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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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1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
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1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg) = 1.1 short tons
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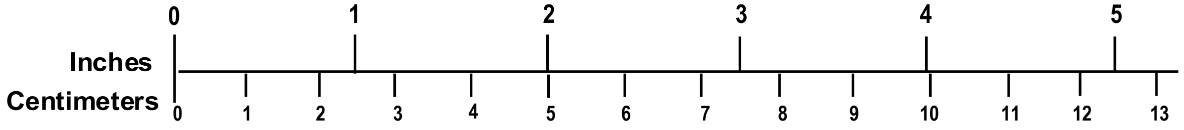

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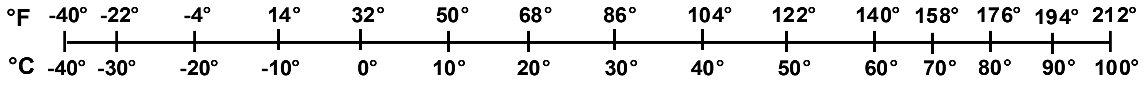

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PREFACE

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 November 14, 2011; 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, 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.

The authors further acknowledge the technical contributions of individuals who have reviewed detailed results of the model (and/or earlier versions of the model) and/or provided specific suggestions regarding the model's design. Among these individuals are Steve Plotkin and Michael Wang of the Department of Energy's Argonne National Laboratory, Jeff Alson, William Charmley, Ben Ellies, David Haugen, Ari Kahan, Richard Rykowski, and Todd Sherwood of the U.S. Environmental Protection Agency (EPA), Gary Rogers of FEV Engine Technology, Inc., David Boggs, Anrico Casadei, Scott Ellsworth, and Sandy Stojkovski of Ricardo, Inc., Jamie Hulan of Transport Canada, and Jonathan Rubin of the University of Maine.

NHTSA is making this draft documentation available at this time to facilitate review of and comment on the agency's analysis supporting proposed CAFE standards for model years 2017 and beyond, and to facilitate planned peer review of the CAFE Compliance and Effects Modeling System, which has undergone a range of modifications since NHTSA last arranged a formal peer review of the system. The agency anticipates some further revisions—in particular, the integration of a vehicle choice model currently under development—prior to undertaking a new formal peer review; such revisions will be reflected in updates to documentation provided to support the planned peer review.

Contents

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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

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.

System Design

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.

CAFE Compliance Simulation

S1.1 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 the Appendix. 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.

S1.1.1 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 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

S1.2 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 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.

S1.2.1 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

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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).

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

S1.2.2 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) 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)

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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. In Table 2, these technologies appear in gray text.

	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 Technology Group (MSM)	Mass Reduction - Level 1 (MR1) 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 Drag Reduction, Level 1 (AERO1) Aero Drag Reduction, Level 2 (AERO2)

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

(AERO)	

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
TechType	Technology group of which the technology is a member
FC	Overall reduction (%) of fuel consumption
FCg	Reduction of fuel consumption applicable to a gasoline component of a vehicle after being converted into a PHEV
FCg Share	Percentage of time a vehicle is expected to run on the gasoline fuel after being converted into a PHEV
Cost-Table	Fully learned-out table of costs by model year[8] (in 2009 dollars)
Year Available	First model year the technology is available for applicability
Year Retired	Last model year the technology is available for applicability
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, and define the technology group of which the technology is a member.

S1.2.3 Technology Applicability

The technology input assumptions have two means of defining technology applicability. One means is with the *Applicability* field. If the field is set to “TRUE”, then the technology is available for the particular class of vehicle, otherwise, the technology is unavailable.

The other applicability control in the input assumptions are the *Year Available* and *Year Retired* fields. 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, there are also other technology applicability factors within the CAFE Model. For example, there are controls for individual vehicles in the market data file that can override the controls here (see Appendix C). 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).

S1.2.4 Technology Fuel Consumption Reduction Factors

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[7] Additional technology assumptions are further discussed in 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—specified in an input file supplied by the user—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:

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

where FE_{orig} is the original fuel economy for the vehicle, and $FCnReduction_{0,1,\ldots n}$ are the fuel consumption reduction factors.

Whenever the modeling system converts a vehicle to a Plug-In Hybrid, 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 + electricity) vehicle fuel economy. The *FCg* field specifies what the improvement in the gasoline-only component of the vehicle's fuel economy would be[9], while the *FCg Share* field specifies the assumed amount of time in gasoline-only operation for the vehicle.

S1.2.5 Technology Cost

The technology input assumptions—specified in an input file supplied by the user—define a fully "learned-out" table of year-by-year technology costs *Cost Table*.

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. The model uses the 'Aux' column to identify when technologies have an associated underlying cost basis.

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

S1.2.6 Technology Synergies

Technology synergies exist when the combination of two technologies yields a fuel consumption reduction which differs from what would be derived directly from equation (1) for fuel consumption reduction. 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,

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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).

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.

S1.2.7 Backfill of Technologies

In some cases, technologies will be bypassed because they are not cost-effective. If the model applies a technology that resides later in the sequence, the model will 'backfill' any bypassed technologies in order to fully account for technology costs and effects, each of which are specified on an incremental basis. This backfill will not occur if the technology is not applicable to the vehicle. In the case where the backfill would backtrack through branches in the sequence, the model would first resolve any limitations and applicability issues. If the branch still exists, it would examine which is the less expensive branch to use.

The algorithm next 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.[10] If any such overrides have been specified, the algorithm reevaluates applicability as shown in Figure 2.

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[10] These overrides, described in Appendix C.2 on page 59, provide a means of accounting for engineering and other issues not otherwise represented by input data or the overall system.

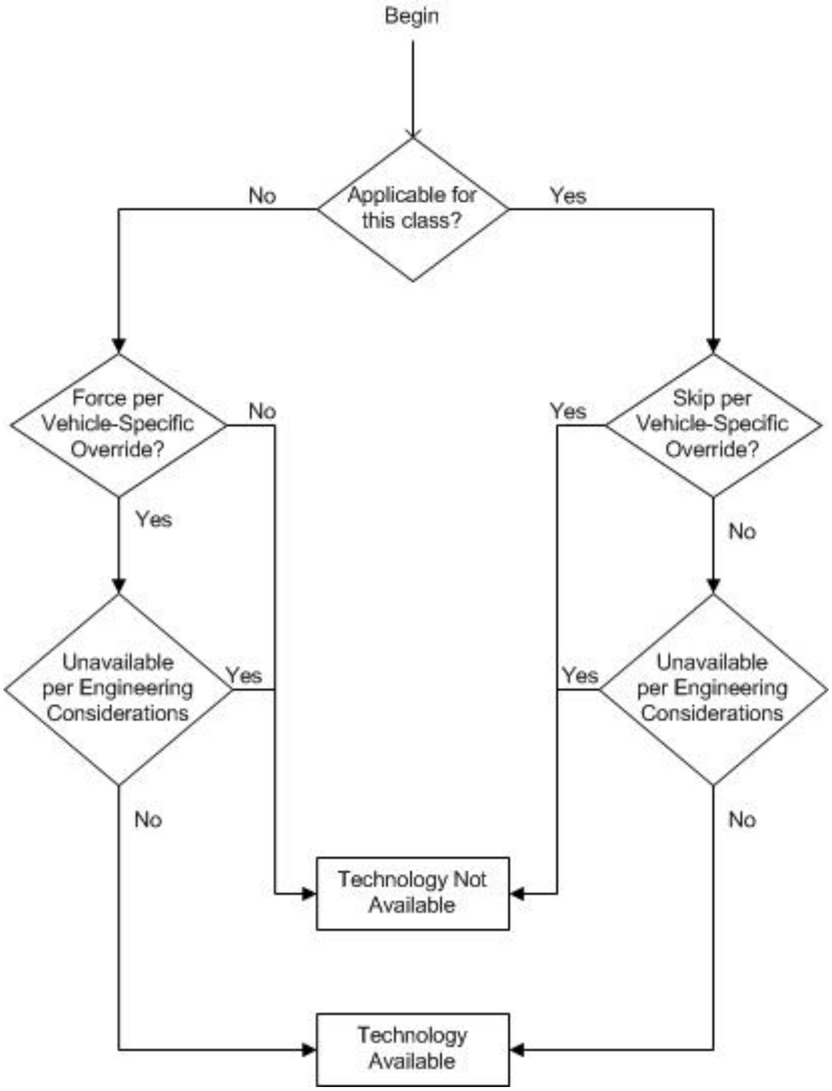

Figure 2. Technology Applicability Determination

S1.2.8 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.

S1.2.8.1 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.

S1.2.8.2 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), then that technology is simply bypassed in the technology path. For example, if engine friction reduction has previously been installed, then 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 overhead cam engines (SOHC) and for engines with dual overhead cams (DOHC).

S1.2.8.3 Engine Technology Sequencing and Branching

Within the engine technology sequence, shown in Figure 3, there are three major sequence paths: single overhead cam (SOHC); dual overhead cam (DOHC); and overhead valve (OHV). The choice of path for a vehicle model is based on the base engine attributes. There are further branches within the DOHC branch. The choice of which branch to take is based on availability for the specific vehicle as well as the vehicle class; phase-in constraints; and, finally, 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 choice of which branch is, again, based on availability for the specific vehicle as well as the vehicle class; phase-in constraints; and, finally, cost-effectiveness.

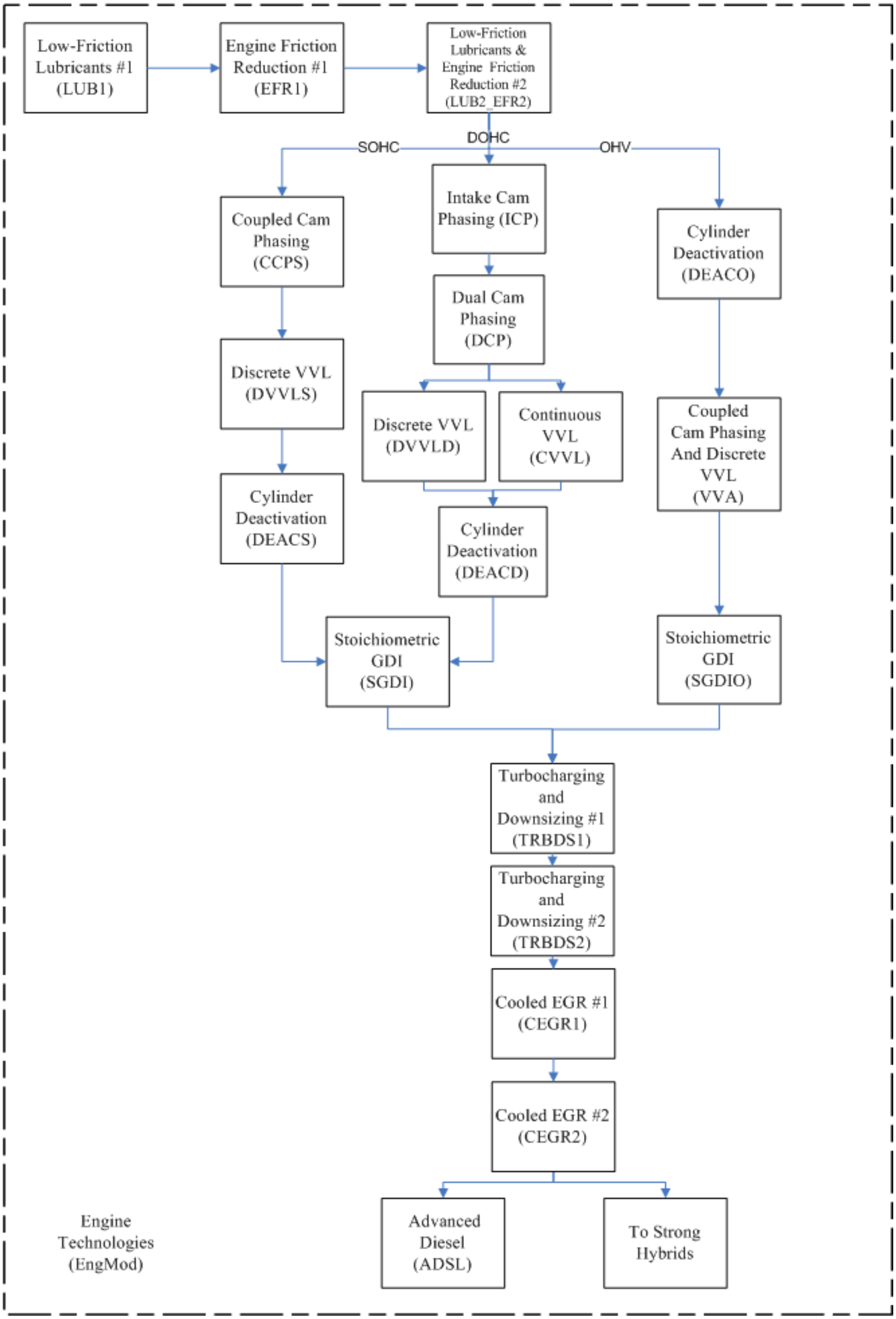

Figure 3. Engine Technology Group Technology Sequence

S1.2.8.4 Transmission Technology Sequencing

Within the transmission technology sequence, shown in Figure 4, there are two separate paths, one used for automatic transmissions, and the other for manual transmissions. Depending on the initial characteristics of a vehicle, one sequence or the other will be followed.

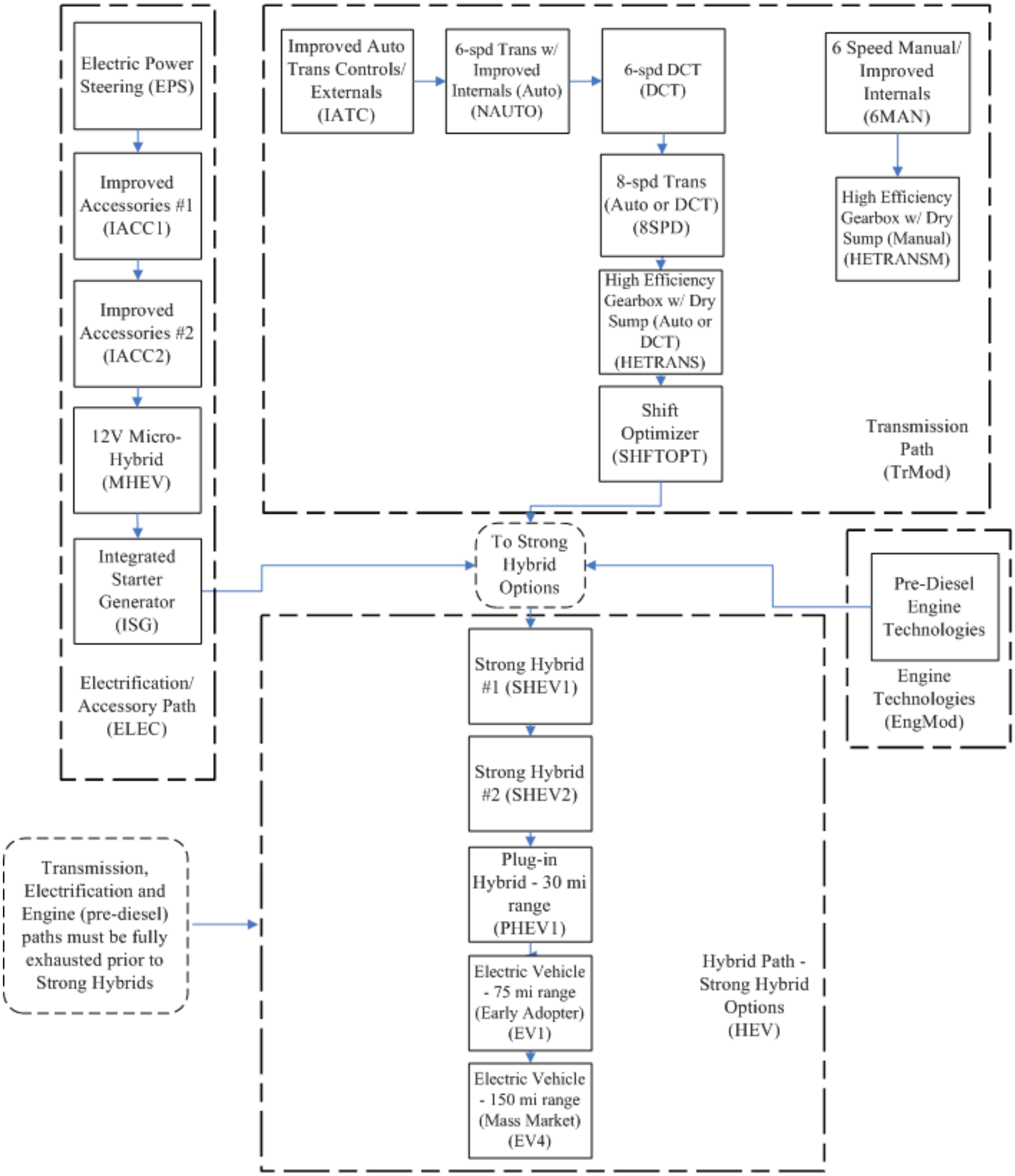

Figure 4. Transmission, Electrification/Accessory, and Hybrid Technology Decision Tree

S1.2.8.5 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), transmission and electrification paths have been exhausted. Thus the engine, transmission an electrification technologies are considered "enablers" that must be installed on a vehicle prior to the application of the strong hybrid technologies. It is important to note that once the engine and transmission paths have been fully applied, the model may skip ahead of the electrical accessory technologies, and apply a strong hybrid, backfilling any skipped electrification technologies in the process.

S1.2.8.6 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.

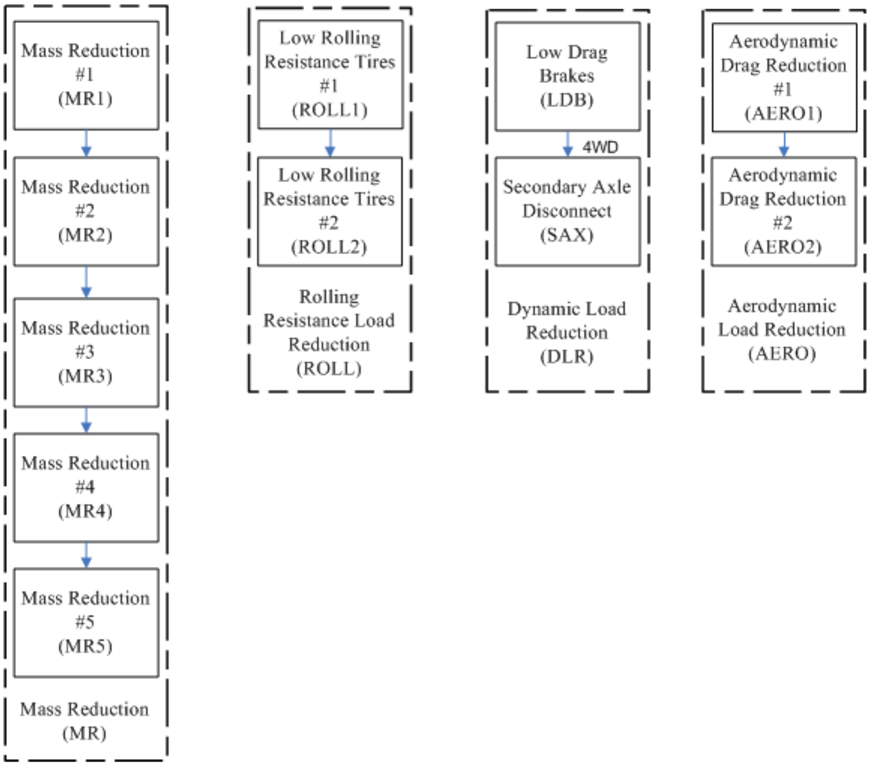

Figure 5. Vehicle Technology Decision Tree

S1.3 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.

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 fines 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.

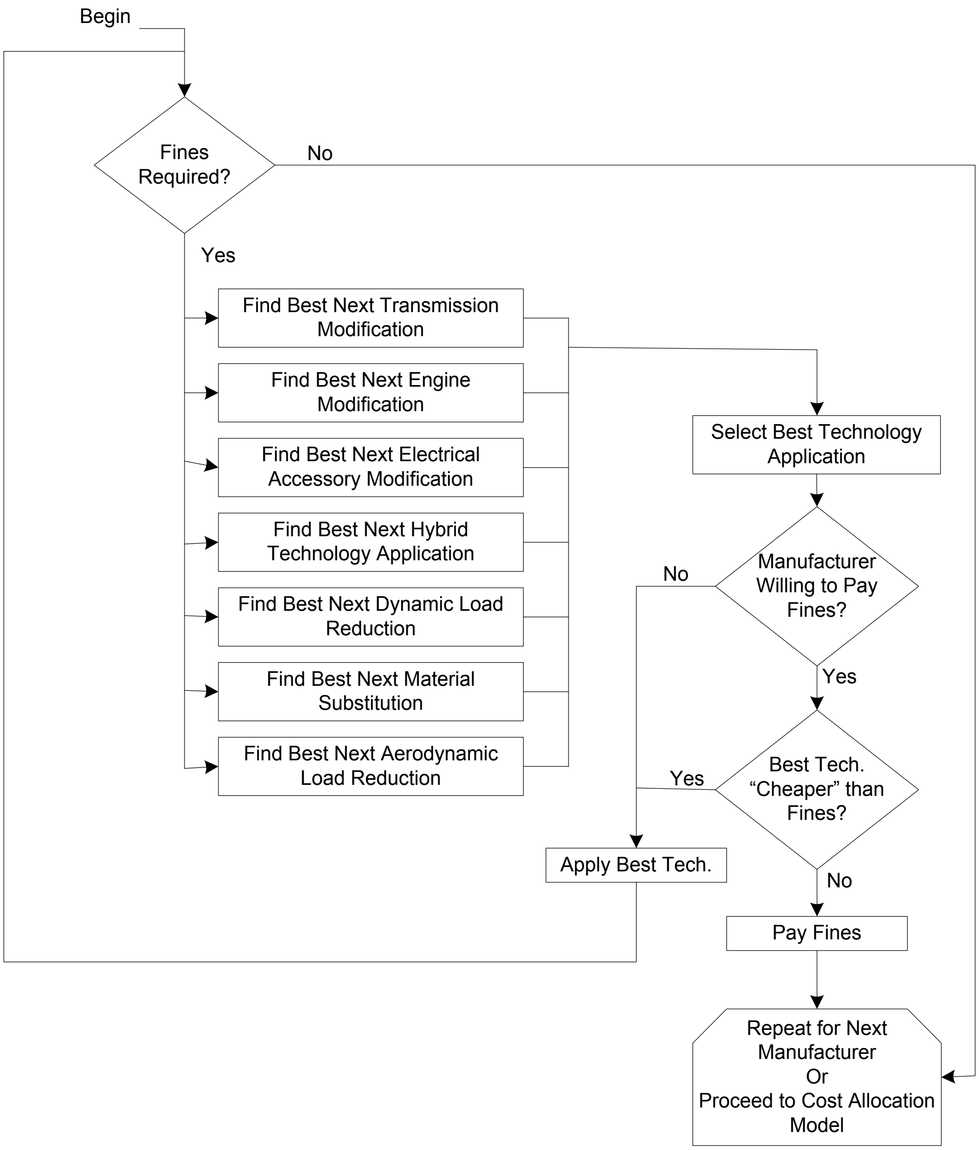

Figure 6. Compliance Simulation Algorithm

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.[11] 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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[11] 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 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.

$$COST_{eff} = \sum_{i=BaseMY}^{i=PresentMY} \frac{\Delta TECHCOST_i + \Delta FINE_i - (VALUE_{FUEL})_i + WELFARELOSS_i}{\left(N_j\right)_i} \qquad (2)$$

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*), *ΔTECHCOST* 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:[12]

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

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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[12] 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.[13] *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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[13] 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.

