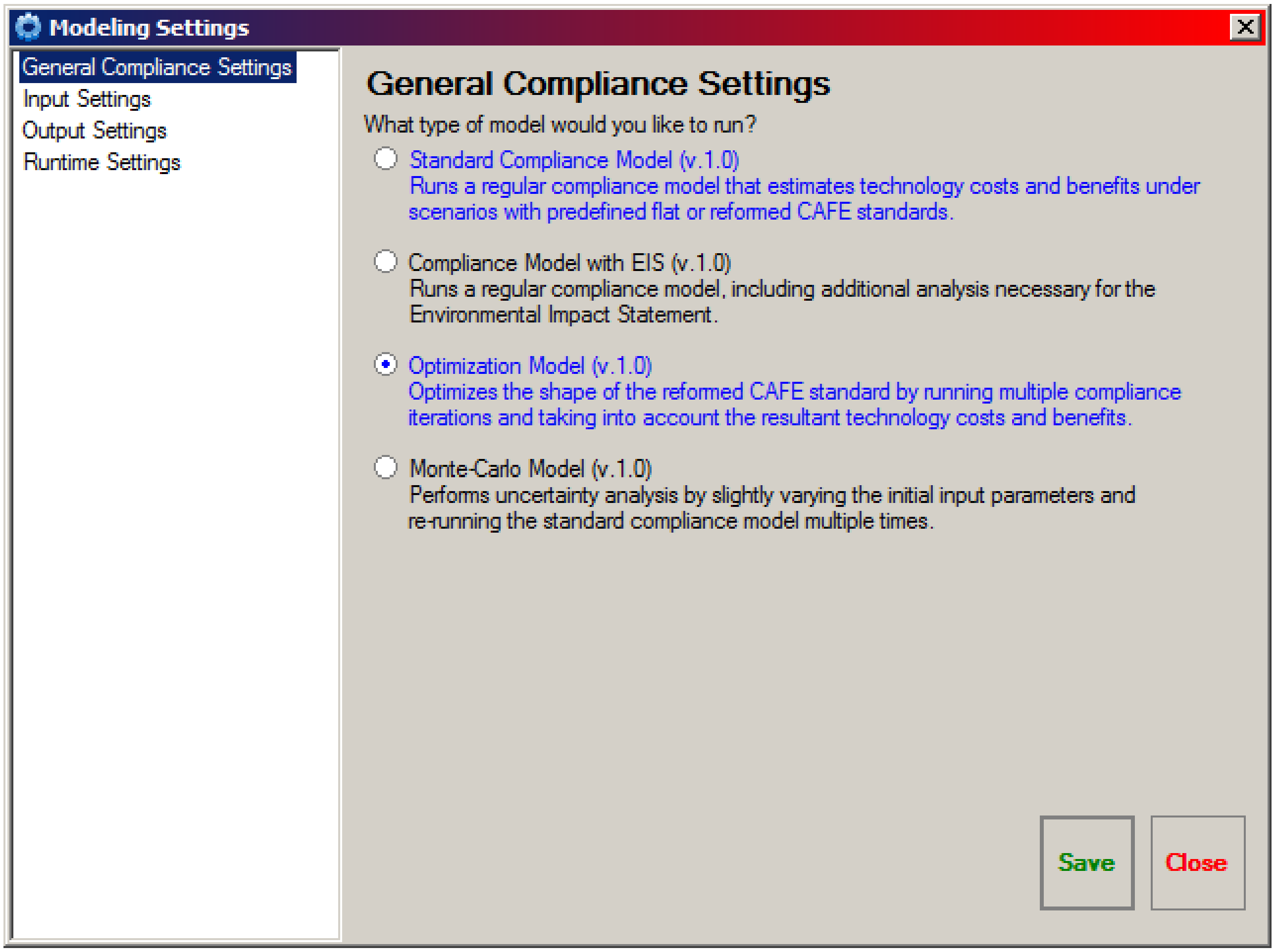
Look in: demo-run

File name: demo.cmsd

Files of type: CAFE Model Session Data (*.cmsd)

Figure 33. Open "demo" Session

- Once the session has been loaded, select **View > Modeling Settings** to bring up the **Modeling Settings** window. There select the *Optimization Model* as in Figure 34.



General Compliance Settings

What type of model would you like to run?

○ Standard Compliance Model (v.1.0)
Runs a regular compliance model that estimates technology costs and benefits under scenarios with predefined flat or reformed CAFE standards.