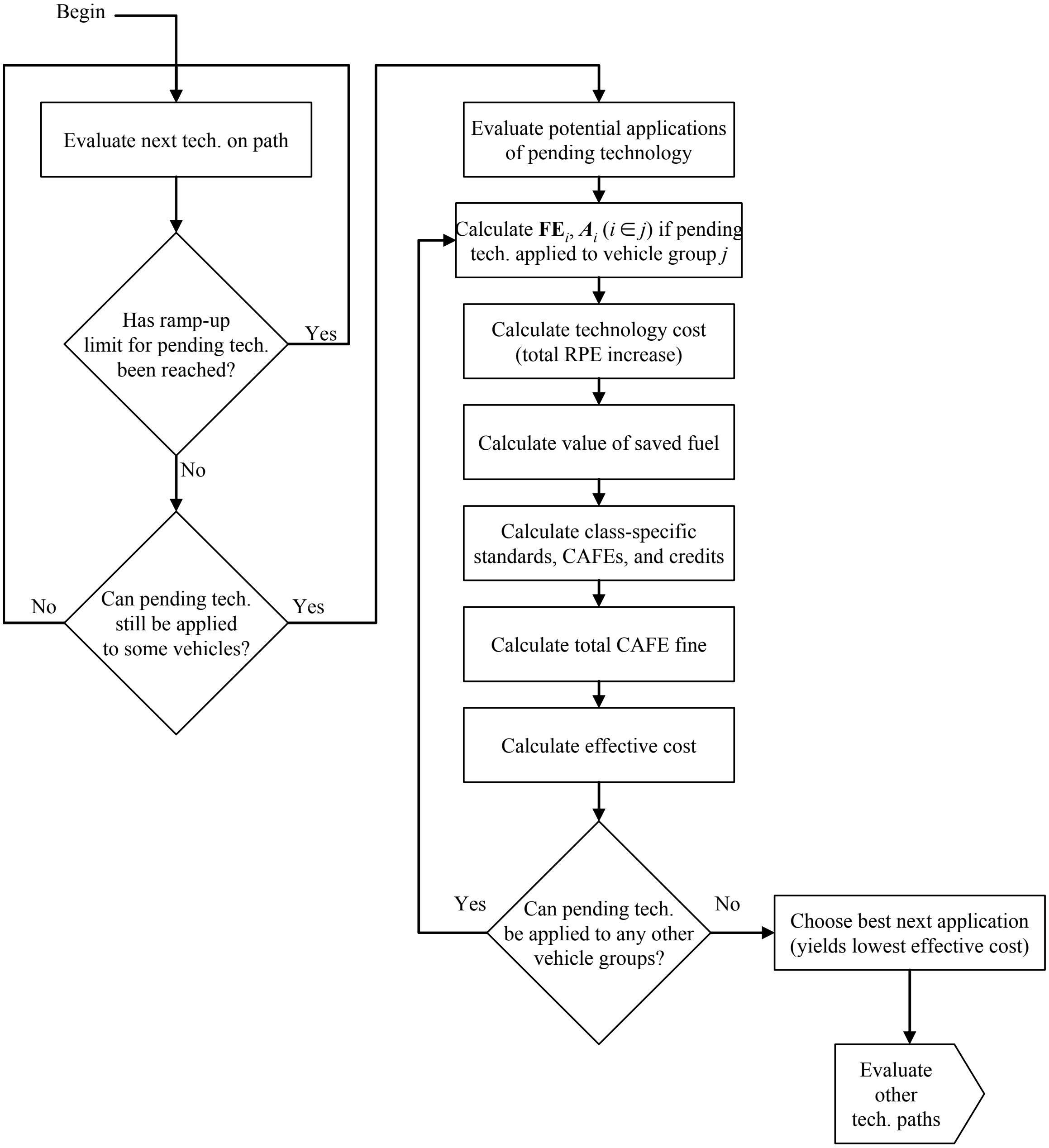

Figure 7. Determination of "Best Next" Technology Application

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 imposition 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.[14] 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 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 class (domestic automobiles, import automobiles, and light trucks) produced during each model year affected by a proposed standard. Cumulative impacts for each CAFE 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.

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:

$$n_{k,MY} = N_{MY} P_{k,MY} \tag{6}$$

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 forecast number of new vehicles of each specific model k produced and sold during future model years was based on a custom long range forecast of vehicle production purchased from CSM Worldwide (CSM). This forecast, which provided projections of vehicle sales by both

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[14] 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.

manufacturer and market segment, was combined with data from a variety of other sources to create the projections of production and sales by vehicle model and future model year. The development of model-level production and sales forecasts involved a complex multistep procedure, which is described in detail in Chapter 1 of the Joint TSD.

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:

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

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:

$$a = t - MY.^{15} \qquad \textbf{(8)}$$

The CAFE model currently accommodates different schedules of survival rates by vehicle age for passenger cars light trucks, as reported in A.3.1. Based on analysis of recent registration data, the maximum ages of passenger automobiles and light trucks are estimated to be 26 years and 36 years, respectively.[16]

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 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.

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[15] 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 is 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.

[16] 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.

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 2001 National Household Travel Survey (NHTS).[17] Separate schedules of average annual miles driven by age of vehicle were developed for passenger automobiles and light trucks.

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 2001 are adjusted to reflect assumed future growth in average vehicle use.[18] The average number of miles driven by cars and light trucks of all ages is assumed to grow by 1.1% per year from 2001 until 2030, and to increase by 0.5% annually after 2030.

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 2001 (when the NHTS data on vehicle use were collected) and each subsequent calendar year. This adjustment employs actual gasoline prices for the years 2002-2010, 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.[19] 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 $m_{k,MY,t,CAFE}$, is given by:

$$m_{k,MY,t,CAFE} = m_{type,t-MY,2001}(1+r)^{t-2001}\left[1+\varepsilon_{m,cpm}\left(\frac{C_{k,MY,t,CAFE}}{C_{k,t-MY,2001}}-1\right)\right] \qquad \textbf{(9)}$$

where $m_{type,t-MY,2001}$ is the average annual mileage for a car or light truck that was of age $t\text{-}MY$ during 2001, r is the rate of growth in average annual miles per vehicle beginning in 2001, $t\text{-}2001$ is the number of years that have elapsed between 2001 and calendar year t, $\varepsilon_{m,cpm}$ is the

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[17] For a description of the survey and methods for estimating annual vehicle use, see ***2001 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).

[18] 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.

[19] 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).

elasticity of annual vehicle use with respect to fuel cost per mile, $c_{k,MY,t,CAFE}$ is fuel cost per mile during year *t* for a car or light truck model *k,* and $c_{k,t\text{-}MY,2001}$ is fuel cost per mile for a car or light truck that was of age *t-MY* during 2001. The *CAFE* subscript on $m_{k,MY,t,CAFE}$ indicates that the value of this expression depends on the CAFE standard that was in effect during model year *MY*, as equation (10) below makes clear.

The CAFE subscript on $m_{k,MY,t,CAFE}$ in equation (9) indicates the value of this expression depends on the CAFE standard that was in effect during model year *MY*, as equation (10) below makes clear. Because the value of $m_{type,t\text{-}MY,t,2001}$ in equation (9) differs between cars and light trucks, the value of $m_{k,MY,t,CAFE}$ 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%).

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.[20]

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[20] 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.

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:

$$g_{k,MY,t,CAFE,fuel} = \frac{m_{k,MY,t,CAFE} s_{k,MY,CAFE,fuel}}{mpg_{k,MY,CAFE,fuel}\left(1 - gap_{fuel}\right)} \tag{10}$$

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.[21]

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

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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.

[21] TWe 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.

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:

$$G_{MY,t,CAFE,fuel} = \sum_{k} g_{k,MY,t,CAFE,fuel} \qquad \textbf{(13)}$$

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:

$$G_{MY,CAFE,fuel} = \sum_{t} \sum_{k} g_{k,MY,t,CAFE,fuel} \qquad \textbf{(14)}$$

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:

$$\Delta G_{MY,t,CAFE,fuel} = G_{MY,t,CAFE,fuel} - G_{MY,t,BASE,fuel} \qquad \textbf{(15)}$$

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:

$$\Delta G_{MY,CAFE,fuel} = \sum_{t} G_{MY,t,CAFE,fuel} = \sum_{t} G_{MY,t,CAFE,fuel} - \sum_{t} G_{MY,t,BASE,fuel} \qquad \textbf{(16)}$$

Combined consumption and savings of all fuel types, as calculated from equations (13) through (16), are reported in both unadjusted gallons and gasoline gallon equivalents. The former calculation simply sums total gallons of gasoline, diesel, and E85, and adds the gasoline gallon equivalent of electricity use by PHEVs and EVs. These are the measures that are typically reported as “fuel consumption” and “fuel savings” in regulatory analyses produced using the CAFE model. In addition, the model calculates the gasoline gallon equivalents of diesel and E85 using their volumetric energy densities relative to that of gasoline, adds gasoline consumption in gallons and the gasoline gallon equivalent of electricity use, and reports their sum as total fuel consumption in gasoline gallon equivalents.

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.[22] 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.[23]

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[22] 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.

[23] 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).

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 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:

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

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:

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

where t again ranges from MY to $(MY+26)$ for cars or $(MY+36)$ 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:

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

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:

$$\Delta CO2^{tot}{}_{MY,CAFE} = CO2^{tot}{}_{MY,CAFE} - CO2^{tot}{}_{MY,BASE} \quad \textbf{(22)}$$

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.

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.[24] 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:

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

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.[25]

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*).[26] Emission rates from vehicle use also depend on

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[24] 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.

[25] 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.

[26] 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:

$$E^{veh}{}_{MY,CAFE} = \sum_t E^{veh}{}_{MY,t,CAFE} \qquad \textbf{(24)}$$

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:

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

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 differs 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:

$$E^{tot}{}_{MY,CAFE} = E^{veh}{}_{MY,CAFE} + E^{ref}{}_{MY,CAFE} \tag{27}$$

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:

$$\Delta E^{tot}{}_{MY,CAFE} = E^{tot}{}_{MY,CAFE} - E^{tot}{}_{MY,BASE} \tag{28}$$

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 by 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. 0 provides examples of specific unit economic values and other parameters used to estimate the aggregate value of these various benefits and costs, explains how these sample values were derived, and reports the specific sources from which they were obtained.

S5.1 Benefits and Costs to New Vehicle Buyers

S5.1.1 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 their higher prices, 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.

S5.1.2 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.

S5.1.3 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.

S5.1.4 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.[27] 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.

S5.1.5 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.

S5.1.6 Social Benefits and Costs from Increased Fuel Economy

S5.1.6.1 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.

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[27] 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.

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.

S5.1.6.2 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 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 light truck 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.

S5.1.6.3 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.

S5.1.7 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.
Emissions Rates	Provides inputs used to project the emissions rates 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	2009	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
	2010	text	
	...		
	2024	text	
	2025	text	
Available Domestic Auto Credits (mpg)	2009	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Domestic Automobiles.
	2010	vehicle-mpg	
	...		
	2024	vehicle-mpg	
	2025	vehicle-mpg	
Available Imported Auto Credits (mpg)	2009	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Imported Automobiles.
	2010	vehicle-mpg	
	...		
	2024	vehicle-mpg	
	2025	vehicle-mpg	
Available Light Truck Credits (mpg)	2009	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Light Trucks.
	2010	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	MY2009	units	Vehicle's projected production for sale in the US.
	MY2010	units	
	...		
	MY2024	units	
	MY2025	units	
MSRP	MY2009	dollars	Vehicle's projected average MSRP (sales-weighted, including options).
	MY2010	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
	Market Segment	integer	The market segment of the vehicle (between 1 and 24).

Within the "Vehicle" 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 (e.g., ladder or unibody).
	Drive	text	Vehicle drive (e.g., 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.

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	text	
	EV2	text	
	EV3	text	
	EV4	text	
	FCV	text	
	MR1	text	
	MR2	text	
	MR3	text	
	MR4	text	
	MR5	text	
	ROLL1	text	
	ROLL2	text	
	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	text	
	TRBDS1_MD	text	
	TRBDS1_LD	text	
	TRBDS2_SD	text	
	TRBDS2_MD	text	
	TRBDS2_LD	text	
	CEGR1_SD	text	
	CEGR1_MD	text	
	CEGR1_LD	text	
	CEGR2_SD	text	
	CEGR2_MD	text	
	CEGR2_LD	text	
	ADSL_SD	text	
	ADSL_MD	text	
	ADSL_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. Below, Table 12 shows sample technologies definitions for all classes while Table 13 shows sample technology assumptions for subcompact cars.

For each technology, Table 12 contains the following:

- ***Index***: Specifies the index of the technology, which loosely reflects the sequence to follow when populating technology groups.
- ***Technology***: Represents the full technology name.
- ***Abbr.***: Represents the technology abbreviation used in output files.
- ***TechType***: Specifies the technology group to which the technology belongs.
- ***Phase-in Values (PV-1 to PV-17)***: Specifies the percentage of the entire fleet to which the technology can be applied, for each model year.
- ***Early Replacement Penalty Cost Table (ERC-1 to ERC-10)***[28]: Provides a table of "early replacement" penalty costs for the technology.

For each technology, Table 13 contains (again, as an example, for subcompact cars) the following:

- ***Index***: Specifies the index of the technology, which loosely reflects the sequence to follow when populating technology groups.
- ***Technology***: Represents the full technology name.
- ***Abbr.***: Represents the technology abbreviation used in output files.
- ***TechType***: Specifies the technology group to which the technology belongs.
- ***Applicable***: Specifies if the technology is available for applicability in a given technology class.
- ***Year Avail.***: Specifies the first year the technology is available for applicability.
- ***Year Retired***: Specifies the last year the technology is available for applicability.

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[28] Additional discussion of stranded capital may be found in Chapter 5 of the TSD.

- ***Electric Range***: Specifies what the range, in miles, of an electric vehicle would be when operating on a battery, as a result of applying the technology. This field should only be specified for PHEV and EV technologies.
- ***Delta Weight (%)***: Specifies the percentage by which the vehicle's weight changes as a result of applying the technology.
- ***Delta Weight (lbs)***: Specifies the amount of pounds by which the vehicle's weight changes as a result of applying the technology.
- ***Loss of Value***: Specifies what the loss in value to the consumer would be after applying the technology.
- ***FC***: Specifies the overall fuel consumption improvement estimate of the technology.
- ***FCg***: Specifies the fuel consumption improvement estimate to apply to the gasoline fuel economy value (applicable to plug-in HEVs only).
- ***FCg Share***: Specifies the percentage of time the vehicle is expected to run on the gasoline fuel after applying the technology (applicable to plug-in HEVs only).
- ***Cost Table***: Provides a table of learned out cost estimates for the technology, for each model year.

Table 12. Technologies Definitions (Sample)

Technology Information				Phase-in Values					Early Replacement Penalty Cost Tabl				
Index	Technology	Abbr.	TechType	PV-1	PV-2	…	PV-16	PV-17	ERC-1	ERC-2	…	ERC-9	ERC-10
1	Low Friction Lubricants - Level 1	LUB1	EngMod	30%	40%	…	100%	100%			…		
2	Engine Friction Reduction - Level 1	EFR1	EngMod	30%	40%		100%	100%					
3	Low Friction Lubricants and Engine	LUB2_EFR2	EngMod	0%	0%		96%	100%					
4	Variable Valve Timing (VVT) - Coupl	CCPS	EngMod	15%	25%		100%	100%					
5	Discrete Variable Valve Lift (DVVL)	DVVLS	EngMod	15%	25%		100%	100%					
6	Cylinder Deactivation on SOHC	DEACS	EngMod	15%	25%		100%	100%					
7	Variable Valve Timing (VVT) - Intake	ICP	EngMod	15%	25%		100%	100%					
8	Variable Valve Timing (VVT) - Dual	DCP	EngMod	15%	25%		100%	100%					
9	Discrete Variable Valve Lift (DVVL)	DVVLD	EngMod	15%	25%		100%	100%					
10	Continuously Variable Valve Lift (CV	CVVL	EngMod	15%	25%		100%	100%					
11	Cylinder Deactivation on DOHC	DEACD	EngMod	15%	25%		100%	100%					
12	Stoichiometric Gasoline Direct Inject	SGDI	EngMod	15%	25%		100%	100%					
13	Cylinder Deactivation on OHV	DEACO	EngMod	15%	25%		100%	100%					
14	Variable Valve Actuation - CCP and	VVA	EngMod	15%	25%		100%	100%					
15	Stoichiometric Gasoline Direct Inject	SGDIO	EngMod	15%	25%		100%	100%					
16	Turbocharging and Downsizing - Le	TRBDS1_SD	EngMod	15%	25%		100%	100%					
17	Turbocharging and Downsizing - Le	TRBDS1_MD	EngMod	15%	25%		100%	100%					
18	Turbocharging and Downsizing - Le	TRBDS1_LD	EngMod	15%	25%		100%	100%					
19	Turbocharging and Downsizing - Le	TRBDS2_SD	EngMod	0%	0%		75%	75%					
20	Turbocharging and Downsizing - Le	TRBDS2_MD	EngMod	0%	0%		75%	75%					
21	Turbocharging and Downsizing - Le	TRBDS2_LD	EngMod	0%	0%		75%	75%					
22	Cooled Exhaust Gas Recirculation (E	CEGR1_SD	EngMod	0%	0%		75%	75%					
23	Cooled Exhaust Gas Recirculation (E	CEGR1_MD	EngMod	0%	0%		75%	75%					
24	Cooled Exhaust Gas Recirculation (E	CEGR1_LD	EngMod	0%	0%		75%	75%	$72.65	$64.51		$8.06	$0.00
25	Cooled Exhaust Gas Recirculation (E	CEGR2_SD	EngMod	0%	0%		45%	50%					
26	Cooled Exhaust Gas Recirculation (E	CEGR2_MD	EngMod	0%	0%		45%	50%					
27	Cooled Exhaust Gas Recirculation (E	CEGR2_LD	EngMod	0%	0%		45%	50%					
28	Advanced Diesel - Small Displaceme	ADSL_SD	EngMod	0%	0%		6%	6%					
29	Advanced Diesel - Medium Displace	ADSL_MD	EngMod	0%	0%		6%	6%					
30	Advanced Diesel - Large Displaceme	ADSL_LD	EngMod	0%	0%		6%	6%					
31	6-Speed Manual/Improved Internals	6MAN	TrMod	15%	25%	…	100%	100%	$35.82	$31.84	…	$3.98	$0.00
32	High Efficiency Gearbox (Manual)	HETRANSM	TrMod	0%	0%		96%	100%					
33	Improved Auto. Trans. Controls/Ext	IATC	TrMod	15%	25%		100%	100%					
34	6-Speed Trans with Improved Intern	NAUTO	TrMod	15%	25%		100%	100%	$79.19	$66.94		$7.81	$0.00
35	6-speed DCT	DCT	TrMod	15%	25%		100%	100%	$35.82	$31.84		$3.98	$0.00
36	8-Speed Trans (Auto or DCT)	8SPD	TrMod	0%	0%		100%	100%	$35.82	$31.84		$3.98	$0.00
37	High Efficiency Gearbox (Auto or D	HETRANS	TrMod	0%	0%		96%	100%					
38	Shift Optimizer	SHFTOPT	TrMod	0%	0%		100%	100%					
39	Electric Power Steering	EPS	ELEC	5%	20%	…	100%	100%			…		
40	Improved Accessories - Level 1	IACC1	ELEC	5%	20%		100%	100%					
41	Improved Accessories - Level 2 (w/	IACC2	ELEC	0%	0%		100%	100%					
42	12V Micro-Hybrid (Stop-Start)	MHEV	ELEC	15%	25%		100%	100%					
43	Integrated Starter Generator	ISG	ELEC	0%	0%		45%	50%					
44	Strong Hybrid - Level 1	SHEV1	ELEC	0%	0%		45%	50%					
45	Conversion from SHEV1 to SHEV2	SHEV1_2	ELEC	0%	0%		45%	50%					
46	Strong Hybrid - Level 2	SHEV2	ELEC	0%	0%		45%	50%					
47	Plug-in Hybrid - 30 mi range	PHEV1	ELEC	0%	0%		13%	14%					
48	Plug-in Hybrid	PHEV2	ELEC	0%	0%		13%	14%					
49	Electric Vehicle (Early Adopter) - 75	EV1	ELEC	0%	0%		5%	5%					
50	Electric Vehicle (Early Adopter) - 10	EV2	ELEC	0%	0%		5%	5%					
51	Electric Vehicle (Early Adopter) - 15	EV3	ELEC	0%	0%		5%	5%					
52	Electric Vehicle (Broad Market) - 150	EV4	ELEC	0%	0%		9%	10%					
53	Fuel Cell Vehicle	FCV	ELEC	0%	0%		9%	10%					
54	Mass Reduction - Level 1	MR1	MR	15%	25%	…	100%	100%			…		
55	Mass Reduction - Level 2	MR2	MR	15%	25%		100%	100%					
56	Mass Reduction - Level 3	MR3	MR	15%	25%		100%	100%					
57	Mass Reduction - Level 4	MR4	MR	0%	0%		100%	100%					
58	Mass Reduction - Level 5	MR5	MR	0%	0%		90%	100%					
59	Low Rolling Resistance Tires - Leve	ROLL1	ROLL	20%	35%	…	100%	100%			…		
60	Low Rolling Resistance Tires - Leve	ROLL2	ROLL	0%	0%		100%	100%					
61	Low Rolling Resistance Tires - Leve	ROLL3	ROLL	0%	0%		0%	0%					
62	Low Drag Brakes	LDB	DLR	20%	35%	…	100%	100%			…		
63	Secondary Axle Disconnect	SAX	DLR	15%	25%		100%	100%					
64	Aero Drag Reduction, Level 1	AERO1	AERO	30%	40%	…	100%	100%			…		
65	Aero Drag Reduction, Level 2	AERO2	AERO	0%	0%		100%	100%					

Table 13. Technologies Assumptions (Sample)

Subcompact PC				Availability			Misc Attributes				FC Improvements			Cost Table				
Index	Technology	Abbr.	TechType	Applicable	Year Avail.	Year Retired	Electric Range	Delta Weight (%)	Delta Weight (lbs)	Loss of Value	FC	FCG	FCG Share	Cost 2009	Cost 2010	…	Cost 2024	Cost 2025
1	Low Friction Lubricants - Level 1	LUB1	EngMod	TRUE	2007						0.5%			4	4		4	4
2	Engine Friction Reduction - Level 1	EFR1	EngMod	TRUE	2007						2.0%			15	15		14	14
3	Low Friction Lubricants and Engine	LUB2_EFR2	EngMod	TRUE	2017						1.0%			16	16		16	15
4	Variable Valve Timing (VVT) - Couple	CCPS	EngMod	TRUE	2007						4.1%			55	54		39	38
5	Discrete Variable Valve Lift (DVVL) o	DVVLS	EngMod	TRUE	2007						2.8%			48	47		33	33
6	Cylinder Deactivation on SOHC	DEACS	EngMod	TRUE	2007						0.4%			38	37		27	26
7	Variable Valve Timing (VVT) - Intake	ICP	EngMod	TRUE	2007						2.2%			55	54		39	38
8	Variable Valve Timing (VVT) - Dual C	DCP	EngMod	TRUE	2007						2.0%			52	51		36	36
9	Discrete Variable Valve Lift (DVVL) o	DVVLD	EngMod	TRUE	2007						2.8%			48	47		33	33
10	Continuously Variable Valve Lift (CV	CVVL	EngMod	TRUE	2007						3.6%			77	75		54	53
11	Cylinder Deactivation on DOHC	DEACD	EngMod	TRUE	2007						0.4%			38	37		27	26
12	Stoichiometric Gasoline Direct Injecti	SGDI	EngMod	TRUE	2007						1.6%			79	77		55	54
13	Cylinder Deactivation on OHV	DEACO	EngMod	TRUE	2007						4.7%			244	238		170	167
14	Variable Valve Actuation - CCP and	VVA	EngMod	TRUE	2007						2.7%			61	60		42	42
15	Stoichiometric Gasoline Direct Injecti	SGDIO	EngMod	TRUE	2007						1.6%			79	77		55	54
16	Turbocharging and Downsizing - Lev	TRBDS1_SD	EngMod	TRUE	2007						7.2%			572	560	…	399	394
17	Turbocharging and Downsizing - Lev	TRBDS1_MD	EngMod	TRUE	2007						6.7%			(15)	(10)		(21)	(17)
18	Turbocharging and Downsizing - Lev	TRBDS1_LD	EngMod	TRUE	2007						6.7%			734	716		495	488
19	Turbocharging and Downsizing - Lev	TRBDS2_SD	EngMod	TRUE	2012						2.9%			12	14		23	5
20	Turbocharging and Downsizing - Lev	TRBDS2_MD	EngMod	TRUE	2012						2.9%			310	303		235	212
21	Turbocharging and Downsizing - Lev	TRBDS2_LD	EngMod	TRUE	2012						2.9%			522	510		397	358
22	Cooled Exhaust Gas Recirculation (E	CEGR1_SD	EngMod	TRUE	2012						3.6%			360	352		274	247
23	Cooled Exhaust Gas Recirculation (E	CEGR1_MD	EngMod	TRUE	2012						3.6%			360	352		274	247
24	Cooled Exhaust Gas Recirculation (E	CEGR1_LD	EngMod	TRUE	2012						3.6%			360	352		274	247
25	Cooled Exhaust Gas Recirculation (E	CEGR2_SD	EngMod	TRUE	2017						1.0%			620	605		471	425
26	Cooled Exhaust Gas Recirculation (E	CEGR2_MD	EngMod	TRUE	2017						1.0%			620	605		471	425
27	Cooled Exhaust Gas Recirculation (E	CEGR2_LD	EngMod	TRUE	2017						1.0%			(413)	(396)		(269)	(285)
28	Advanced Diesel - Small Displaceme	ADSL_SD	EngMod	TRUE	2017						5.5%			1115	1080		845	689
29	Advanced Diesel - Medium Displace	ADSL_MD	EngMod	TRUE	2017						5.5%			1041	1013		875	719
30	Advanced Diesel - Large Displaceme	ADSL_LD	EngMod	TRUE	2017						5.5%			2022	1975		1725	1488
31	6-Speed Manual/Improved Internals	6MAN	TrMod	TRUE	2007						2.0%			336	327		236	232
32	High Efficiency Gearbox (Manual)	HETRANSM	TrMod	TRUE	2017						3.4%			304	296		213	200
33	Improved Auto. Trans. Controls/Exte	IATC	TrMod	TRUE	2007						2.3%			74	72		52	51
34	6-Speed Trans with Improved Interna	NAUTO	TrMod	TRUE	2007						1.9%			(53)	(51)		(35)	(34)
35	6-speed DCT	DCT	TrMod	TRUE	2007						4.0%			(156)	(149)	…	(104)	(101)
36	8-Speed Trans (Auto or DCT)	8SPD	TrMod	TRUE	2014						3.8%			304	297		212	208
37	High Efficiency Gearbox (Auto or DC	HETRANS	TrMod	TRUE	2017						2.2%			304	296		213	200
38	Shift Optimizer	SHFTOPT	TrMod	TRUE	2017						3.3%			2	1		1	1
39	Electric Power Steering	EPS	ELEC	TRUE	2007						1.5%			130	127		92	90
40	Improved Accessories - Level 1	IACC1	ELEC	TRUE	2007						1.2%			106	103		75	73
41	Improved Accessories - Level 2 (w/	IACC2	ELEC	TRUE	2014						1.8%			65	63		48	45
42	12V Micro-Hybrid (Stop-Start)	MHEV	ELEC	TRUE	2007						1.7%			469	469		253	247
43	Integrated Starter Generator	ISG	ELEC	FALSE	2012						0.0%			0	0		0	0
44	Strong Hybrid - Level 1	SHEV1	ELEC	TRUE	2012	2016					14.9%			4365	4306		2818	2622
45	Conversion from SHEV1 to SHEV2	SHEV1_2	ELEC	TRUE	2017						10.0%			1425	1395		1092	983
46	Strong Hybrid - Level 2	SHEV2	ELEC	TRUE	2017						10.1%			4365	4306	…	2818	2622
47	Plug-in Hybrid - 30 mi range	PHEV1	ELEC	TRUE	2020		30				40.7%	0.0%	50.0%	14645	14601		8102	6470
48	Plug-in Hybrid	PHEV2	ELEC	FALSE	2020		0				0.0%			0	0		0	0
49	Electric Vehicle (Early Adopter) - 75	EV1	ELEC	FALSE	2017		75				68.5%			5139	5225		2153	828
50	Electric Vehicle (Early Adopter) - 100	EV2	ELEC	FALSE	2017		100				0.0%			0	0		0	0
51	Electric Vehicle (Early Adopter) - 150	EV3	ELEC	FALSE	2017		150				0.0%			0	0		0	0
52	Electric Vehicle (Broad Market) - 150	EV4	ELEC	FALSE	2017		150			$ 3,561	0.0%			11401	11401		5852	4297
53	Fuel Cell Vehicle	FCV	ELEC	FALSE	2017						0.0%			0	0		0	0
54	Mass Reduction - Level 1	MR1	MR	TRUE	2007			0.0%			0.0%			0	0		0	0
55	Mass Reduction - Level 2	MR2	MR	TRUE	2007			0.0%			0.0%			0	0		0	0
56	Mass Reduction - Level 3	MR3	MR	TRUE	2007			0.0%			0.0%			0	0	…	0	0
57	Mass Reduction - Level 4	MR4	MR	TRUE	2011			0.0%			0.0%			0	0		0	0
58	Mass Reduction - Level 5	MR5	MR	TRUE	2016			0.0%			0.0%			0	0		0	0
59	Low Rolling Resistance Tires - Level	ROLL1	ROLL	TRUE	2007						1.9%			7	7		6	6
60	Low Rolling Resistance Tires - Level	ROLL2	ROLL	TRUE	2017						2.0%			72	72	…	46	43
61	Low Rolling Resistance Tires - Level	ROLL3	ROLL	FALSE							0.0%			0	0		0	0
62	Low Drag Brakes	LDB	DLR	FALSE	2007						0.8%			73	73	…	70	70
63	Secondary Axle Disconnect	SAX	DLR	TRUE	2007						1.4%			116	113		82	81
64	Aero Drag Reduction, Level 1	AERO1	AERO	TRUE	2007						2.3%			58	57	…	41	40
65	Aero Drag Reduction, Level 2	AERO2	AERO	TRUE	2011						2.5%			193	189		146	132

The technologies are organized into technology types specified by TechType field in the fourth column. Each technology type is populated with specific technologies following the sequence specified by the Index column. 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).

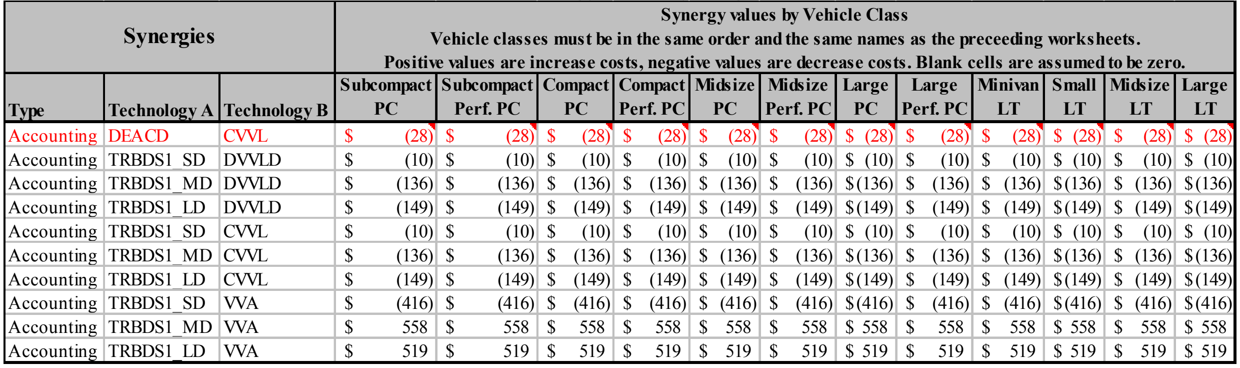
A.2.1 Technology Synergies

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. Samples from the synergy tables are shown in Table 14 and

Table 15 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 Cost Synergies (Sample)



Synergies			Synergy values by Vehicle Class Vehicle classes must be in the same order and the same names as the preceeding worksheets. Positive values are increase costs, negative values are decrease costs. Blank cells are assumed to be zero.											
Type	Technology A	Technology B	Subcompact PC	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
Accounting	DEACD	CVVL	$ (28)	$ (28)	$ (28)	$ (28)	$ (28)	$ (28)	$ (28)	$ (28)	$ (28)	$ (28)	$ (28)	$ (28)
Accounting	TRBDS1_SD	DVVLD	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)
Accounting	TRBDS1_MD	DVVLD	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)
Accounting	TRBDS1_LD	DVVLD	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)
Accounting	TRBDS1_SD	CVVL	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)	$ (10)
Accounting	TRBDS1_MD	CVVL	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)	$ (136)
Accounting	TRBDS1_LD	CVVL	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)	$ (149)
Accounting	TRBDS1_SD	VVA	$ (416)	$ (416)	$ (416)	$ (416)	$ (416)	$ (416)	$ (416)	$ (416)	$ (416)	$ (416)	$ (416)	$ (416)
Accounting	TRBDS1_MD	VVA	$ 558	$ 558	$ 558	$ 558	$ 558	$ 558	$ 558	$ 558	$ 558	$ 558	$ 558	$ 558
Accounting	TRBDS1_LD	VVA	$ 519	$ 519	$ 519	$ 519	$ 519	$ 519	$ 519	$ 519	$ 519	$ 519	$ 519	$ 519

Table 15. Technology Fuel Consumption Synergies (Sample)

Synergies			Fuel Consumption Improvement Synergy values by Vehicle Class Vehicle classes must be in the same order and the same names as the preceeding worksheets. Positive values are [positive] synergies, negative values are dissynergies. Blank cells are assumed to be zero.											
Type	Technology A	Technology B	Subcompact PC	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
Accounting	DEACD	CVVL	-0.40%	-0.40%	-0.40%	-0.40%	-0.70%	-0.70%	-0.70%	-0.70%	-0.20%	-0.40%	-0.20%	-0.60%
Accounting	TRBDS1_SD	DVVLD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Accounting	TRBDS1_MD	DVVLD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Accounting	TRBDS1_LD	DVVLD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Accounting	TRBDS1_SD	CVVL	-0.72%	-0.72%	-0.72%	-0.72%	-1.13%	-1.13%	-1.15%	-1.15%	-1.12%	-0.72%	-1.12%	-0.98%
Accounting	TRBDS1_MD	CVVL	-0.21%	-0.21%	-0.21%	-0.21%	-0.33%	-0.33%	-0.33%	-0.33%	-0.32%	-0.21%	-0.32%	-0.32%
Accounting	TRBDS1_LD	CVVL	-0.21%	-0.21%	-0.21%	-0.21%	-0.33%	-0.33%	-0.33%	-0.33%	-0.32%	-0.21%	-0.32%	-0.32%
Accounting	TRBDS1_SD	VVA	4.79%	4.79%	4.79%	4.79%	6.06%	6.06%	6.62%	6.62%	6.05%	4.78%	6.05%	5.75%
Accounting	TRBDS1_MD	VVA	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Accounting	TRBDS1_LD	VVA	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

For each technology relation, the above two tables contain the following:

- ***Type***: Specifies 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***: Specifies the abbreviation of the first technology in a synergy pair.
- ***Technology B***: Specifies the abbreviation of the second technology in a synergy pair.
- ***Subcompact PC – Large LT***: Contains 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.

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 16. Vehicle Age Data Worksheet (sources data shown as samples)

Category	Model Characteristic	Units	Definition/Notes	Source
Vehicle Age Data	Survival Rates	proportion	Proportion of original vehicle sales that remain in service by vehicle age (year 1 to 26 for cars, 1 - 36 for trucks)	U.S. Environmental Protection Agency, Fleet Characterization Data for MOBILE6: Development and Use of Age Distributions, Average Annual Mileage Accumulation Rates and Projected Vehicle Counts for Use in MOBILE6, EPA420-P-99-011, April 1999,
	Base Miles Driven at various fuel prices	miles	Average annual miles driven by surviving vehicles by vehicle age (year 1 to 26 for cars, 1 - 36 for trucks)	

Separate survival fractions are used for automobiles and light trucks. These measure the proportion of vehicles originally produced during a model year that remain in service at each age (up to 25 years for automobiles and 35 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 17. Forecast Data Worksheet (sources data shown as samples)

Category	Model Characteristic	Units	Definition/Notes	Source
Forecast Data	Retail Fuel Prices	$/gallon	2009 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-1975	Average Values from AEO 2011 Early Release
	Fuel Taxes	$/gallon	2009 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-2000	calculated from "Federal Fuel Tax" and "Average State Fuel Tax" components, obtained from FHWA Highway Statistics, Tables FE-21B and MF-121T

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 18. Fuel Economy Data Worksheet (sources data show as samples)

Category	Model Characteristic	Units	Definition/Notes	Source
Fuel Economy Data	Passenger Cars (FE)	mpg	historic and projected fuel economy levels for passenger cars	
	Passenger Cars (Share)	percent	historic and projected fuel shares for passenger cars	
	Light Trucks (FE)	mpg	historic and projected fuel economy levels for light trucks	
	Light Trucks (Share)	percent	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 Table 19 identifies available sources of information for economic values, the system does not require that the user rely on these sources.

Table 19. Economic Values Worksheet (sources data shown as samples)

Category	Model Characteristic	Units	Definition/Notes	Source
Economic Values	Rebound Effect	percent	increase in the annual use of vehicle models in response to lower per-mile cost of driving a more fuel-efficient vehicle	various
	Social Discount Rate	percent	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	Office of Management and Budget, office of Information and Regulatory Analysis
	Private Discount Rate	percent	sames as social discount rate, but used for calculating consumer-valued benefits	
	Kf	$/mpg	the CAFE fine rate	
	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	Volpe estimates
	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	Leiby et al.
	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)	$/gallon	total economic costs of oil imports (sum of monopsony, price shock, and military security components)	calculated
	Total Economic Costs ($/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	Federal Highway Administration, 1997 Highway Cost Allocation Study, T. V-23
	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	***various***	additional costs arising from emission damage	
	Carbon Monoxide	$/ton	economic costs arising from Carbon Monoxide damage	McCubbin & DeLucchi
	Volatile Organic Compounds	$/ton	economic costs arising from Volatile Organic Compounds damage	OMB (1998), p. 72
	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	
	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	primary base year for annual growth rate for average VMT per vehicle	
	Cars	percent	primary annual growth rate for average VMT per vehicle for passenger cars	
	Trucks	percent	primary annual growth rate for average VMT per vehicle for light trucks	
	Base Year for Average Annual Usage Data (Secondary)	model year	secondary base year for annual growth rate for average VMT per vehicle	
	Cars	percent	secondary annual growth rate for average VMT per vehicle for passenger cars	
	Trucks	percent	secondary annual growth rate for average VMT per vehicle for light trucks	
	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	percent	discount rates to apply to low, average, high, or very high Carbon Dioxide estimates	
	"Gap" between Test and On-Road MPG (by Fuel Type)	percent	difference between a vehicle's EPA fuel economy rating and its actual on-road fuel economy	EPA/OTAQ estimate
	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	percent	average tank volume refilled during a refueling stop	

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 20. Fuel Properties Worksheet (sources data shown as samples)

Category	Model Characteristic	Units	Definition/Notes	Source
Fuel Properties	Share of Total Assumed Fuel Mix	percent	estimated share of total fuel consumption by fuel type	USEPA, Regulatory Impact Analysis for Tier 2 Emissions Standard, Table 19, p. 42; and estimate supplied by Ford Motor Company in comments on proposed 2005-07 Light Truck CAFE Rule
	Energy Density	BTU/unit	amount of energy stored in a given system or region of space per unit volume, specified by fuel type	Wang, Michael, The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model: Version 1.5 Technical Report, Argonne National Laboratory, August 1999, Table 3.3, p. 25 (http://greet.anl.gov/pdfs/esd_3v1.pdf)
	Mass Density	grams/unit	mass per unit volume, specified by fuel type	
	Carbon Content	percent 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	percent	assumed value for share of fuel savings leading to lower fuel imports	Energy Information Administration, Annual Energy Outlook 2003, Tables 1, 2, and 117; and Volpe assumptions
	Share of Fuel Savings Leading to Reduced Domestic Fuel Refining	percent	assumed value for share of fuel savings leading to reduced domestic fuel refining	
	Share of Reduced Domestic Refining from Domestic Crude	percent	assumed value for share of reduced domestic refining from domestic crude	
	Share of Reduced Domestic Refining from Imported Crude	percent	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 21. Upstream Emissions Worksheet (sources data shown as samples)

Category	Model Characteristic	Units	Definition/Notes	Source
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	Argonne National Laboratory, The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, version 1.6, June 2001, Near-Term Output: Petroleum Fuels
	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 prodcution and distribution	calculated

A.3.7 Monte-Carlo

The Monte-Carlo worksheet contains parameters for setting up pseudo-random trials for uncertainty analysis.

Table 22. Monte-Carlo Worksheet

Monte-Carlo	Discount Rates (%)	percent	comma-separated list of discount rates to use during Monte-Carlo modeling
	Fuel Path Randomization Parameters	percent	randomization parameters for the low, reference, or high fuel path
	Rebound Effect Randomization Parameters		parameters for generating randomized rebound effect values
	Carbon Dioxide Randomization Parameters	percent	randomization parameters for the low, average, high or very high Carbon Dioxide path
	Monopsony Randomization Parameters	dollars	parameters for generating randomized monopsony cost values
	Price Shock Randomization Parameters	dollars	parameters for generating randomized price shock cost values
	Military Security Randomization Parameters	dollars, percent	parameters for generating randomized military security cost values

A.3.8 Safety Values

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

Table 23. Safety Values Worksheet

Category	Model Characteristic	Units	Definition/Notes	Source
Safety Values	PC Threshold	lbs	the boundary between small and large weigth effects by safety class	
	LT/SUV Threshold	lbs		
	CUV/Minivan Threshold	lbs		
	Change per 100 lbs	percent	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	
	Discount Rate	percent	discount rate to apply to costs arising from vehicle fatalities	

A.4 Emissions Rates 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 24. Emissions Rates Worksheet

Category	Model Characteristic	Units	Definition/Notes	Source
	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.	U.S. Environmental Protection Agency, MOBILE Motor Vehicle Emission Factor Model, version 6.1/6.2, October 2004.
	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 25. Regulatory Classes

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

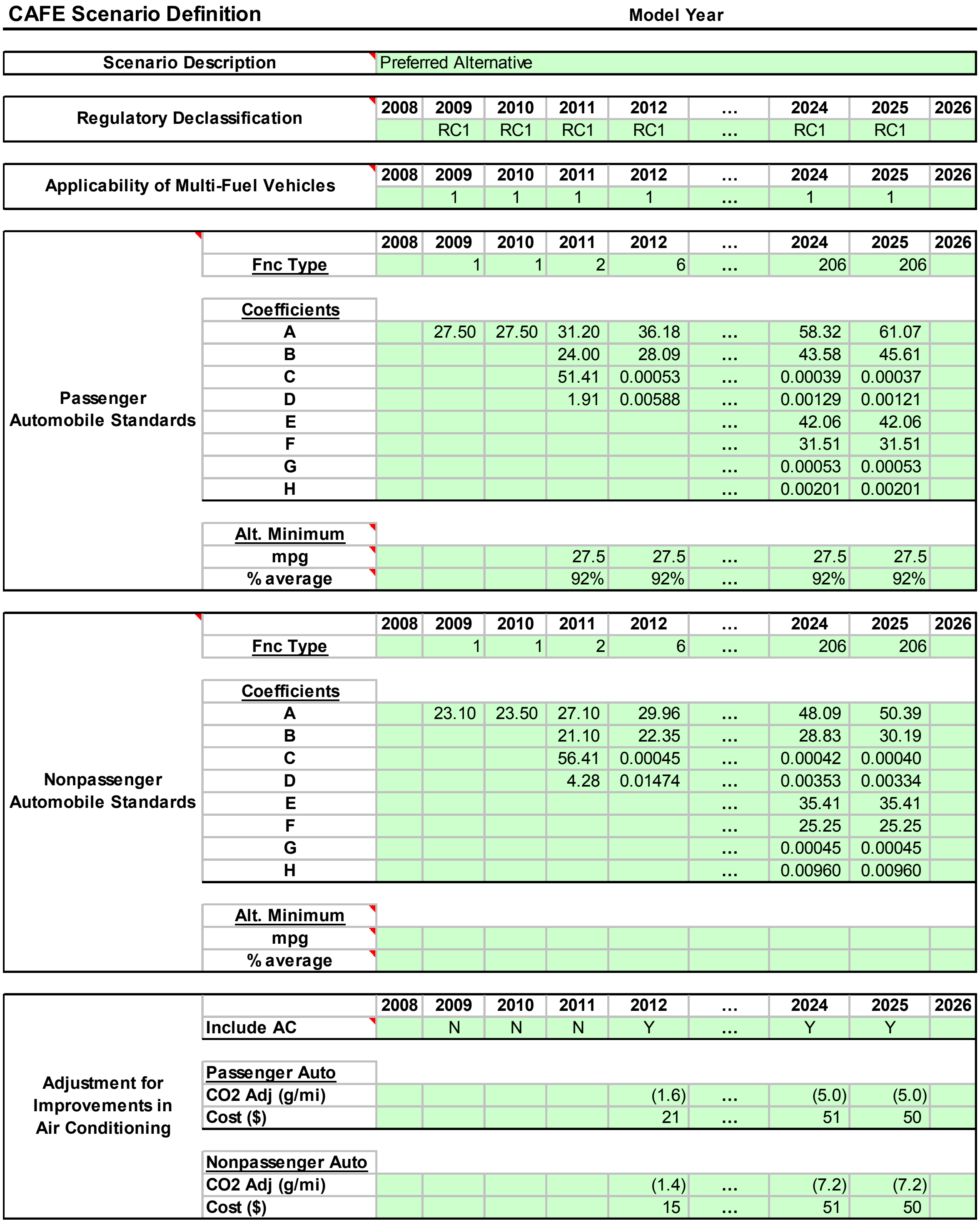
The "Regulatory Class" column on the vehicles worksheet discussed above is used to indicate whether the vehicle is regulated as a passenger or nonpassenger automobile. The vehicle origin is further used to differentiate between regulatory classes 1 and 2 (domestic or imported). Vehicles from one regulatory class may also be reassigned into another via the Regulatory Declassification section of the scenario as shown in Table 26.