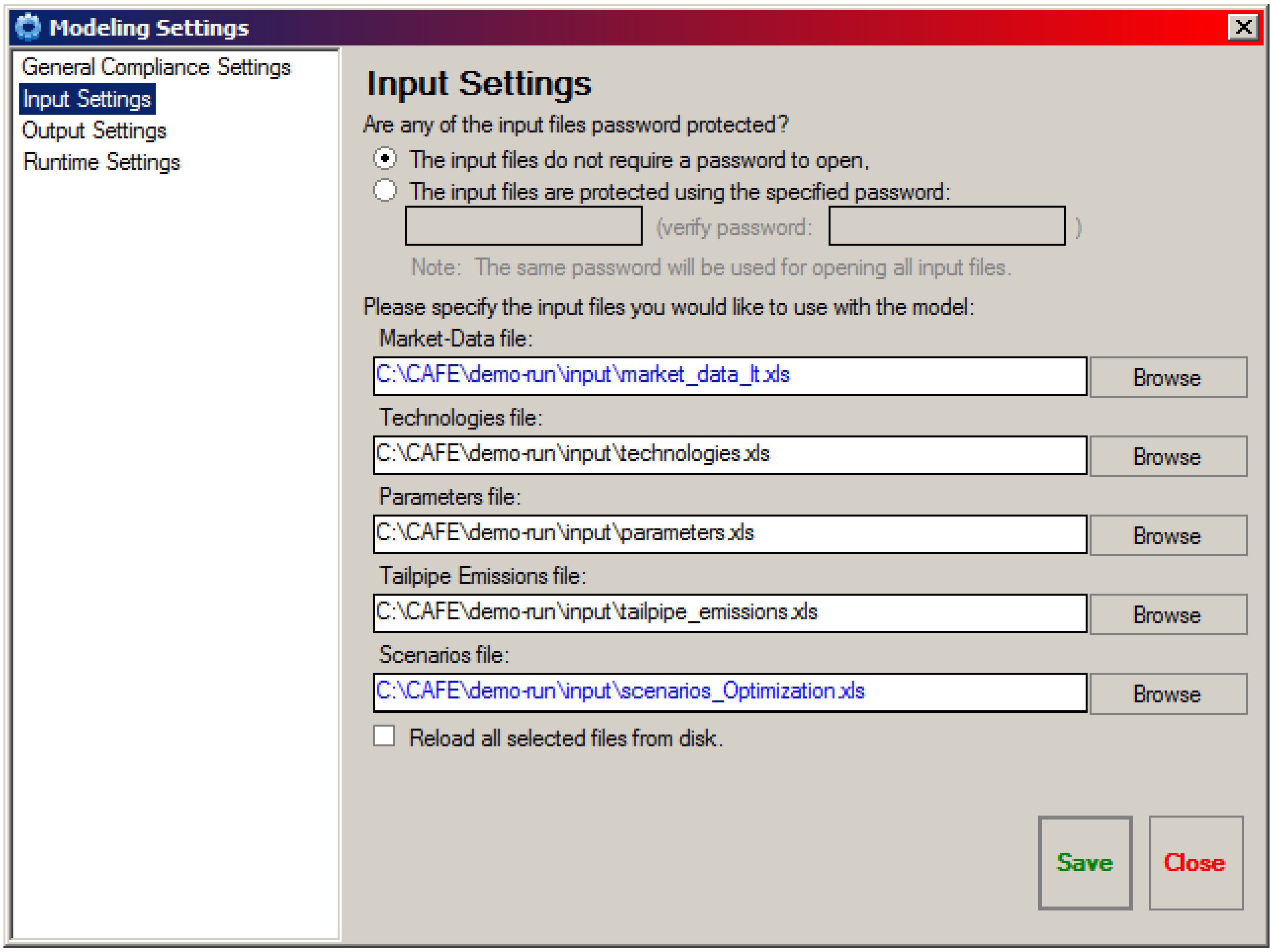
○ Compliance Model with EIS (v.1.0)
Runs a regular compliance model, including additional analysis necessary for the Environmental Impact Statement.

● Optimization Model (v.1.0)
Optimizes the shape of the reformed CAFE standard by running multiple compliance iterations and taking into account the resultant technology costs and benefits.

○ Monte-Carlo Model (v.1.0)
Performs uncertainty analysis by slightly varying the initial input parameters and re-running the standard compliance model multiple times.