Table 26. 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 27 shows an example of a CAFE scenario definition worksheet.

Table 27. Scenario Definition Worksheet (Sample)



CAFE Scenario Definition **Model Year**

Scenario Description	Preferred Alternative

Regulatory Declassification	**2008**	**2009**	**2010**	**2011**	**2012**	**…**	**2024**	**2025**	**2026**
		RC1	RC1	RC1	RC1	…	RC1	RC1	

Applicability of Multi-Fuel Vehicles	**2008**	**2009**	**2010**	**2011**	**2012**	**…**	**2024**	**2025**	**2026**
		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		27.50	27.50	31.20	36.18	…	58.32	61.07	
	B				24.00	28.09	…	43.58	45.61	
	C				51.41	0.00053	…	0.00039	0.00037	
	D				1.91	0.00588	…	0.00129	0.00121	
	E						…	42.06	42.06	
	F						…	31.51	31.51	
	G						…	0.00053	0.00053	
	H						…	0.00201	0.00201	
	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		23.10	23.50	27.10	29.96	…	48.09	50.39	
	B				21.10	22.35	…	28.83	30.19	
	C				56.41	0.00045	…	0.00042	0.00040	
	D				4.28	0.01474	…	0.00353	0.00334	
	E						…	35.41	35.41	
	F						…	25.25	25.25	
	G						…	0.00045	0.00045	
	H						…	0.00960	0.00960	
	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	

Each section in Table 27 contains the following:

- Scenario Description: A short name describing the key features of the scenario.
- Regulatory Declassification: Specifies whether vehicles from one regulatory class should be merged with vehicles from another regulatory class.
- 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 27, 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.
- Adjustments 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.

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 2007.

Table 28. Fleet Data Worksheet (Sample)

Vehicle Age	Car Fleet (by Model Year)										
	1975	1976	1977	1978	1979	1980	1981	1982	...	2006	2007
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	...	7,476,857	7,765,778
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	...	7,439,284	7,726,754
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	...	7,387,435	7,672,901
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	...	7,312,291	7,594,853
5	6,608,778	8,632,878	9,552,440	9,911,813	9,781,534	8,511,328	7,882,011	7,082,456	...	7,208,591	7,487,147
...	...	...	...	...	...	...	...	...	...	...	...
25	243,184	346,009	445,606	495,961	589,311	394,720	383,262	341,428	...	226,184	234,925
26	212,919	300,888	392,570	448,988	528,824	338,916	289,038	257,489	...	170,578	177,169
27	187,363	267,571	356,875	401,147	461,134	0	0	0	...	0	0
28	169,579	268,922	320,266	349,590	0	0	0	0	...	0	0
29	162,788	245,921	280,102	0	0	0	0	0	...	0	0
30	150,873	220,318	0	0	0	0	0	0	...	0	0
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

Vehicle Age	Truck Fleet (by Model Year)										
	1975	1976	1977	1978	1979	1980	1981	1982	...	2006	2007
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	...	7,623,624	7,485,061
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	...	7,463,489	7,327,837
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	...	7,357,755	7,224,024
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	...	7,217,541	7,086,359
5	1,717,860	2,458,364	2,967,591	3,210,082	3,367,079	1,870,570	1,843,863	1,958,795	...	7,041,317	6,913,337
...	...	...	...	...	...	...	...	...	...	...	...
25	266,538	382,567	473,109	536,874	579,713	272,646	292,428	315,962	...	1,166,146	1,144,951
26	229,689	329,210	415,832	505,596	502,617	246,500	255,923	276,519	...	1,020,570	1,002,020
27	197,691	289,805	399,388	452,733	452,792	215,595	223,836	241,850	...	892,615	876,392
28	173,875	270,615	354,133	399,354	395,270	188,206	195,400	211,126	...	779,219	765,056
29	162,660	242,343	320,112	348,306	344,744	164,148	170,423	184,138	...	679,613	667,261
30	145,220	216,331	278,970	303,540	300,436	143,051	148,520	160,472	...	592,267	581,503
31	129,439	188,345	242,881	264,273	261,570	124,545	129,306	139,712	...	515,648	506,276
32	112,706	163,997	211,483	230,110	227,756	108,445	112,591	121,652	...	448,989	440,829
33	97,897	142,448	183,694	199,873	197,829	94,196	97,796	105,667	...	389,992	382,904
34	85,203	123,978	159,876	173,957	172,178	81,982	85,115	91,965	...	339,424	333,254
35	74,048	107,746	138,944	151,181	149,635	71,248	73,972	79,925	...	294,984	289,623
36	64,239	93,473	120,538	131,155	129,813	61,810	64,173	69,337	...	255,909	251,257

The Sales Data worksheet contains projected vehicle production for sale in the U.S. between model years 2005 and 2060. The Sales worksheet is used to estimate additional car and truck fleet values,,beyond what is available on the Fleet Data worksheet.

Table 29. 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	6,614,097	5,830,264	12,444,360
2009	5,158,841	4,659,383	9,818,224
2010	5,467,937	5,328,596	10,796,533
2011	6,417,840	6,185,476	12,603,316
2012	7,490,112	7,204,277	14,694,389
2013	8,329,210	7,752,341	16,081,551
2014	8,347,886	7,525,188	15,873,074
2015	8,602,032	7,556,467	16,158,499
2016	8,680,343	7,514,833	16,195,176
2017	8,688,595	7,117,727	15,806,322
2018	8,620,452	6,955,959	15,576,410
2019	8,711,840	6,866,818	15,578,658
2020	8,993,485	6,902,454	15,895,939
...	...	...	...
2059	13,862,229	9,591,650	23,453,879
2060	13,985,445	9,676,907	23,662,353

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 2060, 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 2060. The fuel share of additional fuel types (E85, electricity, and hydrogen) is assumed to be 0.

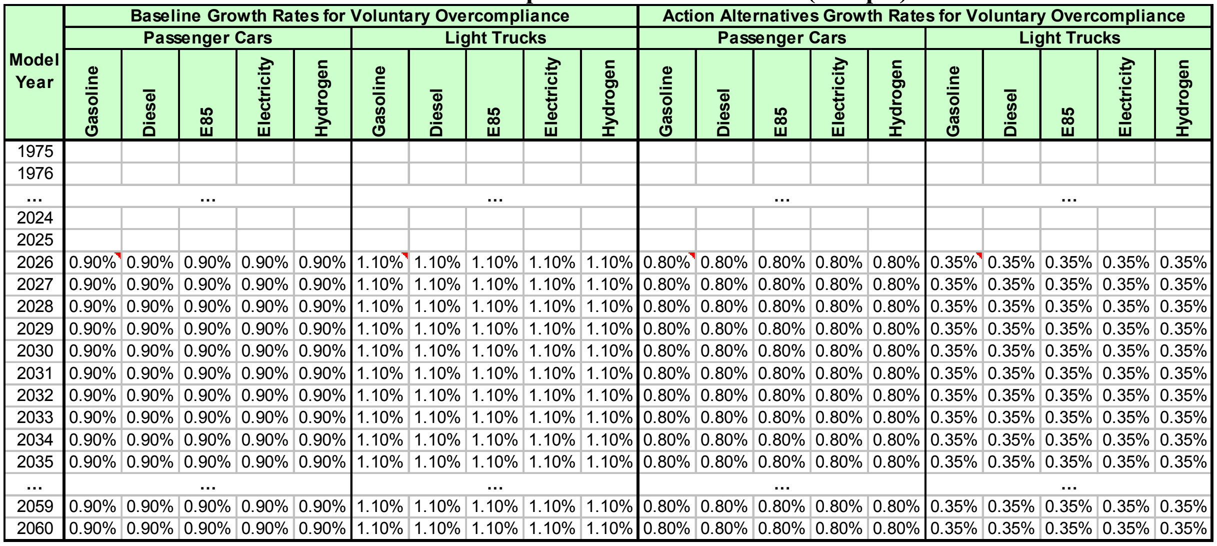
Table 30. No CAFE Data Worksheet (Sample)

Model Year	Passenger Cars										Light Trucks									
	Gasoline FE	Diesel FE	E85 FE	Electricity FE	Hydrogen FE	Gasoline Share	Diesel Share	E85 Share	Electricity Share	Hydrogen Share	Gasoline FE	Diesel FE	E85 FE	Electricity FE	Hydrogen FE	Gasoline Share	Diesel Share	E85 Share	Electricity Share	Hydrogen Share
1975	15.8	15.8	-	-	-	99.69%	0.31%	-	-	-	13.7	13.7	-	-	-	99.69%	0.31%	-	-	-
1976	17.5	17.5	-	-	-	98.89%	1.11%	-	-	-	14.4	14.4	-	-	-	99.69%	0.31%	-	-	-
1977	18.3	18.3	-	-	-	98.09%	1.91%	-	-	-	15.6	15.6	-	-	-	99.69%	0.31%	-	-	-
1978	18.3	18.3	-	-	-	98.09%	1.91%	-	-	-	15.2	15.2	-	-	-	99.69%	0.31%	-	-	-
1979	18.3	18.3	-	-	-	98.09%	1.91%	-	-	-	15.2	15.2	-	-	-	99.69%	0.31%	-	-	-
1980	18.3	18.3	-	-	-	98.09%	1.91%	-	-	-	15.2	15.2	-	-	-	99.69%	0.31%	-	-	-
1981	18.3	18.3	-	-	-	98.09%	1.91%	-	-	-	15.2	15.2	-	-	-	99.69%	0.31%	-	-	-
1982	18.3	18.3	-	-	-	98.09%	1.91%	-	-	-	15.2	15.2	-	-	-	99.69%	0.31%	-	-	-
...	...					...					...					...				
2059	18.3	18.3	-	-	-	98.09%	1.91%	-	-	-	15.2	15.2	-	-	-	99.69%	0.31%	-	-	-
2060	18.3	18.3	-	-	-	98.09%	1.91%	-	-	-	15.2	15.2	-	-	-	99.69%	0.31%	-	-	-

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, e85, electricity, and hydrogen), to estimate additional fuel economy growth beyond the last model year covered during the main compliance modeling. For this analysis, the last year examined was 2025, and the growth rates are specified for model years between 2026 and 2060. Different growth rates are provided for the baseline alternative and the action alternatives.

Table 31. Overcompliance Data Worksheet (Sample)



Model Year	Baseline Growth Rates for Voluntary Overcompliance										Action Alternatives Growth Rates for Voluntary Overcompliance									
	Passenger Cars					Light Trucks					Passenger Cars					Light Trucks				
	Gasoline	Diesel	E85	Electricity	Hydrogen	Gasoline	Diesel	E85	Electricity	Hydrogen	Gasoline	Diesel	E85	Electricity	Hydrogen	Gasoline	Diesel	E85	Electricity	Hydrogen
1975																				
1976																				
...			...					...					...					...		
2024																				
2025																				
2026	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2027	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2028	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2029	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2030	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2031	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2032	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2033	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2034	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2035	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
...			...					...					...					...		
2059	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%
2060	0.90%	0.90%	0.90%	0.90%	0.90%	1.10%	1.10%	1.10%	1.10%	1.10%	0.80%	0.80%	0.80%	0.80%	0.80%	0.35%	0.35%	0.35%	0.35%	0.35%

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 32. EIS Tailpipe Emissions Worksheet (Sample for Gasoline - LDV only)

Vehicle Age	Gasoline - LDV (by Model Year)										
	1975	1976	1977	1978	1979	1980	1981	1982	…	2010	2011
1	30.68	30.68	30.68	30.48	30.22	15.49	17.30	17.45	…	1.15	1.74
2	34.85	34.85	34.85	34.62	34.33	21.49	22.53	22.25		1.47	1.75
3	42.14	42.14	42.14	41.91	41.56	28.10	25.40	25.38		1.84	1.77
4	48.75	48.75	48.75	48.48	48.30	26.46	29.82	29.94		2.24	1.78
5	55.51	55.51	55.51	54.98	44.75	26.92	33.50	33.60		2.63	3.00
6	61.64	61.64	61.64	50.58	44.57	28.07	37.12	37.25		2.99	3.03
7	56.27	56.27	56.27	49.70	46.10	30.34	40.40	40.61		3.34	3.61
8	54.77	54.77	54.77	50.81	48.16	33.22	43.61	34.98		3.67	3.64
9	55.39	55.39	55.39	52.68	50.49	36.17	37.21	37.33		3.98	3.94
10	57.16	57.16	57.16	55.02	52.97	32.90	39.38	39.50		4.28	3.98
11	59.31	59.31	59.31	57.40	53.07	35.34	41.32	41.44		4.56	4.90
12	61.66	61.66	61.66	57.23	55.47	37.72	42.30	32.22		4.84	4.95
13	60.98	60.98	60.98	59.21	57.49	39.66	32.46	32.67		5.11	5.01
14	62.85	62.85	62.85	61.19	59.38	32.00	32.78	32.86		5.36	5.07
15	64.94	64.94	64.94	63.15	58.82	33.56	32.91	32.94		5.61	5.14
16	67.00	67.00	67.00	62.42	60.80	34.87	33.33	33.63		5.86	5.74
17	66.15	66.15	66.15	64.32	62.21	36.23	34.03	34.34		6.10	5.82
18	67.98	67.98	67.98	65.81	63.53	37.86	34.75	35.06		6.34	5.91
19	69.50	69.50	69.50	67.03	65.36	39.54	35.47	35.72		6.57	5.99
20	70.96	70.96	70.96	69.16	67.36	41.28	36.19	36.50		6.80	6.09
21	73.92	73.92	73.92	72.05	70.20	44.05	36.99	37.27		7.03	6.91
22	76.97	76.97	76.97	75.04	73.66	46.49	37.80	38.08		7.26	7.02
23	80.12	80.12	80.12	78.68	76.74	49.30	38.64	38.51		7.49	7.13
24	83.97	83.97	83.97	81.92	80.22	52.28	39.21	39.26		7.72	7.24
25	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.34
26	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.44
27	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.53
28	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.61
29	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.67
30	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.70
31	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.70
32	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.70
33	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.70
34	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.70
35	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.70
36	78.90	78.90	78.90	77.79	76.98	51.21	42.97	42.36		7.96	7.70

Appendix B Model Outputs

The system produces eight types of formatted output files, all as Microsoft Excel workbooks. The system places all files in the "reports" folder, located in the user selected output path (ex: **C:\cafe\demo-run\demo\reports**). Table 33 lists the available output types and their contents. As discussed earlier, the first scenario appearing in the scenarios file is assigned to Scenario 0 and is treated as the baseline. Wherever applicable, output files for all other scenarios report absolute and relative changes compared to this baseline.[29]

Table 33. Output Files

Output File	Contents
Technology Utilization Summary (one per scenario)	Contains industry-wide technology application and penetration rates for each model year and technology analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
Industry Compliance Summary (one per scenario)	Contains industry-wide summary of compliance model results, where each worksheet tab represents a single model year analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
Industry Effects Summary (one per scenario)	Contains industry-wide summary of energy and emissions effects, where each worksheet tab represents a single model year analyzed.
Industry Effects Details (one per scenario)	Contains a more detailed view of industry-wide energy and emissions effects, where the results are disaggregated by regulatory class. Each worksheet tab represents a single model year analyzed.
Industry Societal Costs Details (one per scenario and societal cost)	Contains details of undiscounted and discounted industry-wide societal costs for each calendar and model year. The results are presented by regulatory class, as well as combined over the entire fleet. The system produces multiple individual output files for each socially valued owner and societal costs attribute.
Manufacturer Compliance Summary (one per scenario and manufacturer)	Contains manufacturer-level summary of compliance model results, where each worksheet tab represents a single model year analyzed. The results are disaggregated by regulatory class, as well as combined over the entire manufacturer's fleet. The system produces multiple individual output files for each manufacturer.
Vehicle Details Report (one per scenario)	Contains disaggregate vehicle-level summary of compliance model results.
Optimized Industry Report (one per optimization run)	Provides industry-wide and manufacturer-specific technology costs, fines, and benefits, as well as carbon dioxide and fuel savings, and benefit-cost ratios, for all iterations from industry optimization. This report also graphs the socially optimized functional form (aka, optimized shape) for the entire industry by model year, and displays benefit-cost, marginal benefit:cost, net benefits, and optimized shape charts.

The remainder of this section shows sample output files for a scenario based on reformed passenger automobile standards and reformed nonpassenger automobile standards. This scenario addresses model years spawning 17 years (2009-2025), however, only model year 2017 is displayed in most screenshots. The scenario assumes regulatory merging of all passenger automobiles into RC1 (domestic passenger autos), while nonpassenger automobiles are regulated

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[29] For example, if the baseline scenario involves a flat 27.5 mpg standard for passenger automobiles and Scenario 2 examines a reformed standard with a higher average required value of CAFE standard, Industry_Compliance_Summary_Sn2.xls might report total technology costs of $2.2b, of which about $2.0b might be attributable to the increase in the overall standard.

independently. Also, because the output files produced by the system are extensive, the text shows only portions of some files. Furthermore, although the system produces output specific to each represented vehicle model, only the more summarized output files are shown here.

B.1 Technology Utilization Summary

Table 34. Technology Utilization Summary (Sample)

Technolog Utilization Summary for the Industry (Scenario 2 -- Preferred Alternative)

Technology Penetration Rates for All Vehicles

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1. LUB1	48%	49%	52%	61%	60%	59%	63%	77%	81%	86%	86%	85%	85%	85%	85%	85%	85%
2. EFR1	8%	14%	23%	40%	52%	59%	66%	79%	84%	87%	89%	89%	89%	89%	89%	89%	90%
3. LUB2_EFR2	- %	- %	- %	- %	- %	- %	- %	- %	11%	20%	32%	42%	55%	62%	70%	76%	77%
4. CCPS	5%	5%	6%	7%	6%	6%	6%	7%	8%	8%	10%	10%	11%	11%	11%	11%	11%
5. DVVLS	8%	10%	10%	11%	12%	12%	11%	12%	13%	13%	13%	13%	13%	13%	13%	13%	12%
6. DEACS	2%	2%	3%	4%	4%	4%	4%	4%	4%	3%	3%	3%	1%	0%	0%	0%	0%
7. ICP	35%	33%	30%	25%	24%	22%	23%	15%	12%	9%	6%	5%	3%	2%	2%	2%	2%
8. DCP	24%	26%	30%	39%	42%	45%	47%	55%	60%	63%	65%	64%	67%	67%	67%	67%	65%
9. DVVLD	6%	7%	10%	14%	22%	29%	32%	36%	40%	44%	50%	51%	57%	61%	62%	63%	62%
10. CVVL	2%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
11. DEACD	0%	0%	1%	2%	1%	1%	2%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%
12. SGDI	7%	9%	12%	16%	22%	26%	28%	31%	34%	38%	46%	48%	59%	66%	69%	76%	76%
13. DEACO	5%	5%	5%	7%	7%	7%	9%	10%	8%	8%	7%	5%	4%	4%	3%	3%	2%
14. VVA	4%	5%	5%	5%	8%	9%	11%	11%	9%	9%	11%	10%	10%	9%	9%	9%	9%
15. SGDIO	0%	0%	0%	0%	1%	1%	2%	2%	2%	2%	3%	5%	6%	6%	6%	6%	6%
16. TRBDS1_SD	1%	1%	1%	1%	3%	3%	4%	5%	6%	7%	8%	8%	10%	8%	6%	5%	3%
17. TRBDS1_MD	2%	4%	7%	10%	16%	20%	22%	23%	24%	24%	28%	27%	29%	28%	23%	15%	11%
18. TRBDS1_LD	1%	1%	1%	1%	1%	1%	2%	2%	1%	1%	1%	1%	2%	2%	2%	2%	2%
19. TRBDS2_SD	- %	- %	- %	- %	- %	0%	0%	0%	1%	1%	3%	3%	3%	5%	5%	4%	4%
20. TRBDS2_MD	- %	- %	- %	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%
21. TRBDS2_LD	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %
22. CEGR1_SD	- %	- %	- %	- %	0%	1%	1%	1%	1%	2%	2%	4%	6%	11%	13%	19%	23%
23. CEGR1_MD	- %	- %	- %	0%	0%	0%	0%	2%	2%	4%	5%	8%	8%	10%	12%	19%	21%
24. CEGR1_LD	- %	- %	- %	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	- %	0%
25. CEGR2_SD	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	0%	1%	1%	1%	2%	3%	2%
26. CEGR2_MD	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	0%	0%	2%	3%	4%	5%	5%
27. CEGR2_LD	- %	- %	- %	- %	- %	- %	- %	- %	0%	1%	1%	2%	3%	4%	5%	5%	5%
28. ADSL_SD	- %	- %	- %	- %	- %	- %	- %	- %	- %	0%	1%	1%	2%	2%	2%	3%	3%
29. ADSL_MD	- %	- %	- %	- %	- %	- %	- %	- %	- %	1%	1%	2%	3%	3%	3%	3%	5%
30. ADSL_LD	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	0%	0%	0%
31. 6MAN	2%	2%	2%	2%	2%	2%	3%	3%	3%	2%	2%	1%	0%	0%	0%	- %	- %
32. HETRANSM	- %	- %	- %	- %	- %	- %	- %	- %	1%	1%	2%	3%	4%	4%	5%	6%	6%
33. IATC	30%	34%	37%	35%	27%	19%	14%	11%	8%	3%	3%	0%	0%	0%	0%	0%	- %
34. NAUTO	29%	32%	34%	32%	38%	29%	25%	21%	18%	12%	7%	3%	0%	0%	0%	0%	- %
35. DCT	3%	7%	12%	27%	37%	41%	41%	37%	33%	22%	14%	8%	3%	1%	0%	0%	- %
36. 8SPD	0%	0%	0%	0%	0%	12%	22%	32%	31%	31%	25%	20%	13%	12%	11%	10%	6%
37. HETRANS	- %	- %	- %	- %	- %	- %	- %	- %	8%	24%	39%	53%	60%	63%	63%	61%	62%
38. SHFTOPT	- %	- %	- %	- %	- %	- %	- %	- %	19%	36%	51%	63%	82%	89%	87%	85%	82%
39. EPS	26%	26%	29%	33%	36%	40%	45%	53%	54%	57%	63%	70%	80%	85%	89%	91%	91%
40. IACC1	31%	32%	34%	37%	38%	40%	45%	49%	53%	56%	58%	65%	79%	83%	86%	89%	91%
41. IACC2	- %	- %	- %	- %	- %	5%	12%	17%	25%	32%	43%	54%	65%	71%	79%	84%	86%
42. MHEV	1%	2%	2%	3%	2%	3%	3%	3%	5%	7%	12%	20%	26%	29%	33%	35%	33%
43. ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
44. SHEV1	3%	2%	2%	2%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	2%	2%
45. SHEV1_2	- %	- %	- %	- %	- %	- %	- %	- %	- %	0%	0%	0%	0%	0%	0%	0%	0%
46. SHEV2	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	0%	0%	0%	0%	3%	4%	6%
47. PHEV1	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	0%	0%	1%	2%	3%
48. PHEV2	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %
49. EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
50. EV2	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %
51. EV3	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %
52. EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
53. FCV	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %
54. MR1	4%	8%	15%	26%	34%	43%	49%	65%	69%	73%	75%	76%	76%	76%	76%	76%	75%
55. MR2	2%	2%	4%	7%	8%	10%	18%	25%	29%	41%	57%	62%	65%	66%	67%	67%	67%
56. MR3	1%	1%	1%	2%	2%	3%	8%	13%	13%	16%	18%	23%	26%	30%	34%	40%	45%
57. MR4	- %	- %	- %	- %	- %	0%	1%	2%	2%	3%	3%	5%	8%	9%	11%	14%	20%
58. MR5	- %	- %	- %	- %	- %	- %	- %	- %	0%	1%	1%	2%	3%	3%	5%	8%	14%
59. ROLL1	37%	42%	58%	70%	78%	81%	89%	95%	96%	98%	99%	100%	100%	100%	100%	100%	100%
60. ROLL2	0%	0%	0%	0%	0%	0%	0%	0%	18%	36%	52%	64%	76%	87%	89%	92%	92%
61. ROLL3	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %	- %
62. LDB	53%	51%	53%	57%	58%	60%	63%	71%	71%	72%	73%	76%	78%	81%	83%	84%	86%
63. SAX	0%	1%	1%	1%	4%	3%	4%	5%	5%	7%	7%	7%	8%	8%	9%	10%	12%
64. AERO1	21%	29%	47%	59%	68%	77%	87%	94%	95%	98%	100%	100%	100%	100%	100%	100%	100%
65. AERO2	- %	- %	4%	10%	22%	29%	38%	46%	50%	58%	73%	80%	88%	92%	92%	92%	92%

B.2 Industry Compliance Summary

Table 35. Industry Compliance Summary (Sample)

Compliance Summary for the Industry (Scenario 2, Model Year 2017)

Fuel Economy Standards by Regulatory Class

	Domestic Auto	Imported Auto	Light Trucks	Unregulated	Total
Prodcution for Sale	9,987,667	-	5,818,655	-	15,806,322
Value of Preliminary CAFE Standard (mpg)	39.97	-	29.41	-	35.30
Value of Final CAFE Standard (mpg)	39.97	-	29.41	-	35.30
Average Fuel Economy (mpg)	38.70	-	29.04	-	34.48
Average Fuel Economy (with AC; mpg)*	39.56	-	29.53	-	35.16
Average Curb Weight (lb.)	3,197	-	4,292	-	3,600
Average Area (sq. ft.)	45	-	54	-	48
Changes vs. Baseline					
Prodcution for Sale	-	-	-	-	-
Value of Preliminary CAFE Standard	*1.43*	-	*0.10*	-	*0.77*
Value of Final CAFE Standard	*1.43*	-	*0.10*	-	*0.77*
Average Fuel Economy	*1.46*	-	*0.25*	-	*0.87*
Average Fuel Economy (with AC)	*1.56*	-	*0.27*	-	*0.93*
Average Curb Weight	*-12*	-	*-11*	-	*-12*
Average Area	-	-	-	-	-

Revenue by Regulatory Class

	Domestic Auto	Imported Auto	Light Trucks	Unregulated	Total
Average Technology Costs (RPE)	$ 768.53	$ -	$ 826.29	$ -	$ 789.79
Average Fines Incurred (RPE)	$ 44.86	$ -	$ 8.47	$ -	$ 31.47
Average Price Increase Per Vehicle (RPE)	$ 811.81	$ -	$ 837.47	$ -	$ 821.26
Average Loss of Value to Consumer ($)	$ -	$ -	$ -	$ -	$ -
Total Incurred Technology Costs ($m)	$ 7,675.84	$ -	$ 4,807.87	$ -	$ 12,483.72
Total Fines Owed ($m)	$ 448.07	$ -	$ 49.30	$ -	$ 497.38
Total Increase in Sales Revenue ($m)	$ 8,108.12	$ -	$ 4,872.98	$ -	$ 12,981.10
Total Loss of Value to Consumer ($m)	$ -	$ -	$ -	$ -	$ -
Changes vs. Baseline					
Average Technology Costs	*$ 228.25*	*$ -*	*$ 44.23*	*$ -*	*$ 160.51*
Average Fines Incurred	*$ 12.56*	*$ -*	*$ 0.33*	*$ -*	*$ 8.06*
Average Price Increase Per Vehicle	*$ 240.36*	*$ -*	*$ 45.33*	*$ -*	*$ 168.57*
Average Loss of Value to Consumer	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*
Total Incurred Technology Costs	*$ 2,279.67*	*$ -*	*$ 257.36*	*$ -*	*$ 2,537.03*
Total Fines Owed	*$ 125.47*	*$ -*	*$ 1.90*	*$ -*	*$ 127.37*
Total Increase in Sales Revenue	*$ 2,400.66*	*$ -*	*$ 263.75*	*$ -*	*$ 2,664.41*
Total Loss of Value to Consumer	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*

Credit Transfers/Trading by Regulatory Class

	Domestic Auto	Imported Auto	Light Trucks	Unregulated	Total
Total Credits Earned (millions of vehicle-mpg)	33	-	10	-	43
Credits Transferred or Traded Out (m. veh-mpg)	-	-	-	-	-
Credits Transferred or Traded In (m. veh-mpg)	-	-	-	-	-
Changes vs. Baseline					
Total Credits Earned	*18*	-	*11*	-	*30*
Credits Transferred or Traded Out	-	-	-	-	-
Credits Transferred or Traded In	-	-	-	-	-

B.3 Industry Effects Summary

The summary of effects for each scenario is organized into sections. The first section presents calculated levels of energy consumed by fuel type (in MMBTU, 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 and average fuel economy levels are also presented to provide a basis for comparison.

The second section presents estimates of full fuel cycle carbon dioxide and criteria pollutant emissions by fuel type. As shown in Table 36 below, carbon dioxide emissions are reported in thousand 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).

The third section presents additional fatalities by safety class. Changes in fatalities, lifetime VMT, and average vehicle curb weight are shown for each safety class.

The third section of the effects summary presents monetized consumer and social costs and benefits of each scenario. These effects include the following:

- Pretax Fuel Expenditures: Savings in pretax cost to vehicle users of vehicle fuel.
- Fuel Tax Revenues: Reduction in total (federal and state) fuel tax revenues.
- Travel Value: The value derived from additional driving due to the “rebound effect”.
- Refueling Time Value: Savings in the value of vehicle occupants’ time during refueling.
- Loss of Value: Loss of value to consumer resulting from the reduction in travel range of electric vehicles.
- Petroleum Market Externalities: Reduction in costs of economic externalities resulting from crude petroleum imports.
- Congestion Costs: The additional cost of highway congestion from added driving due to the “rebound effect”.
- Accident Costs: Additional injury and damage costs of highway crashes.
- Noise Costs: The additional cost of highway noise from added driving due to the “rebound effect”.
- Fatality Costs: Additional costs resulting from fatal crashes, due to decreases in vehicle weight.
- Emissions Damage Costs: The change in damage costs from air pollutant emissions (by species).

In all cases, these costs and benefits 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-2003 dollars. The primary text discusses these types of costs and benefits in greater detail, and Appendix A (Model Inputs) discusses corresponding input assumptions.

Table 36. Industry Effects Summary (Sample)

Modeling Effects Summary for the Industry (Scenario 2, Model Year 2017)

Energy Consumption by Fuel Type

	Gasoline	Diesel	Ethanol-85	Electricity	Hydrogen	Total
Lifetime Energy Consumption (MMBTU)	14,052,029,420	20,187,790	146,900,998	3,677,267	-	14,222,795,475
Fuel Consumption (k gal.)	121,959,096	155,905	1,785,075	31,915	-	123,931,991
Electricity Use (mW-h)	-	-	-	1,077,745	-	1,077,745
Hydrogen Use (Mcf)	-	-	-	-	-	-
Lifetime VMT (k mi.)	3,404,703,811	4,456,934	22,828,494	6,361,400	-	3,438,350,639
Rated Fuel Economy (mpg)	34.90	35.73	15.99	284.74	-	34.68
On Road Fuel Economy (mpg)	27.92	28.59	12.79	199.32	-	27.74
Changes vs. Baseline						
Lifetime Energy Consumption	*-324,969,383*	*-63,392*	*72,922*	*-23,213*	-	*-324,983,066*
Fuel Consumption	*-2,820,445*	*-490*	*886*	*-201*	-	*-2,820,250*
Electricity Use	-	-	-	*-6,803*	-	*-6,803*
Hydrogen Use	-	-	-	-	-	-
Lifetime VMT	*12,698,514*	*1,893*	*21,009*	*777*	-	*12,722,193*
Rated Fuel Economy	*0.92*	*0.13*	*0.01*	*1.82*	-	*0.90*
On Road Fuel Economy	*0.73*	*0.10*	*0.01*	*1.27*	-	*0.72*

Emissions by Fuel Type

	Gasoline	Diesel	Ethanol-85	Electricity	Hydrogen	Total
Carbon Dioxide (mmT)	1,331	2	16	1	-	1,350
Carbon Monoxide (tons)	15,283,602	17,419	448,526	275	-	15,749,822
Volatile Organic Compounds (tons)	740,904	449	15,170	13	-	756,536
Nitrous Oxides (tons)	807,359	1,753	15,940	494	-	825,546
Particulate Matter (tons)	65,541	66	486	74	-	66,168
Sulfur Oxides (tons)	146,497	176	725	884	-	148,281
Changes vs. Baseline						
Carbon Dioxide	*-31*	*-0*	*0*	*-0*	-	*-31*
Carbon Monoxide	*52,185*	*7*	*422*	*-2*	-	*52,613*
Volatile Organic Compounds	*-6,354*	*-0*	*13*	*-0*	-	*-6,341*
Nitrous Oxides	*-2,970*	*-0*	*14*	*-3*	-	*-2,959*
Particulate Matter	*-425*	*-0*	*0*	*-0*	-	*-425*
Sulfur Oxides	*-3,388*	*-1*	*0*	*-6*	-	*-3,394*

Fatalities by Vehicle Type

				Changes vs. Baseline		
	Cars	**CUVs/Minivans**	**Trucks/SUVs**	*Cars*	*CUVs/Minivans*	*Trucks/SUVs*
Changes in Fatalities	61.45	-54.93	-2.74	*4.07*	*-8.67*	*5.38*
Lifetime VMT (k mi.)	1,714,185,957	907,783,948	816,380,734	*8,907,630*	*2,804,266*	*1,010,297*
Average Curb Weight (lbs.)	3,144	3,874	4,427	*-5*	*-28*	*-10*

Owner and Societal Costs (k $)

			Changes vs. Baseline	
	Undiscounted	**Discounted**	*Undiscounted*	*Discounted*
Consumer Valued Costs				
Retail Fuel Costs	431,570,873	275,370,728	*-9,834,544*	*-6,361,524*
Travel Value	-70,254	-45,203	*-70,254*	*-45,203*
Refueling Time Value	-455,254	-299,800	*-455,254*	*-299,800*
Loss of Value	-	-	-	-
Total Consumer Costs	431,045,365	275,025,726	*-10,360,051*	*-6,706,526*
Socially Valued Costs				
Lifetime Pretax Fuel Expenditures	385,061,843	310,377,240	*-8,771,396*	*-7,123,855*
Fuel Tax Revenues	46,509,030	38,010,578	*-1,063,147*	*-875,841*
Travel Value	-70,254	-57,076	*-70,254*	*-57,076*
Refueling Time Value	-455,254	-373,607	*-455,254*	*-373,607*
Loss of Value	-	-	-	-
Petroleum Market Externalities	20,235,282	16,455,843	*-466,823*	*-382,297*
Congestion Costs	180,804,385	147,530,664	*684,300*	*560,567*
Accident Costs	86,757,848	70,641,318	*313,232*	*256,180*
Noise Costs	3,438,351	2,802,692	*12,722*	*10,414*
Fatality Costs	23,922	30,411	*4,940*	*4,696*
Emissions				
Carbon Dioxide	40,781,944	32,440,110	*-924,135*	*-741,877*
Carbon Monoxide	-	-	-	-
Volatile Organic Compounds	1,210,458	921,357	*-10,146*	*-8,502*
Nitrous Oxides	5,448,607	4,161,547	*-19,530*	*-16,823*
Particulate Matter	19,850,409	15,277,063	*-127,496*	*-107,027*
Sulfur Oxides	5,782,978	4,703,278	*-132,354*	*-108,391*
Subtotals				
Retail Fuel Costs	431,570,873	348,387,817	*-9,834,544*	*-7,999,695*
Total Social Costs	748,870,518	604,910,839	*-9,962,195*	*-8,087,596*

B.4 Industry Effects Details

Table 37. Industry Effects Details (Sample)

Modeling Effects Details for the Industry (Scenario 2, Model Year 2017)

Energy Consumption by Fuel Type and Regulatory Class

					Changes vs. Baseline			
	Domestic Auto	**Imported Auto**	**Light Trucks**	**Unregulated**	*Domestic Auto*	*Imported Auto*	*Light Trucks*	*Unregulated*
Energy Consumption for Gasoline								
Energy Consumption (MMBTU)	7,433,169,914	-	6,618,859,507	-	*-270,094,583*	-	*-54,874,800*	-
Fuel Consumption (k gal.)	64,513,292	-	57,445,803	-	*-2,344,180*	-	*-476,264*	-
Lifetime VMT (k mi.)	2,042,449,733	-	1,362,254,078	-	*10,971,766*	-	*1,726,748*	-
Rated Fuel Economy (mpg)	39.57	-	29.64	-	*1.59*	-	*0.28*	-
On Road Fuel Economy (mpg)	31.66	-	23.71	-	*1.27*	-	*0.22*	-
Energy Consumption for Diesel								
Energy Consumption (MMBTU)	3,526,655	-	16,661,135	-	*0*	-	*0*	-
Fuel Consumption (k gal.)	27,235	-	128,669	-	*-21*	-	*-469*	-
Lifetime VMT (k mi.)	977,896	-	3,479,038	-	*108*	-	*1,785*	-
Rated Fuel Economy (mpg)	44.88	-	33.80	-	*0.04*	-	*0.14*	-
On Road Fuel Economy (mpg)	35.91	-	27.04	-	*0.03*	-	*0.11*	-
Energy Consumption for Ethanol-85								
Energy Consumption (MMBTU)	30,603,435	-	116,297,563	-	*-694*	-	*73,616*	-
Fuel Consumption (k gal.)	371,879	-	1,413,196	-	*-8*	-	*895*	-
Lifetime VMT (k mi.)	5,965,067	-	16,863,428	-	*3,823*	-	*17,187*	-
Rated Fuel Economy (mpg)	20.05	-	14.92	-	*0.01*	-	*0.01*	-
On Road Fuel Economy (mpg)	16.04	-	11.93	-				
Energy Consumption for Electricity								
Energy Consumption (MMBTU)	3,677,267	-	-	-	*-23,213*	-	-	-
Fuel Consumption (k GEG)	31,915	-	-	-	*-201*	-	-	-
Electricity Use (mW-h)	1,077,745	-	-	-	*-6,803*	-	-	-
Lifetime VMT (k mi.)	6,361,400	-	-	-	*777*	-	-	-
Rated Fuel Economy (mi/GEG)	284.74	-	-	-	*1.82*	-	-	-
On Road Fuel Economy (mi/GEG)	199.32	-	-	-	*1.27*	-	-	-
Energy Consumption for Hydrogen								
Energy Consumption (MMBTU)	-	-	-	-	-	-	-	-
Fuel Consumption (k GEG)	-	-	-	-	-	-	-	-
Hydrogen Use (Mcf)	-	-	-	-	-	-	-	-
Lifetime VMT (k mi.)	-	-	-	-	-	-	-	-
Rated Fuel Economy (mi/GEG)	-	-	-	-	-	-	-	-
On Road Fuel Economy (mi/GEG)	-	-	-	-	-	-	-	-

Emissions by Fuel Type and Regulatory Class

					Changes vs. Baseline			
	Domestic Auto	**Imported Auto**	**Light Trucks**	**Unregulated**	*Domestic Auto*	*Imported Auto*	*Light Trucks*	*Unregulated*
Emissions from Gasoline Use								
Carbon Dioxide (mmT)	704	-	627	-	*-26*	-	*-5*	-
Carbon Monoxide (tons)	8,209,965	-	7,073,637	-	*43,496*	-	*8,689*	-
Volatile Organic Compounds (tons)	393,536	-	347,368	-	*-5,280*	-	*-1,074*	-
Nitrous Oxides (tons)	415,512	-	391,847	-	*-2,495*	-	*-475*	-
Particulate Matter (tons)	32,785	-	32,756	-	*-357*	-	*-68*	-
Sulfur Oxides (tons)	77,493	-	69,004	-	*-2,816*	-	*-572*	-
Emissions from Diesel Use								
Carbon Dioxide (mmT)	0	-	2	-	*-0*	-	*-0*	-
Carbon Monoxide (tons)	3,027	-	14,392	-	*0*	-	*7*	-
Volatile Organic Compounds (tons)	73	-	376	-	*-0*	-	*-0*	-
Nitrous Oxides (tons)	283	-	1,471	-	*-0*	-	*-0*	-
Particulate Matter (tons)	10	-	56	-	*-0*	-	*-0*	-
Sulfur Oxides (tons)	31	-	145	-	*-0*	-	*-1*	-
Emissions from Ethanol-85 Use								
Carbon Dioxide (mmT)	3	-	13	-	*-0*	-	*0*	-
Carbon Monoxide (tons)	102,099	-	346,427	-	*66*	-	*356*	-
Volatile Organic Compounds (tons)	2,503	-	12,667	-	*1*	-	*12*	-
Nitrous Oxides (tons)	2,332	-	13,609	-	*1*	-	*13*	-
Particulate Matter (tons)	116	-	370	-	*0*	-	*0*	-
Sulfur Oxides (tons)	151	-	574	-	*-0*	-	*0*	-
Emissions from Electricity Use								
Carbon Dioxide (mmT)	1	-	-	-	*-0*	-	-	-
Carbon Monoxide (tons)	275	-	-	-	*-2*	-	-	-
Volatile Organic Compounds (tons)	13	-	-	-	*-0*	-	-	-
Nitrous Oxides (tons)	494	-	-	-	*-3*	-	-	-
Particulate Matter (tons)	74	-	-	-	*-0*	-	-	-
Sulfur Oxides (tons)	884	-	-	-	*-6*	-	-	-
Emissions from Hydrogen Use								
Carbon Dioxide (mmT)	-	-	-	-	-	-	-	-
Carbon Monoxide (tons)	-	-	-	-	-	-	-	-
Volatile Organic Compounds (tons)	-	-	-	-	-	-	-	-
Nitrous Oxides (tons)	-	-	-	-	-	-	-	-
Particulate Matter (tons)	-	-	-	-	-	-	-	-
Sulfur Oxides (tons)	-	-	-	-	-	-	-	-

B.5 Industry Societal Costs Details

Table 38. Industry Societal Costs Details (Sample for Total Social Costs)

Total Social Costs Details for the Industry (Scenario 2 -- Preferred Alternative)

Undiscounted Total Social Costs for All Vehicles (b $)

MY:	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
CY: 2009	29.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	32.3	36.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	32.4	36.6	43.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	31.7	36.2	43.0	50.7	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	31.5	36.0	43.1	50.7	56.0	-	-	-	-	-	-	-	-	-	-	-	-
2014	30.6	35.5	42.4	50.4	55.5	55.5	-	-	-	-	-	-	-	-	-	-	-
2015	29.7	34.6	41.9	49.7	55.3	55.1	57.0	-	-	-	-	-	-	-	-	-	-
2016	28.2	33.2	40.4	48.7	54.1	54.4	56.2	57.3	-	-	-	-	-	-	-	-	-
2017	26.8	31.7	39.1	47.2	53.2	53.5	55.7	56.7	56.2	-	-	-	-	-	-	-	-
2018	25.1	30.0	37.2	45.5	51.4	52.5	54.6	56.1	55.5	55.2	-	-	-	-	-	-	-
2019	23.3	28.0	35.0	43.1	49.4	50.6	53.4	54.8	54.8	54.3	54.7	-	-	-	-	-	-
2020	21.1	26.0	32.8	40.7	46.8	48.6	51.5	53.6	53.5	53.6	53.9	55.7	-	-	-	-	-
2021	18.4	23.5	30.4	38.0	44.1	46.0	49.4	51.6	52.3	52.3	53.0	54.7	56.2	-	-	-	-
2022	15.7	20.6	27.6	35.4	41.4	43.6	47.0	49.8	50.6	51.4	52.0	54.1	55.5	57.4	-	-	-
2023	13.2	17.5	24.0	31.9	38.3	40.7	44.2	47.1	48.4	49.4	50.8	52.8	54.6	56.4	58.1	-	-
2024	11.1	14.8	20.5	27.9	34.8	37.8	41.5	44.5	46.1	47.5	49.0	51.7	53.5	55.7	57.3	59.2	-
2025	9.3	12.5	17.3	23.8	30.3	34.2	38.5	41.6	43.4	45.1	47.1	49.9	52.3	54.4	56.5	58.2	60.5
2026	7.7	10.5	14.6	20.0	25.7	29.7	34.8	38.6	40.6	42.5	44.6	47.8	50.4	53.1	55.1	57.3	59.5
2027	6.4	8.7	12.2	17.0	21.7	25.3	30.3	35.0	37.8	39.8	42.2	45.4	48.4	51.3	54.0	56.1	58.7
2028	5.3	7.2	10.2	14.2	18.3	21.3	25.7	30.3	34.1	36.9	39.4	42.8	45.9	49.2	52.0	54.8	57.2
2029	4.5	6.0	8.5	11.8	15.3	18.0	21.6	25.8	29.6	33.4	36.6	40.1	43.3	46.7	50.0	52.9	56.1
2030	3.8	5.1	7.0	9.7	12.7	14.9	18.1	21.5	25.0	28.8	32.9	37.0	40.3	43.8	47.1	50.4	53.7
2031	3.2	4.3	5.8	8.0	10.4	12.3	15.0	18.0	20.7	24.2	28.2	33.1	37.1	40.6	44.1	47.4	51.1
2032	2.7	3.6	4.9	6.7	8.6	10.1	12.3	14.8	17.3	20.1	23.7	28.4	33.2	37.4	40.9	44.4	48.1
2033	2.3	3.1	4.1	5.6	7.2	8.3	10.1	12.2	14.3	16.8	19.7	23.9	28.5	33.5	37.7	41.2	45.0
2034	2.0	2.6	3.6	4.7	6.0	6.9	8.3	10.0	11.7	13.9	16.5	19.9	24.0	28.8	33.8	38.1	41.9
2035	1.5	2.2	3.0	4.1	5.1	5.8	7.0	8.2	9.6	11.4	13.6	16.6	20.0	24.2	29.0	34.1	38.6
2036	1.4	1.8	2.6	3.4	4.3	4.9	5.8	6.9	7.9	9.3	11.1	13.7	16.6	20.1	24.4	29.3	34.6
2037	1.2	1.6	2.0	3.0	3.7	4.2	4.9	5.8	6.6	7.6	9.1	11.2	13.7	16.7	20.2	24.6	29.7
2038	1.1	1.4	1.8	2.3	3.2	3.5	4.2	4.8	5.5	6.4	7.5	9.1	11.2	13.8	16.8	20.4	24.9
2039	0.9	1.2	1.6	2.1	2.5	3.0	3.5	4.1	4.6	5.3	6.2	7.5	9.1	11.2	13.8	16.9	20.6
2040	0.8	1.1	1.4	1.8	2.2	2.4	3.0	3.5	3.9	4.4	5.2	6.2	7.5	9.2	11.3	13.9	17.1
2041	0.7	0.9	1.2	1.6	1.9	2.1	2.3	3.0	3.3	3.8	4.3	5.2	6.2	7.5	9.2	11.3	14.0
2042	0.6	0.8	1.1	1.4	1.7	1.8	2.1	2.3	2.8	3.2	3.7	4.3	5.2	6.2	7.5	9.2	11.5
2043	0.5	0.7	0.9	1.2	1.5	1.6	1.8	2.0	2.2	2.7	3.1	3.7	4.3	5.2	6.2	7.5	9.3
2044	0.5	0.6	0.8	1.1	1.3	1.4	1.6	1.8	1.9	2.1	2.7	3.1	3.6	4.3	5.2	6.2	7.6
2045	-	0.5	0.7	0.9	1.1	1.2	1.4	1.6	1.7	1.8	2.0	2.6	3.1	3.6	4.3	5.2	6.3
2046	-	-	0.6	0.8	1.0	1.1	1.2	1.4	1.5	1.6	1.8	2.0	2.6	3.1	3.6	4.3	5.2
2047	-	-	-	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.6	3.0	3.6	4.3
2048	-	-	-	-	0.7	0.8	0.9	1.1	1.1	1.2	1.4	1.5	1.7	2.0	2.6	3.0	3.7
2049	-	-	-	-	-	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.7	1.9	2.6	3.1
2050	-	-	-	-	-	-	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.6
2051	-	-	-	-	-	-	-	0.7	0.8	0.8	0.9	1.0	1.2	1.3	1.5	1.7	1.9
2052	-	-	-	-	-	-	-	-	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.5	1.7
2053	-	-	-	-	-	-	-	-	-	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.5
2054	-	-	-	-	-	-	-	-	-	-	0.6	0.7	0.8	0.9	1.0	1.2	1.3
2055	-	-	-	-	-	-	-	-	-	-	-	0.6	0.7	0.8	0.9	1.0	1.2
2056	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.7	0.8	0.9	1.0
2057	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.7	0.8	0.9
2058	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.7	0.8
2059	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.7
2060	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6
2061	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2062	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2063	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2064	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2066	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2067	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2068	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2069	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2070+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	457.1	517.3	606.9	705.9	767.6	754.9	767.5	769.3	748.9	731.6	722.6	732.3	738.1	747.9	755.5	763.7	776.5