Figure 34. Select Optimization Model

- Under the **Input Settings** panel, select a market data file containing data for the light truck fleet only, as well as a scenarios file required for optimization modeling (Figure 35).



Are any of the input files password protected?

● The input files do not require a password to open.

○ The input files are protected using the specified password:

(verify password:)

Note: The same password will be used for opening all input files.

Please specify the input files you would like to use with the model:

Market-Data file: C:\CAFE\demo-run\input\market_data_lt.xls

Technologies file: C:\CAFE\demo-run\input\technologies.xls

Parameters file: C:\CAFE\demo-run\input\parameters.xls

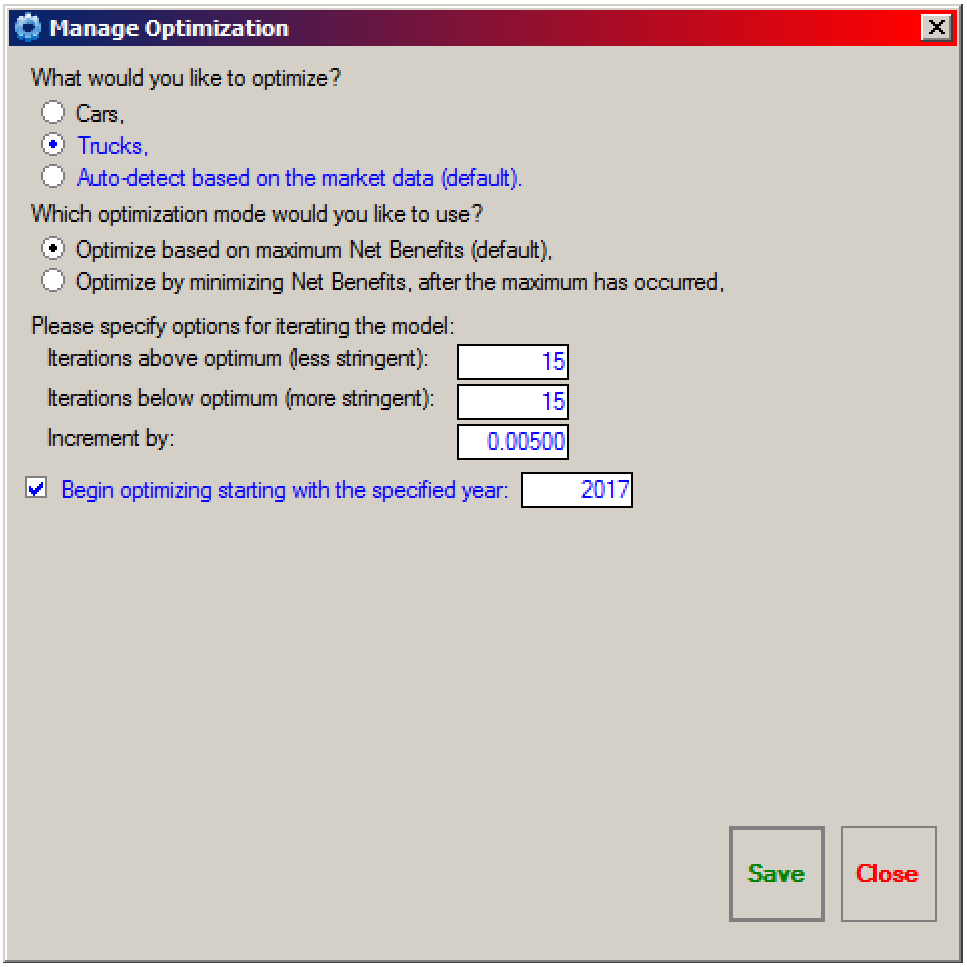
Tailpipe Emissions file: C:\CAFE\demo-run\input\tailpipe_emissions.xls

Scenarios file: C:\CAFE\demo-run\input\scenarios_Optimization.xls

☐ Reload all selected files from disk.

Figure 35. Select Scenarios File for Optimization

- The **Output Settings** and **Runtime Settings** panels are not used for this exercise.
- Click the **Save** button to save the updated modeling settings; then click **Close**, once saving completes.
- Select **View** > **Optimization Settings** to bring up the **Manage Optimization** window, then configure the system for optimization modeling as specified in Figure 36. (****Note**: with this version of the model, the system has been modified from using linear/additive stringency increments to multiplicative stringency increments. Hence, setting the increment incorrectly may lead to undesired behavior.)