Table 39. Industry Societal Costs Details (Sample for Retail Fuel Costs)

Retail Fuel Costs Details for the Industry (Scenario 2 -- Preferred Alternative)

Undiscounted Retail Fuel Costs for All Vehicles (b $)

MY:	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
CY: 2009	17.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	19.2	21.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	19.5	22.1	26.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	19.0	21.7	25.4	29.5	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	19.2	22.0	26.1	30.2	32.8	-	-	-	-	-	-	-	-	-	-	-	-
2014	18.9	21.8	25.9	30.3	32.8	32.3	-	-	-	-	-	-	-	-	-	-	-
2015	18.3	21.3	25.6	30.1	32.8	32.3	33.0	-	-	-	-	-	-	-	-	-	-
2016	17.5	20.5	24.8	29.4	32.2	32.0	32.6	32.9	-	-	-	-	-	-	-	-	-
2017	16.6	19.7	24.0	28.7	31.8	31.7	32.6	32.8	32.1	-	-	-	-	-	-	-	-
2018	15.7	18.6	22.9	27.6	30.8	31.0	32.1	32.5	31.8	31.1	-	-	-	-	-	-	-
2019	14.5	17.5	21.6	26.3	29.6	30.0	31.3	31.9	31.5	30.8	30.4	-	-	-	-	-	-
2020	13.2	16.2	20.3	24.8	28.2	28.9	30.3	31.2	30.9	30.5	30.0	30.6	-	-	-	-	-
2021	11.4	14.6	18.7	23.1	26.4	27.3	28.9	29.9	30.0	29.7	29.5	30.0	30.3	-	-	-	-
2022	9.9	12.9	17.1	21.5	24.9	25.9	27.7	28.9	29.2	29.2	29.1	29.9	30.1	30.8	-	-	-
2023	8.3	11.0	14.9	19.4	22.9	24.1	26.0	27.4	27.9	28.0	28.3	29.1	29.6	30.2	30.9	-	-
2024	7.0	9.3	12.8	17.1	20.9	22.4	24.4	25.9	26.6	27.0	27.5	28.5	29.2	30.1	30.6	31.2	-
2025	5.9	7.8	10.8	14.6	18.2	20.3	22.5	24.2	25.0	25.6	26.3	27.5	28.4	29.3	30.2	30.7	31.5
2026	4.9	6.6	9.1	12.3	15.6	17.7	20.4	22.4	23.4	24.1	24.9	26.3	27.3	28.6	29.5	30.3	31.1
2027	4.1	5.5	7.7	10.4	13.2	15.2	17.9	20.4	21.7	22.7	23.6	25.1	26.4	27.7	28.9	29.8	30.8
2028	3.4	4.6	6.4	8.7	11.1	12.8	15.2	17.7	19.6	20.9	22.0	23.6	24.9	26.5	27.8	28.9	30.1
2029	2.9	3.9	5.3	7.3	9.3	10.8	12.9	15.1	17.2	19.0	20.4	22.2	23.6	25.3	26.8	28.0	29.4
2030	2.4	3.2	4.4	6.0	7.7	8.9	10.6	12.6	14.4	16.3	18.2	20.2	21.8	23.4	25.0	26.4	28.0
2031	2.0	2.7	3.6	5.0	6.3	7.3	8.8	10.4	12.0	13.7	15.7	18.1	19.9	21.7	23.3	24.8	26.5
2032	1.7	2.3	3.1	4.1	5.2	6.0	7.3	8.6	9.9	11.4	13.2	15.6	17.8	19.9	21.6	23.2	24.9
2033	1.5	1.9	2.6	3.5	4.3	5.0	6.0	7.1	8.2	9.5	11.0	13.1	15.3	17.8	19.8	21.5	23.2
2034	1.3	1.6	2.2	2.9	3.7	4.1	4.9	5.9	6.8	7.9	9.1	10.9	12.9	15.3	17.8	19.7	21.6
2035	1.0	1.4	1.9	2.5	3.1	3.5	4.1	4.8	5.6	6.5	7.6	9.1	10.8	12.9	15.3	17.7	19.8
2036	0.9	1.1	1.6	2.1	2.6	2.9	3.4	4.0	4.6	5.3	6.2	7.5	8.9	10.8	12.9	15.2	17.8
2037	0.8	1.0	1.3	1.8	2.2	2.5	2.9	3.4	3.8	4.4	5.1	6.2	7.4	8.9	10.7	12.8	15.3
2038	0.7	0.9	1.1	1.5	1.9	2.1	2.5	2.8	3.2	3.6	4.2	5.0	6.1	7.3	8.9	10.7	12.9
2039	0.6	0.8	1.0	1.3	1.5	1.8	2.1	2.4	2.7	3.0	3.5	4.1	5.0	6.0	7.3	8.8	10.7
2040	0.5	0.7	0.9	1.1	1.3	1.4	1.8	2.0	2.3	2.5	2.9	3.4	4.1	4.9	6.0	7.3	8.8
2041	0.5	0.6	0.8	1.0	1.2	1.3	1.4	1.8	1.9	2.2	2.4	2.9	3.4	4.0	4.9	5.9	7.3
2042	0.4	0.5	0.7	0.9	1.0	1.1	1.2	1.4	1.7	1.8	2.1	2.4	2.8	3.3	4.0	4.9	6.0
2043	0.4	0.5	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.6	1.7	2.0	2.3	2.8	3.3	4.0	4.9
2044	0.3	0.4	0.5	0.7	0.8	0.9	1.0	1.1	1.1	1.2	1.5	1.7	2.0	2.3	2.7	3.3	4.0
2045	-	0.4	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.5	1.7	2.0	2.3	2.7	3.3
2046	-	-	0.4	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1.0	1.1	1.4	1.7	1.9	2.3	2.7
2047	-	-	-	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.4	1.6	1.9	2.3
2048	-	-	-	-	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.4	1.6	1.9
2049	-	-	-	-	-	0.4	0.5	0.6	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.4	1.6
2050	-	-	-	-	-	-	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	1.0	1.4
2051	-	-	-	-	-	-	-	0.4	0.5	0.5	0.5	0.6	0.7	0.7	0.8	0.9	1.0
2052	-	-	-	-	-	-	-	-	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.9
2053	-	-	-	-	-	-	-	-	-	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8
2054	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.4	0.5	0.6	0.6	0.7
2055	-	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.4	0.5	0.6	0.6
2056	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.4	0.4	0.5	0.5
2057	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.4	0.4	0.5
2058	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.4	0.4
2059	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.4
2060	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3
2061	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2062	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2063	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2064	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2066	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2067	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2068	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2069	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2070+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	281.6	319.3	372.4	428.3	459.8	447.4	450.5	447.4	431.6	415.5	403.3	403.3	399.9	401.5	401.6	401.2	403.8

B.6 Manufacturer Compliance Summary

The Manufacturer Compliance Summary output file is identical in structure to the Industry Compliance Summary. To protect potential manufacturer Confidential Business Information, a sample of this output file is not provided.

B.7 Vehicles Report

For each included scenario, the model produces an output file providing results at the level of individual vehicle model types specified in the market data input file. This vehicle-level report includes separate worksheets (tabs) for each model year, each containing the following information:

Table 40. Vehicles Report (Contents)

Group	Column	Contents
No.		Unique vehicle ID per manufacturer.
Manufacturer		The manufacturer of the vehicle.
Model		Name of the vehicle model.
Name Plate		The nameplate of the vehicle.
Engine	No.	ID number of the vehicle's engine.
	Fuel	Engine fuel type.
	Type	Engine type (configuration, cylinders, displacement).
	HP	Engine horsepower.
Transmission	ID#	ID number of the vehicle's transmission.
	Type	Type of the transmission.
Fuel Econ. (mpg)	Initial (mpg)	Initial fuel economy.
	Initial (fuel)	Initial fuel type of the vehicle.
	Final (mpg)	Final fuel economy.
	Final (mpg-AC)	Final fuel economy, with AC adjustment.
	Final	Final fuel type of the vehicle.
Regulatory Classification	Reg Class	The regulatory class assignment of the vehicle.
	Technology Class	The technology class of the vehicle.
	Safety Class	The safety class of the vehicle.
Redesign State		Redesign state of the vehicle.
Refresh State		Refresh state of the vehicle.
Total Sales	Initial	Initial sales volume (units).
	Final	Final sales volume (units).
MSRP ($)	Initial	Initial MSRP ($).
	Final	Intial Price ($).
Curb Weight (lb)	Initial	Initial curb weight.
	Final	Final curb weight.
Area (sf)		Vehicle footprint.
Unit Costs ($)	Incurred Tech Cost	Unit technology cost ($).
	Price Increase	Unit price increase ($).
	Loss Of Value	Unit loss of value to consumer ($).
Total Costs ($k)	Incurred Tech Cost	Total technology cost ($k).
	Increase in Sales Rev.	Total increase in revenue ($k).
	Loss Of Value	Total loss of value to consumer ($k).
Technology Utilization/Applicability		Usage of each technology by the vehicle.

B.8 Optimized Industry Report

Appendix C (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 range, estimating corresponding costs, fuel savings, CO2 emission reductions, and benefits at each iteration. Table 41 shows a sample of industry-level reporting. Average required CAFE levels for each iteration are shown in the "Standards" section, with resultant average achieved fuel economy levels shown under "CAFE", and resultant incremental costs (relative to the baseline standards) shown under "Tech Costs". Estimated optimal stringencies (e.g., for MY2017, index number 56, producing an average required CAFE of 42.6 mpg) are shown in the "Optimized" section.

Table 41. Optimized Industry Report - Data (Sample)

Optimized	A	B	C	D	E	F	G	H	Stnd	Index
2009	27.5									
2010	27.5									
2011	31.2	24.0	51.4	1.9						
2012	35.9	27.9	0.0	0.0						
2013	36.8	28.5	0.0	0.0						
2014	37.8	29.0	0.0	0.0						
2015	39.2	29.9	0.0	0.0						
2016	41.1	31.0	0.0	0.0						
2017	46.4	34.9	0.0	0.0	41.1	31.0	0.0	0.0	42.6	56
2018	48.5	36.5	0.0	0.0	41.1	31.0	0.0	0.0	44.6	65
2019	49.7	37.5	0.0	0.0	41.1	31.0	0.0	0.0	45.7	70
2020	51.0	38.4	0.0	0.0	41.1	31.0	0.0	0.0	46.8	75
2021	51.5	38.8	0.0	0.0	41.1	31.0	0.0	0.0	47.3	77
2022	51.8	39.0	0.0	0.0	41.1	31.0	0.0	0.0	47.6	78
2023	52.3	39.4	0.0	0.0	41.1	31.0	0.0	0.0	48.0	80
2024	53.1	40.0	0.0	0.0	41.1	31.0	0.0	0.0	48.8	83
2025	53.6	40.4	0.0	0.0	41.1	31.0	0.0	0.0	49.3	85

Standards	0	1	2	3	4	5	6	7	8	9
2009										
2010										
2011										
2012										
2013										
2014										
2015										
2016										
2017	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
2018	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
2019	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
2020	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6
2021	39.7	39.7	39.7	39.7	39.7	39.7	39.7	39.7	39.7	39.7
2022	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
2023	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3
2024	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7
2025	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3

CAFE										
2009										
2010										
2011										
2012										
2013										
2014										
2015										
2016										
2017	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
2018	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5
2019	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5
2020	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6
2021	46.8	46.8	46.8	46.8	46.8	46.8	46.8	46.8	46.8	46.8
2022	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3
2023	47.5	47.5	47.5	47.5	47.5	47.5	47.5	47.5	47.5	47.5
2024	47.9	47.9	47.9	47.9	47.9	47.9	47.9	47.9	47.9	47.9
2025	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8

The optimized industry report also produces graphs of numerous measures (e.g., incremental costs, incremental benefits) versus stringency. Figure 8 below shows a sample graph in which net benefits (relative to baseline standards) are plotted versus average required CAFE levels for each model year during MY2009-2025.

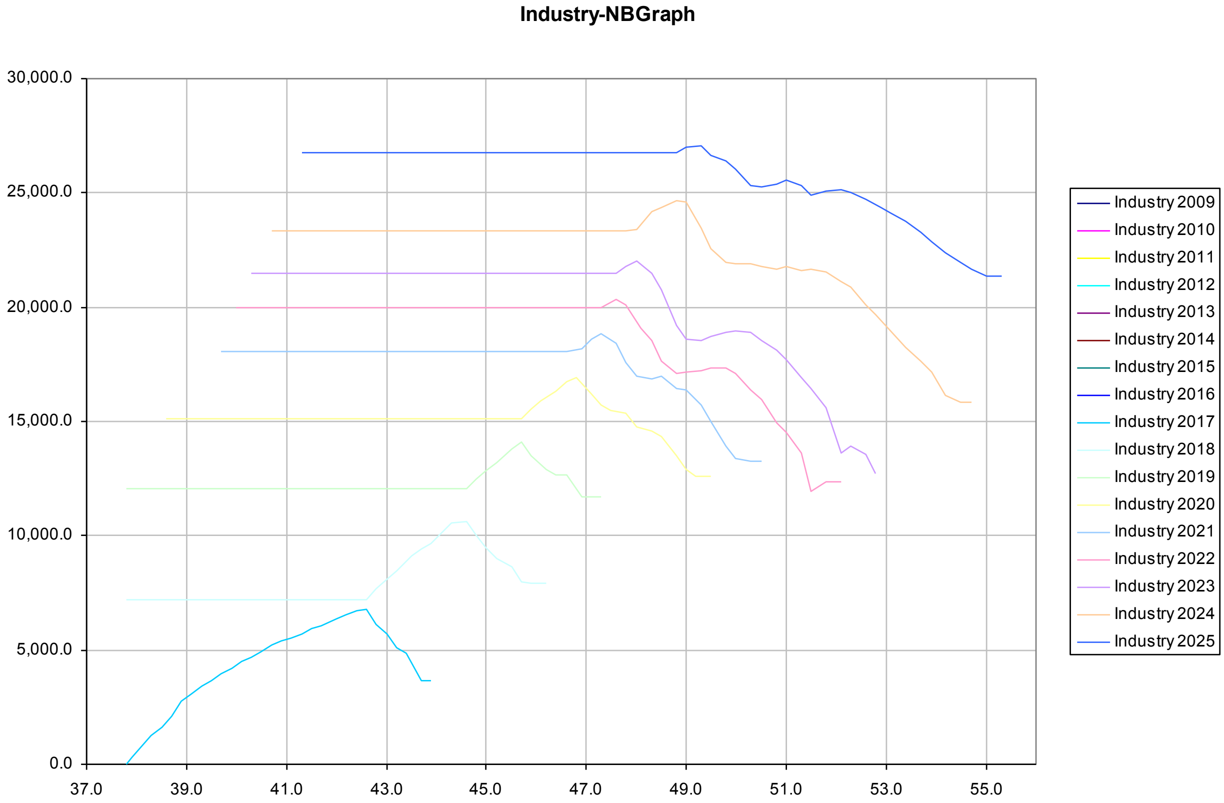

Figure 8. Optimized Industry Report - Net Benefits Graph (Sample)

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 technology costs, fines owed, benefits, fuel savings, and benefit-cost ratios 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 9 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.

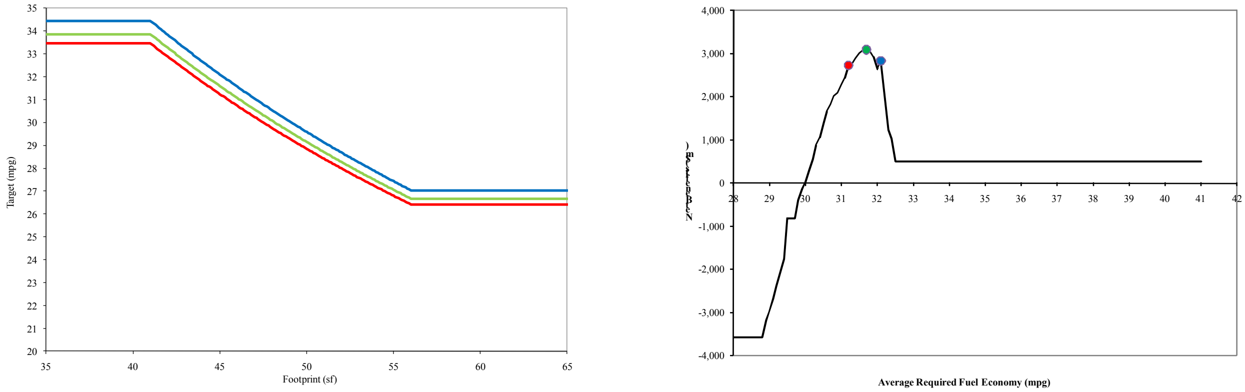

Figure 9. Maximizing Net Benefits

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 standard (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 10 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.

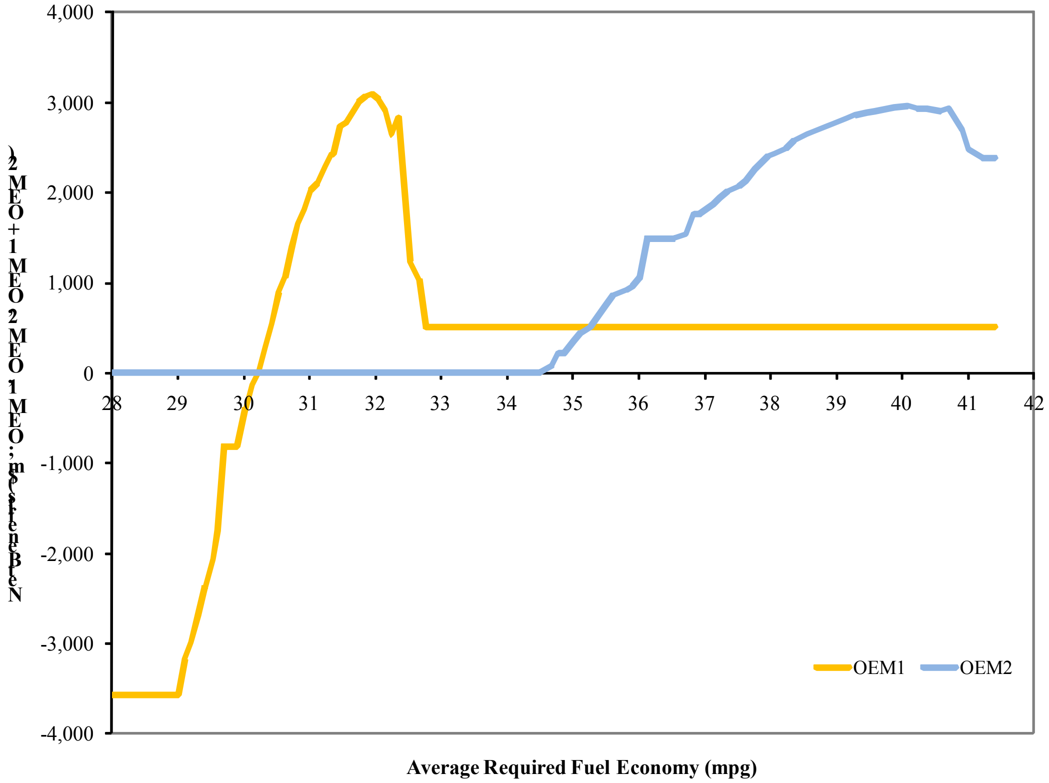

Figure 10. Net Benefits versus Stringency for Hypothetical 2-Manufacturer Fleet

Figure 11 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.

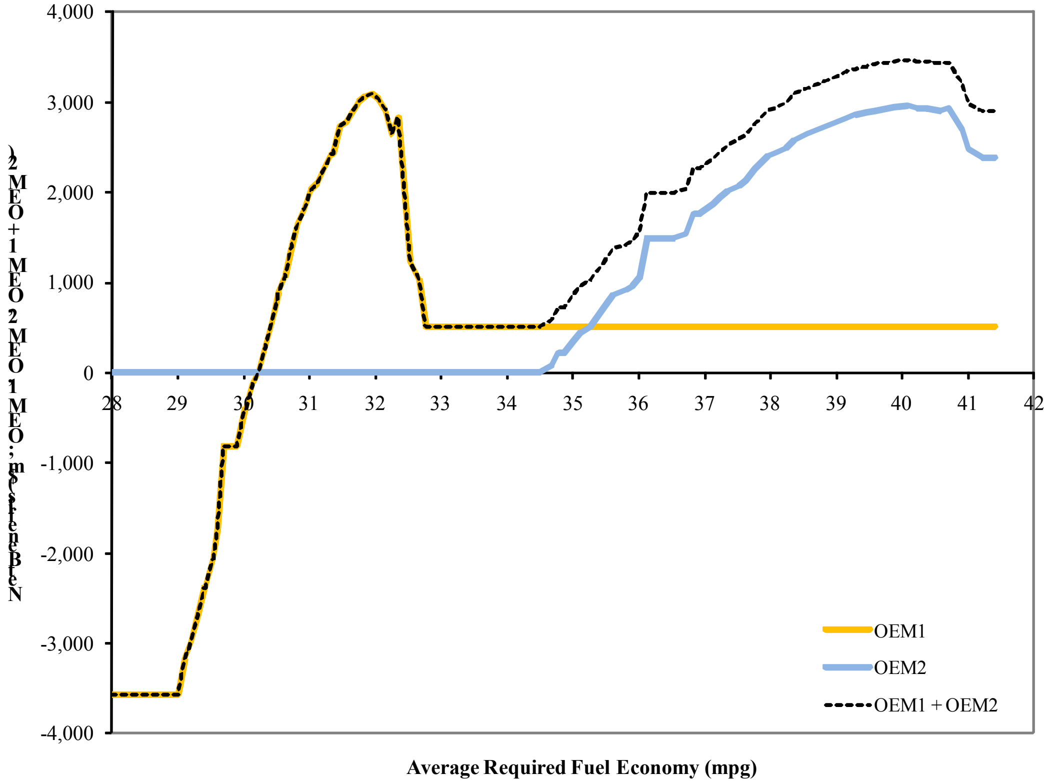

Figure 11. Sum of Net Benefits Attributable to OEM1 and OEM2

For the same hypothetical fleet, Figure 12 demonstrates the effect of selecting the "Merge the fleet before optimizing" 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.

---

[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.

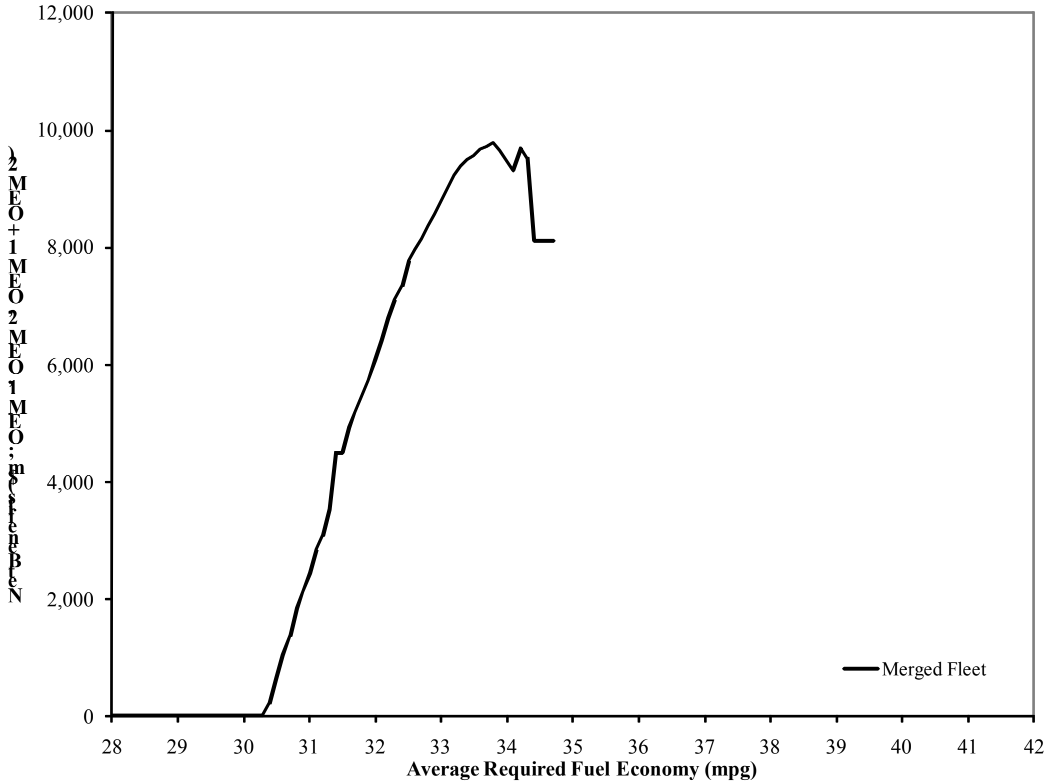

Figure 12. Net Benefits for Hypothetical Merged Fleet

Figure 13 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.

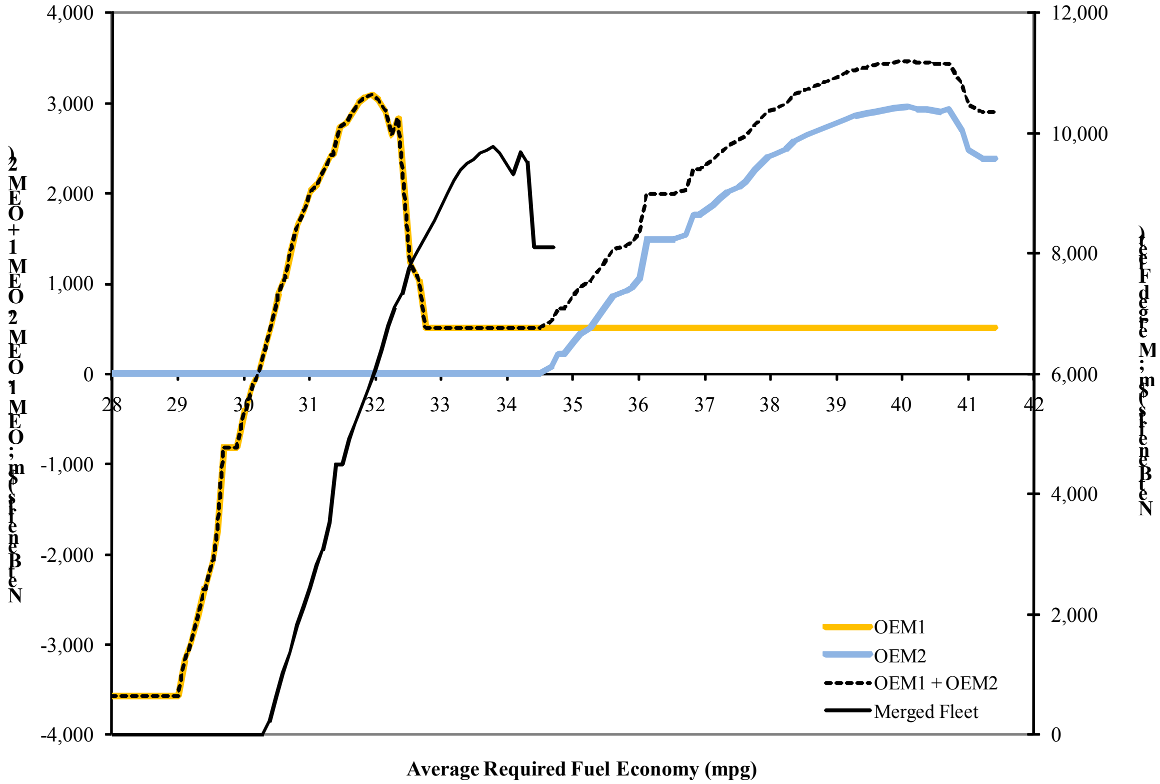

Figure 13. Comparison of Net Benefits with and without Merging of Fleet

Appendix D Monte Carlo Analysis

Uncertainty analysis (e.g., Monte-Carlo simulation) may be performed, such that all included scenarios are examined under varying discount rates, technology costs and fuel consumption effects, pretax fuel prices, rebound effect, and fuel-related externalities (monopsony, price shock, military security, and carbon dioxide costs). Monte-Carlo analysis may be set up and run using directions provided in the CAFE Model Software Manual document.

The results of the analysis are located in the output folder selected during modeling. Unlike other model runs, Monte-Carlo simulation does not produce formatted Excel reports. 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 (0) 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 pseudo-randomly generated Monte-Carlo trials used as input to the analysis. The contents of the file are summarized in Table 42.
- ***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 (0) provides the totals accrued during that scenario. The log files for the results of non-baseline scenarios (Sn1, Sn2, …) contain changes compared to the baseline. The contents of the file are summarized in Table 43.

Table 42. MC_Trials.csv Contents

Column	Contents
Index	Unique index of the trial.
FuelPriceEstimates	Randomized pretax fuel prices; the probabilities are: 50% for average fuel prices and 25% for and high prices.
DiscountRate	Value of the discount rate examined with each trial.
ReboundEffect	Randomized value of the rebound effect.
CO2Estimates	Randomized carbon dioxide cost estimates; the probabilites are: 25% for low, average, high, and very high cost estimates.
MonopsonyCost	Randomized value of the monopsony cost.
PriceShockCost	Randomized value of the price shock cost.
MilitarySecurityCost	Randomized value of the military security cost.
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.

Table 43. MC_Sn*_data.csv Contents

Column	Contents
Index	Unique index of the trial.
DiscountRate	Value of the discount rate examined with each trial.
AvePrice_MFR*(MY)	Average regulatory costs accumulated by the manufacturers for each model year.
TechCost_MFR*(MY)	Total technology costs accumulated by the manufacturers for each model year.
TechCost(MY)	Total technology costs accumulated by the entire industry for each model year.
SocialBenefits(MY)	Discounted social benefits accumulated by the entire industry for each model year.
FuelSavings(MY)	Fuel savings accumulated by the entire industry for each model year.
BCRatio(MY)	Ratio of social benefits to total technology costs for 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

Some of the icons and/or images used by the CAFE Compliance and Effects Modeling System may have been obtained from www.kde-look.org and are the sole property of their respective owners.

To the best of our knowledge, all images are distributed under the GNU GPL or the GNU LGPL licenses. If any of the icons violate the original author's copyright or terms of use, 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.

Because the software makes extensive use of Microsoft® Excel files for input and output, Excel must be installed on the system. To provide a means of protecting confidential business information (CBI) contained in input and output files (if the user is relying on CBI), the software makes use of encryption algorithms available in Excel 2003. These algorithms are not available in older versions of Excel. Unencrypted files, however, may be used with such versions.

The software 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 44. 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[34].

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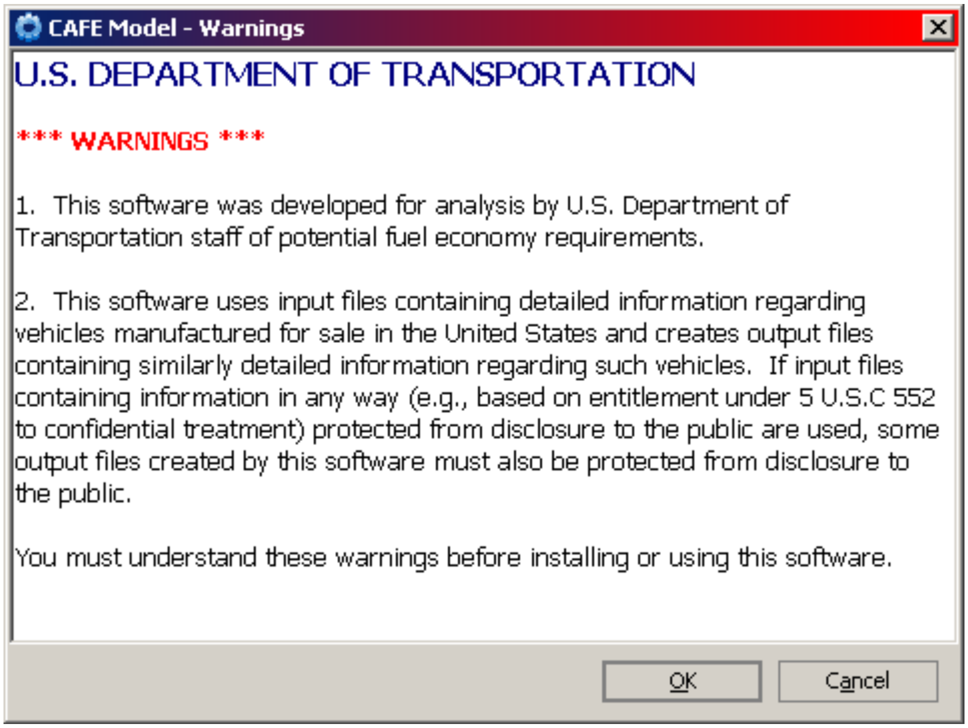
[34] The CAFE Model files provided may be in a zip archive, which will need to be extracted using a zip utility such as WinZip (www.winzip.com) or 7Zip (www.7-zip.org).

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.[35] 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 14). 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 installing or using this software.

Figure 14. Warnings Dialog Box

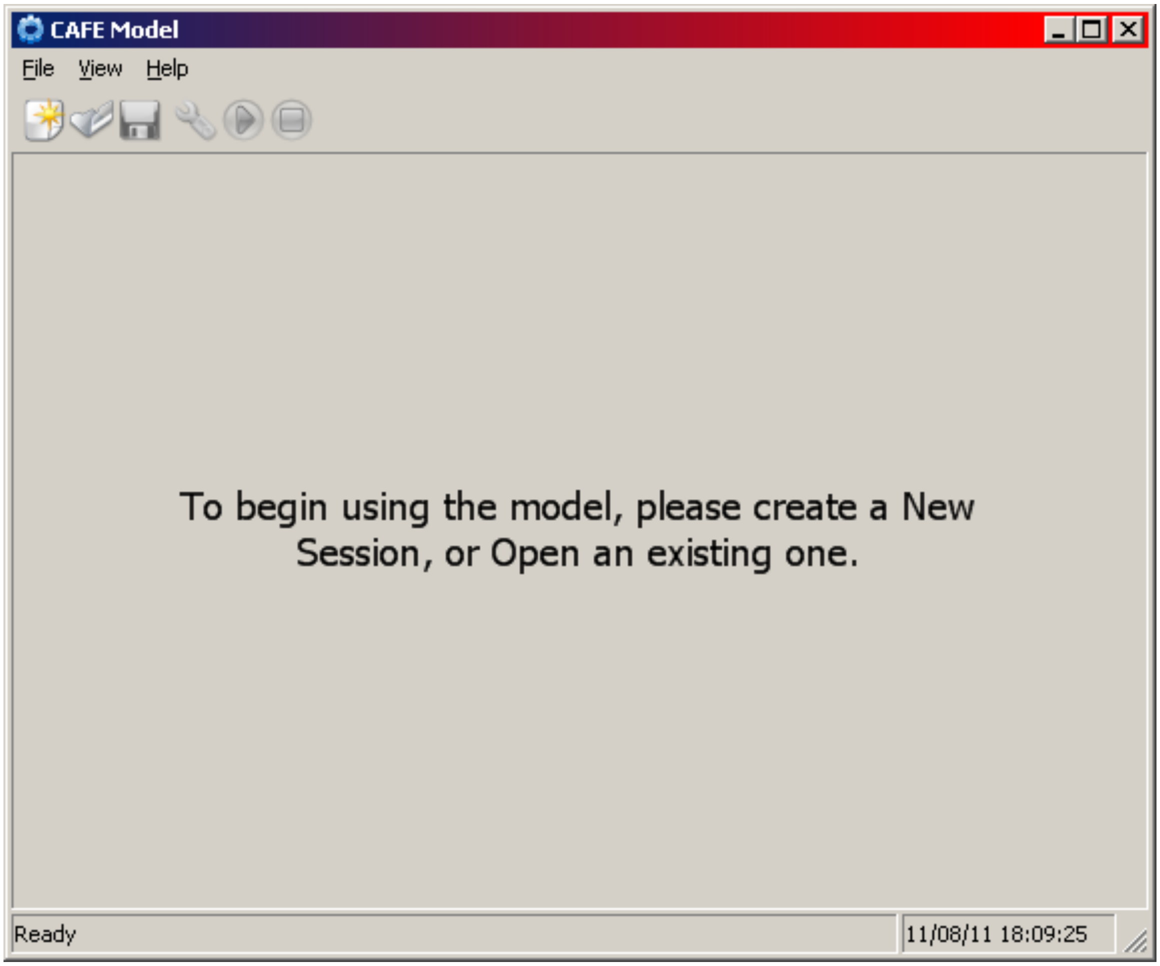
After clicking the **OK** button in the **Warnings** dialog box, the main **CAFE Model** window, described below, opens.

---

[35] 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 15) 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, as well as to generate modeling reports.



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

Ready

11/08/11 18:09:25

Figure 15. 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 16), with most commonly used shortcuts also available on the model toolbar (Figure 17). For user convenience, most of the menu entries may also be controlled using keyboard shortcuts.

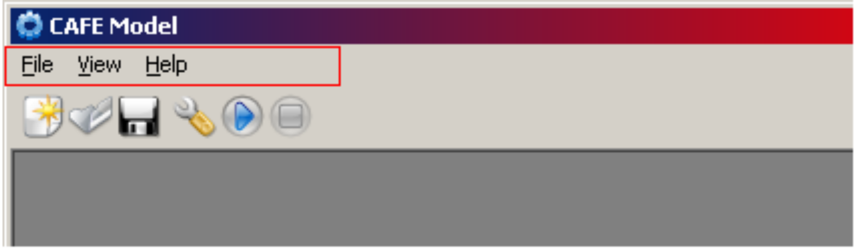


Figure 16. CAFE Model File Menu

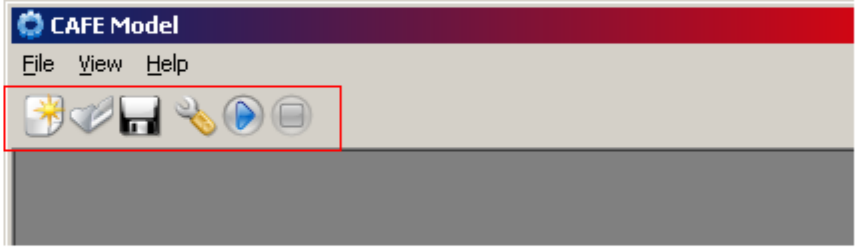


Figure 17. CAFE Model Toolbar

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.

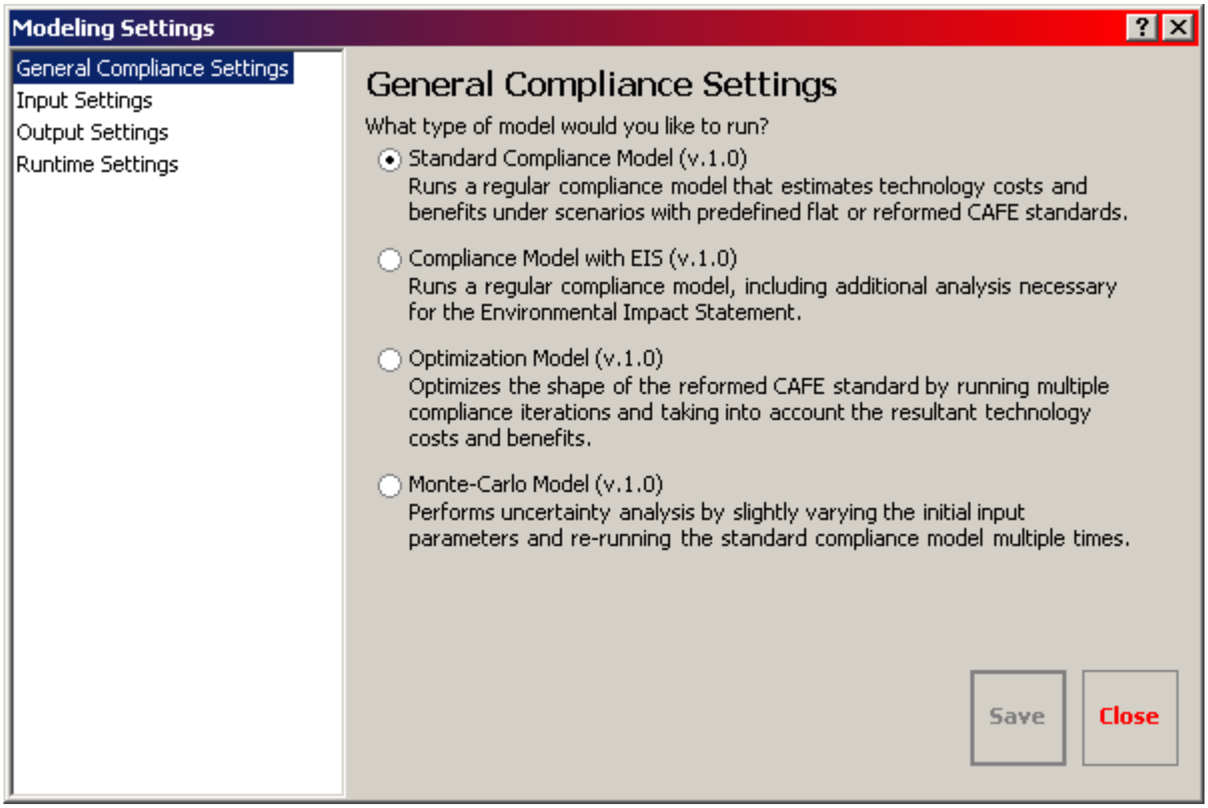
E.4.2 Modeling Settings Window

The **Modeling Settings** window contains multiple panels for configuring all of the runtime options available to the model. The user can use 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 18) 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 sensitivity analysis and optimize 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.

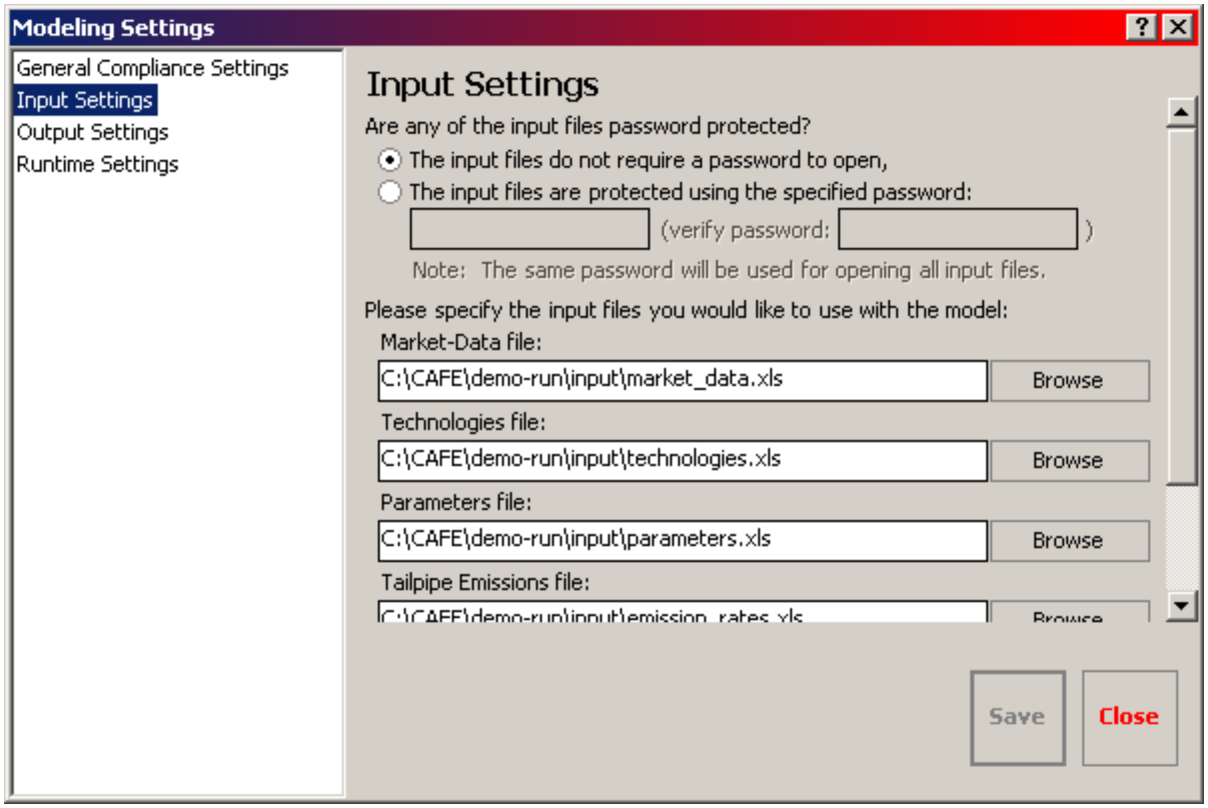
○ Optimization Model (v.1.0)
Optimizes the shape of the reformed CAFE standard by running multiple compliance iterations and taking into account the resultant technology costs and benefits.