What would you like to optimize?

○ Cars,

● Trucks,

○ Auto-detect based on the market data (default).

Which optimization mode would you like to use?

● Optimize based on maximum Net Benefits (default).

○ Optimize by minimizing Net Benefits, after the maximum has occurred.

Please specify options for iterating the model:

Iterations above optimum (less stringent): 15

Iterations below optimum (more stringent): 15

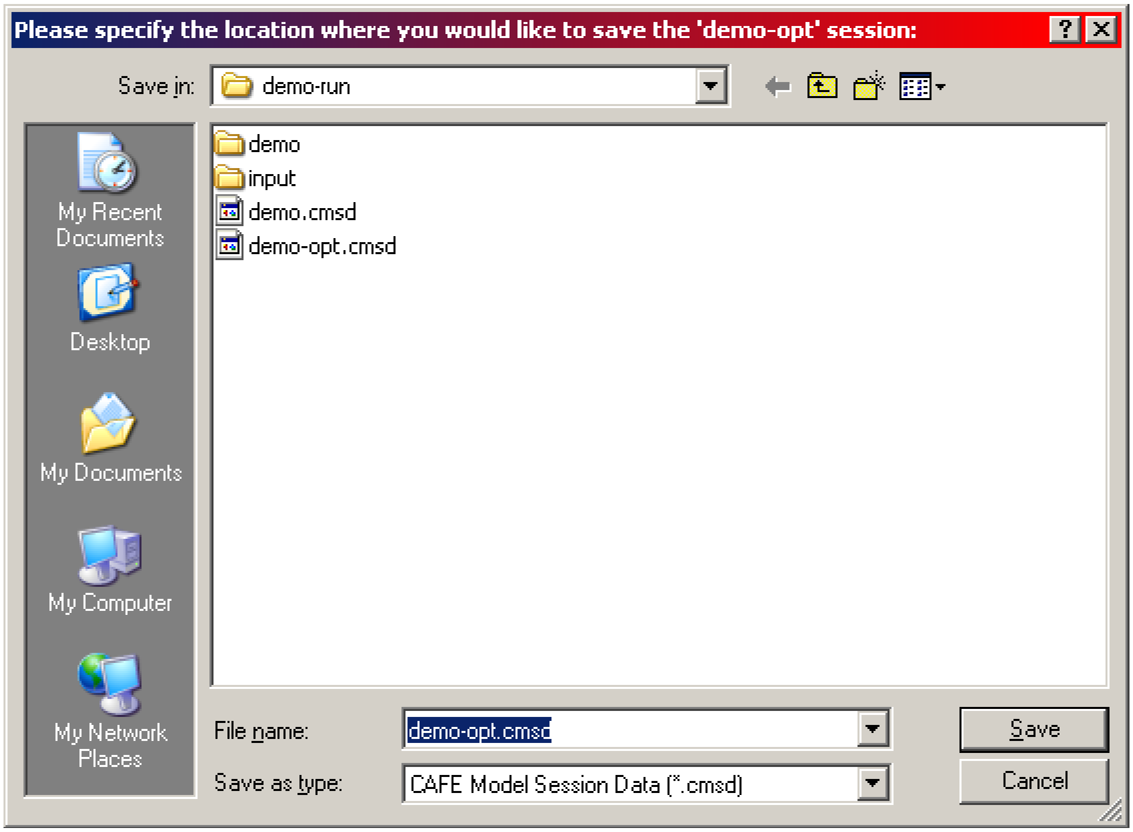
Increment by: 0.00500

☑ Begin optimizing starting with the specified year: 2017

Figure 36. Configure Optimization Model Settings

- Click the **Save** button to save the *Optimization Model* settings; then click **Close**.

- To prevent overwriting results from the “demo” session, select **File** > **Save Session As...** to save the modified session with a new name. For this example, the optimization session was saved as “demo-opt.cmsd” (Figure 37).



Please specify the location where you would like to save the 'demo-opt' session:

Save in: demo-run

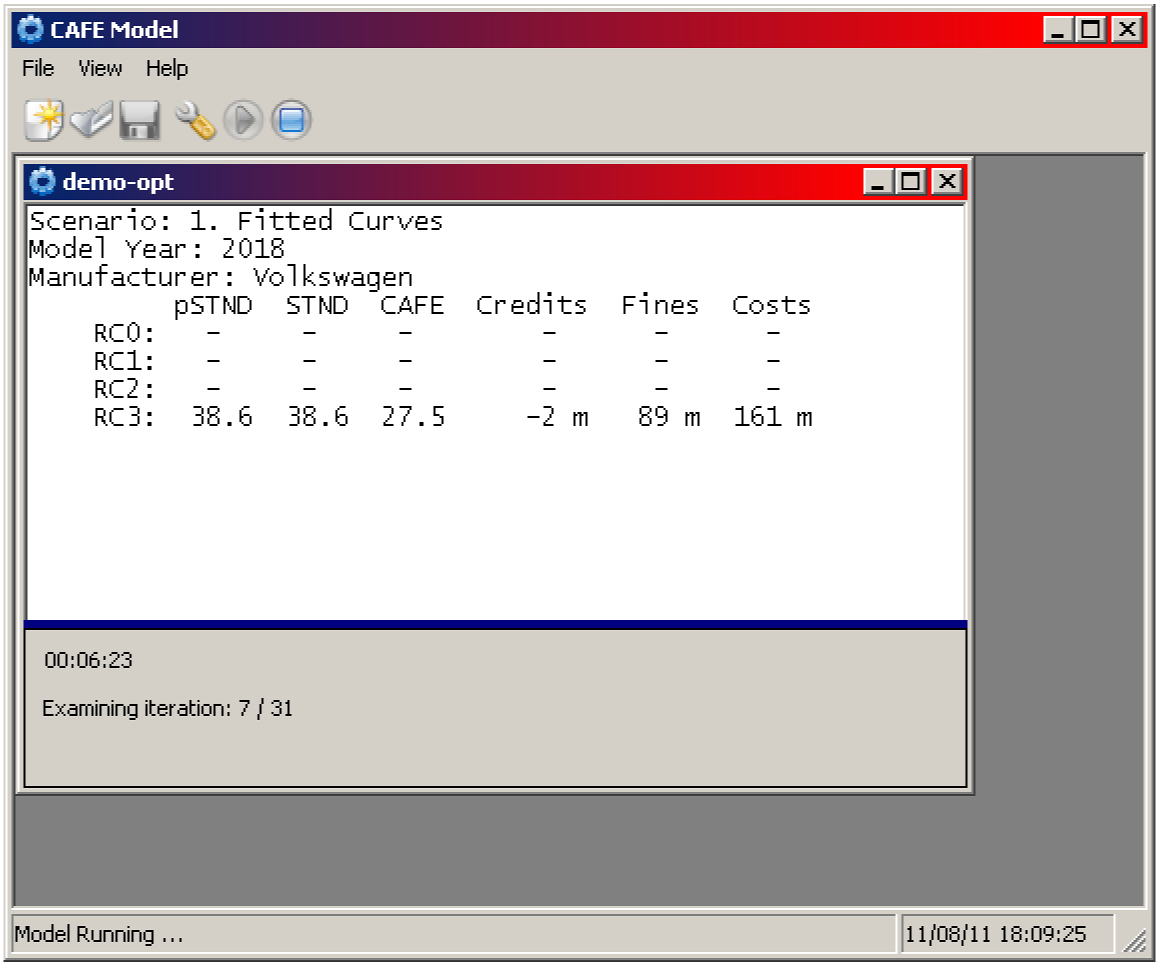
demo
input
demo.cmsd
demo-opt.cmsd

File name: demo-opt.cmsd

Save as type: CAFE Model Session Data (*.cmsd)

Figure 37. Save Modified Session

- Select **File > Start Modeling** to start the optimization modeling process. As the model runs, the progress of the *Optimization Model* is displayed in the session window (Figure 38).



```
Scenario: 1. Fitted Curves
Model Year: 2018
Manufacturer: Volkswagen
          pSTND   STND   CAFE    Credits   Fines   Costs
    RC0:    -      -      -         -        -       -
    RC1:    -      -      -         -        -       -
    RC2:    -      -      -         -        -       -
    RC3:  38.6   38.6   27.5      -2 m     89 m   161 m
```

```
00:06:23

Examining iteration: 7 / 31
```

```
Model Running ...                11/08/11 18:09:25
```

Figure 38. Modeling Progress from the Optimization Model

- After optimization modeling has completed, the "Modeling Completed!" message appears at the bottom of the main **CAFE Model** window. Select **File > Exit** to exit the model.

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