○ 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 18. General Compliance Settings Panel

E.4.2.2 Input Settings Panel

On the **Input Settings** panel (Figure 19), 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 CAFE Model, 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

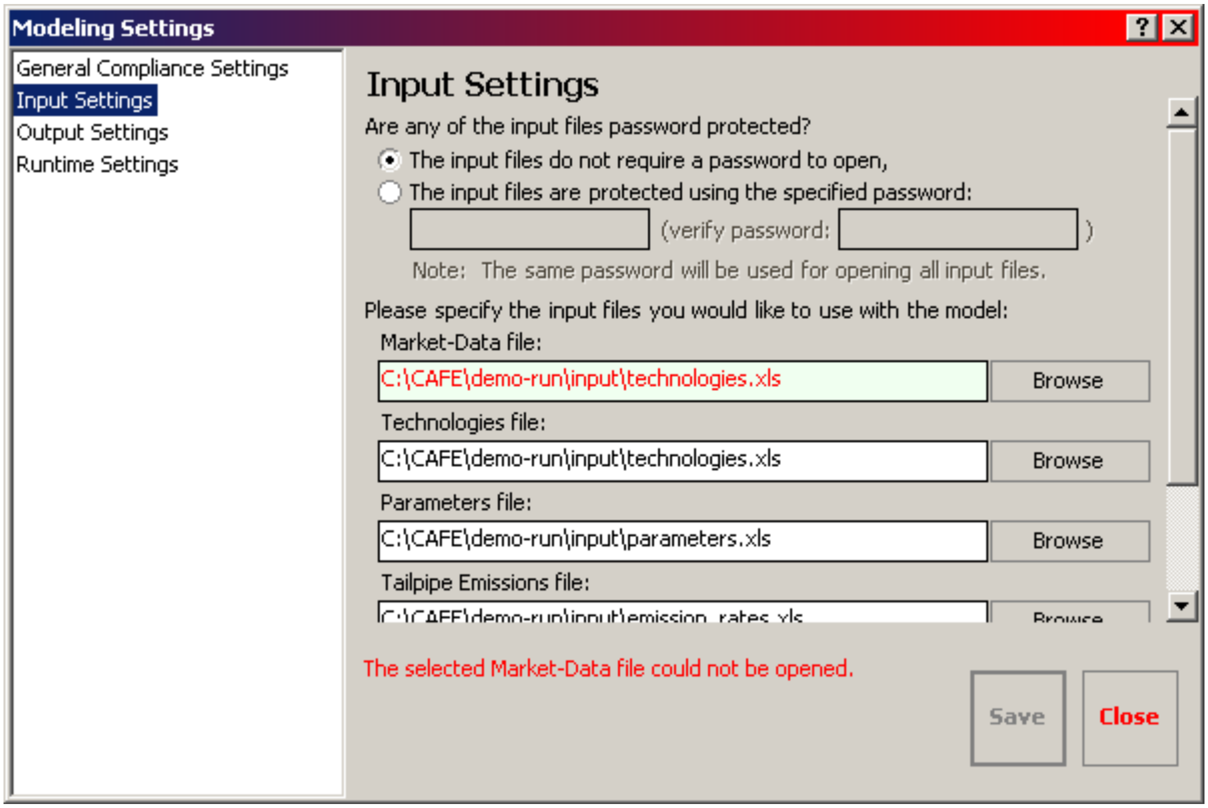
Technologies file: C:\CAFE\demo-run\input\technologies.xls

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

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

Figure 19. Input Settings Panel (1)

When selecting input files, the model will attempt to verify that an appropriate file was selected. If incorrect file path is entered, an error message will be displayed (Figure 20).



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

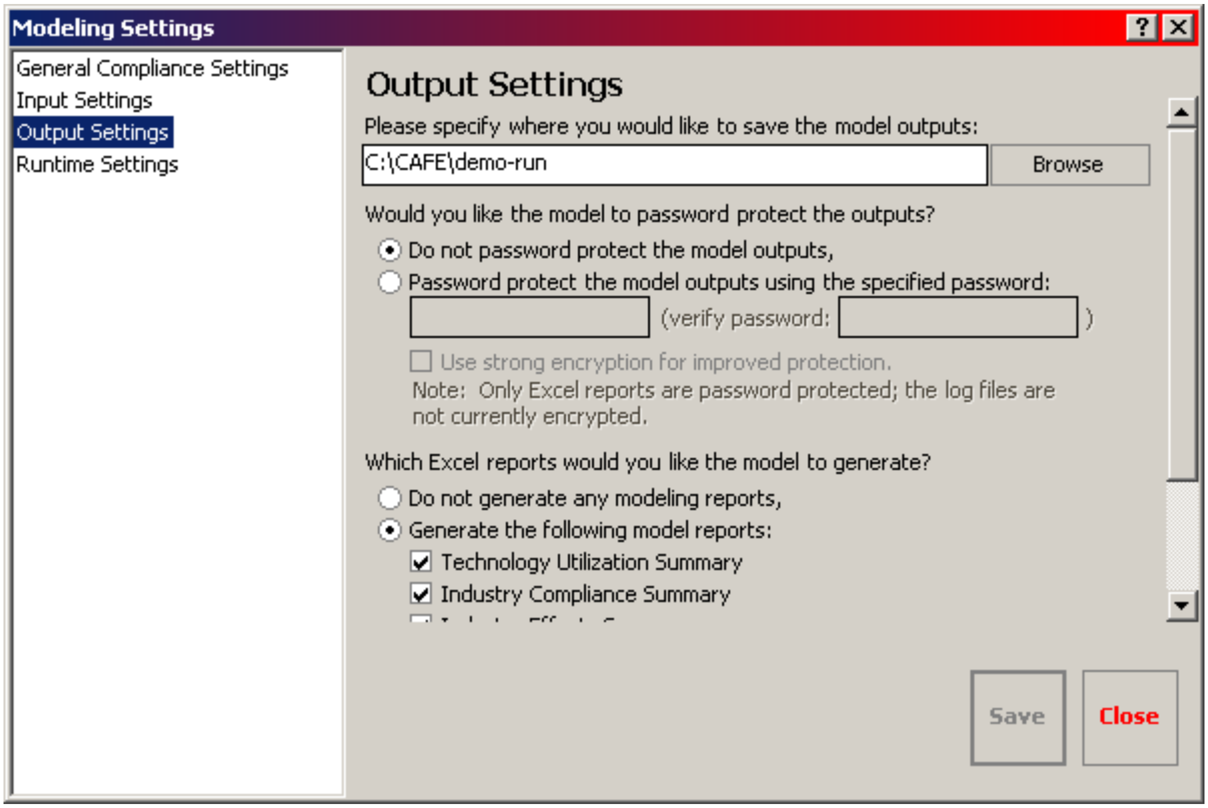
Tailpipe Emissions file: C:\CAFE\demo-run\input\emission_rates.xls

The selected Market-Data file could not be opened.

Figure 20. Input Settings Panel (2)

E.4.2.3 Output Settings Panel

The **Output Settings** panel (Figure 21) is used to configure the location where modeling results will be saved and which modeling reports the CAFE Model should generate. If input data contained CBI, it may be necessary to protect outputs produced by the model. The system provides the ability to password protect the Excel reports that the model generates, however, the modeling logs are not encrypted.



Output Settings

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

C:\CAFE\demo-run

Would you like the model to password protect the outputs?

● Do not password protect the model outputs,

○ Password protect the model outputs using the specified password: (verify password:)

☐ Use strong encryption for improved protection.

Note: Only Excel reports are password protected; the log files are not currently encrypted.

Which Excel reports would you like the model to generate?

○ Do not generate any modeling reports,

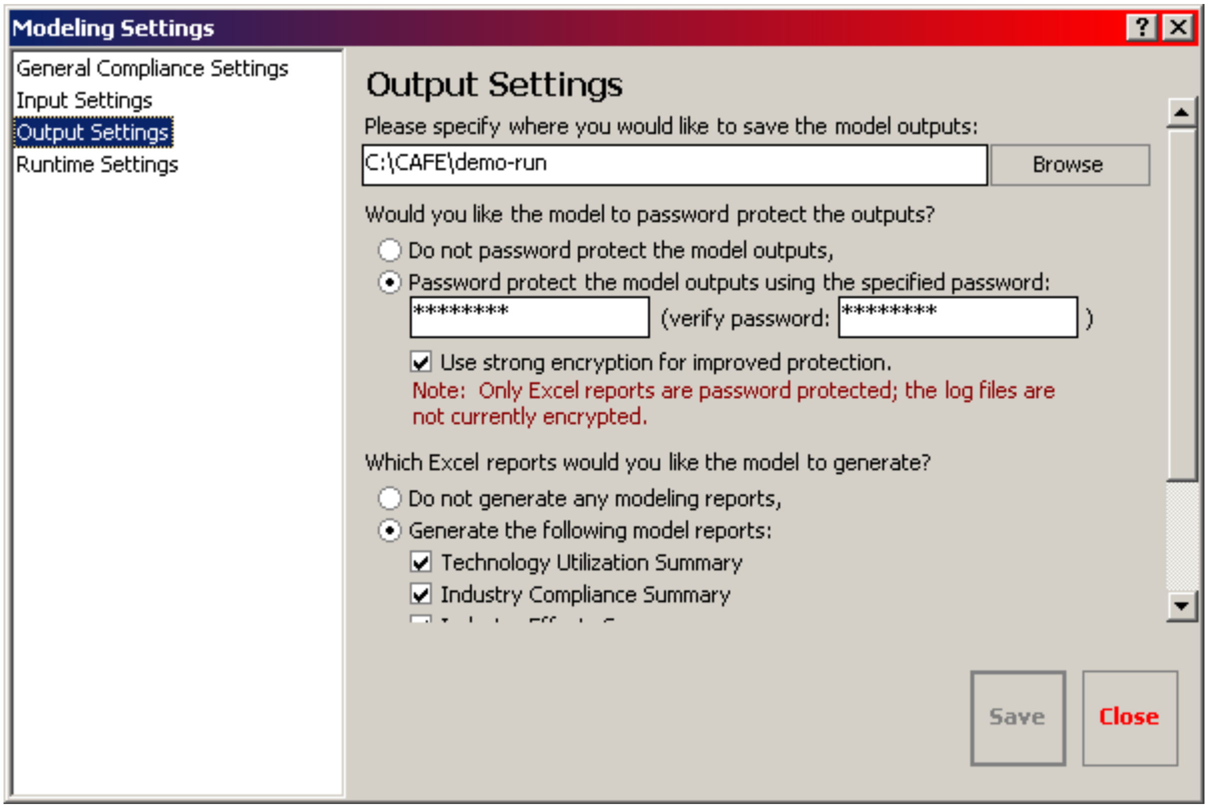
● Generate the following model reports:

☑ Technology Utilization Summary

☑ Industry Compliance Summary

Figure 21. Output Settings Panel (1)

When password protecting the Excel reports, "strong encryption" option may be used for improved security (Figure 22).



Output Settings

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

C:\CAFE\demo-run

Would you like the model to password protect the outputs?

○ Do not password protect the model outputs,

● Password protect the model outputs using the specified password:

********* (verify password: *********)

☑ Use strong encryption for improved protection.

Note: Only Excel reports are password protected; the log files are not currently encrypted.

Which Excel reports would you like the model to generate?

○ Do not generate any modeling reports,

● Generate the following model reports:

☑ Technology Utilization Summary

☑ Industry Compliance Summary

Figure 22. Output Settings Panel (2)

The modeling system is configured to generate eight different report types (Figure 23)[36]:

- ***Technology Utilization Summary***: Provides industry-wide technology application and penetration rates for each model year and technology analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
- ***Industry Compliance Summary***: Provides industry-wide summary of compliance model results, where each worksheet tab represents a single model year analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
- ***Industry Effects Summary***: Provides industry-wide summary of energy and emissions effects, where each worksheet tab represents a single model year analyzed.
- ***Industry Effects Details***: Provides a more detailed view of industry-wide energy and emissions effects, where the results are disaggregated by regulatory class. Each worksheet tab represents a single model year analyzed.
- ***Industry Societal Costs Details***: Provides details of undiscounted and discounted industry-wide societal costs for each calendar and model year. The results are presented

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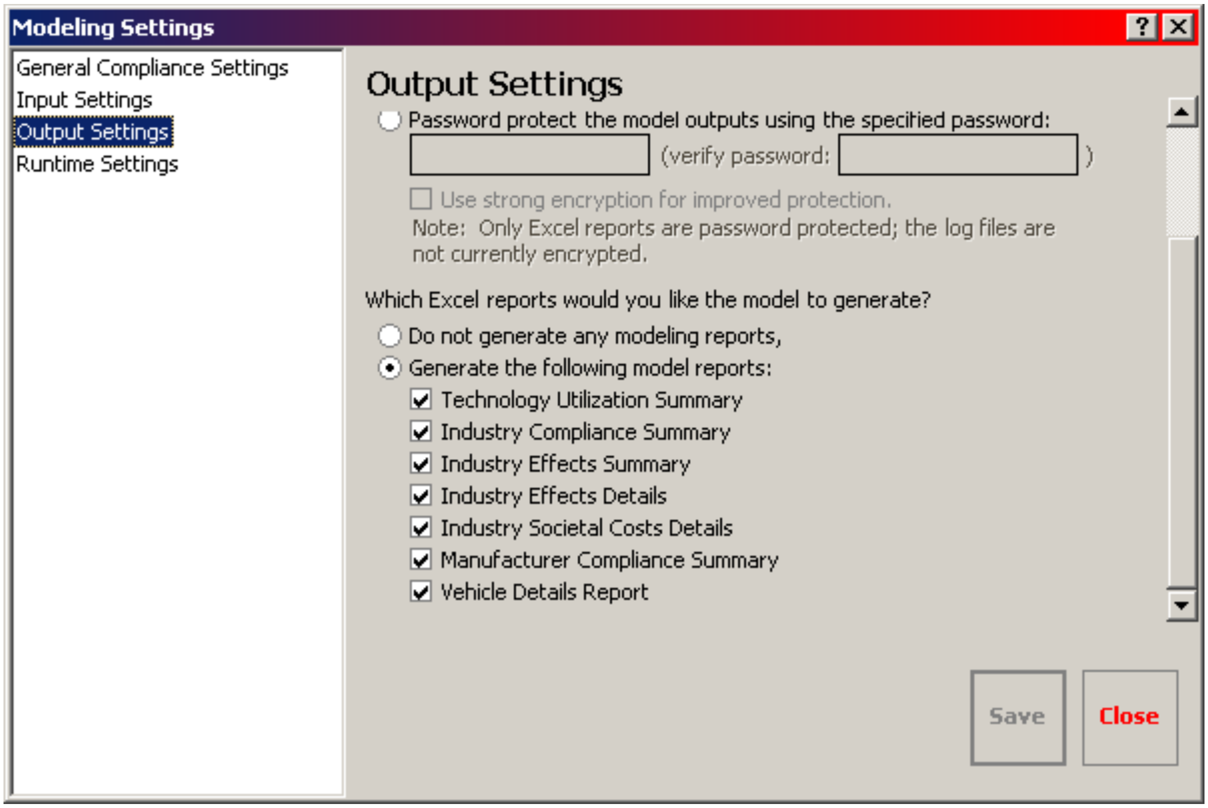
[36] Note: The Monte-Carlo Model does not support any of the modeling reports provided on the Output Settings panel. Selecting any of the reports during Monte-Carlo modeling will have no effect.

by regulatory class, as well as combined over the entire fleet. When this option is selected, multiple output files are generated for each socially valued owner and societal costs attribute.

- ***Manufacturer Compliance Summary***: Provides manufacturer-level summary of compliance model results, where each worksheet tab represents a single model year analyzed. The results are disaggregated by regulatory class, as well as combined over the entire manufacturer's fleet. When this option is selected, a separate output file is generated for each manufacturer.
- ***Vehicle Details Report***: Presents disaggregate vehicle-level summary of compliance model results.
- ***Optimized Industry Report***: Provides industry-wide and manufacturer-level technology costs, fines, and benefits, as well as carbon dioxide and fuel savings, and benefit-cost ratios, for all iterations from industry optimization. This report also graphs the socially optimized functional form (aka, optimized shape) for the entire industry by model year, and displays benefit-cost, marginal benefit:cost, net benefits, and optimized shape charts. **Note**: The Optimized Industry report is automatically generated whenever the ***Optimization Model*** is run. This report is not selectable in the model GUI.



Output Settings

○ Password protect the model outputs using the specified password:

(verify password:)

☐ Use strong encryption for improved protection.

Note: Only Excel reports are password protected; the log files are not currently encrypted.

Which Excel reports would you like the model to generate?

○ Do not generate any modeling reports,

● Generate the following model reports:

- ☑ Technology Utilization Summary
- ☑ Industry Compliance Summary
- ☑ Industry Effects Summary
- ☑ Industry Effects Details
- ☑ Industry Societal Costs Details
- ☑ Manufacturer Compliance Summary
- ☑ Vehicle Details Report

Figure 23. Output Settings Panel (3)

E.4.2.4 Runtime Settings Panel

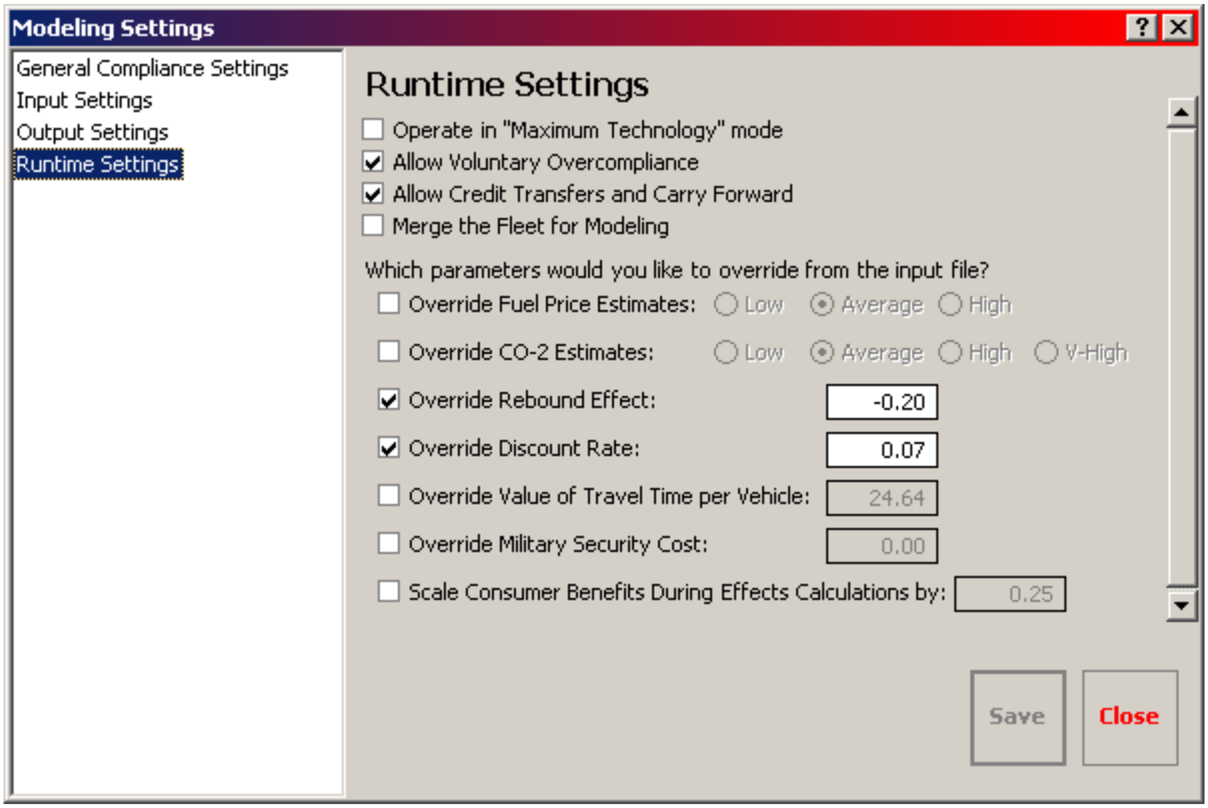
The **Runtime Settings** panel (Figure 24) provides additional modeling options to further customize the model behavior, beyond what is available in the input files:

- ***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.
- ***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 24 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
☐ 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 ○ V-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 24. Parameters Overrides Panel

E.4.3 Manage Optimization Window

The **Manage Optimization** window (Figure 25) 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 value 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 value 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.

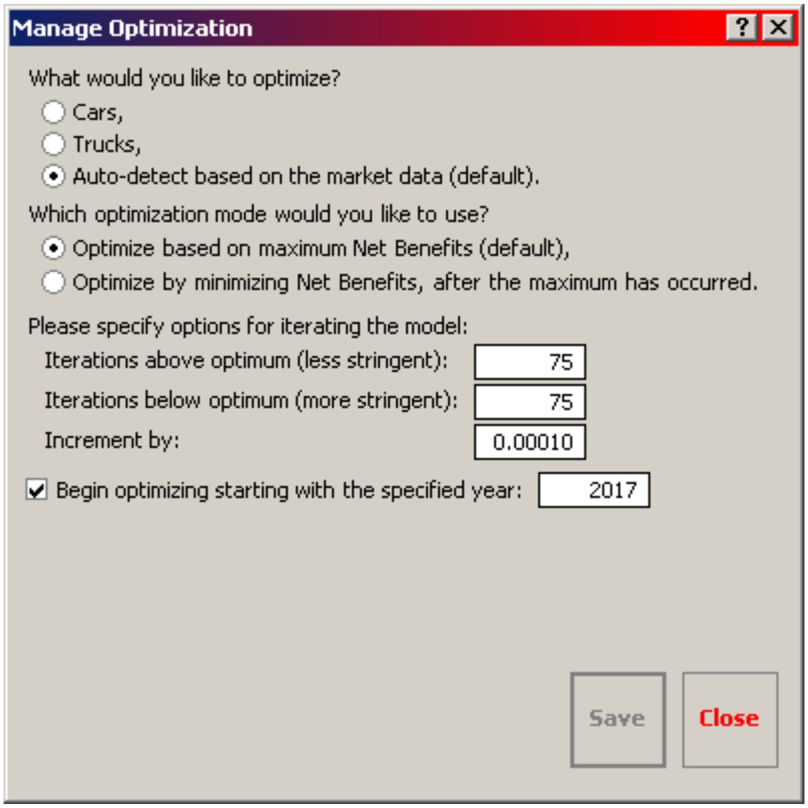
The next set of options determines the optimization mode the model should use when identifying the optimum value of the CAFE standard:

- ***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 asymptotes upward in GPM space. Increasing the asymptotes 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 asymptotes down in GPM space. Decreasing the asymptotes produces a less 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.



Manage Optimization

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

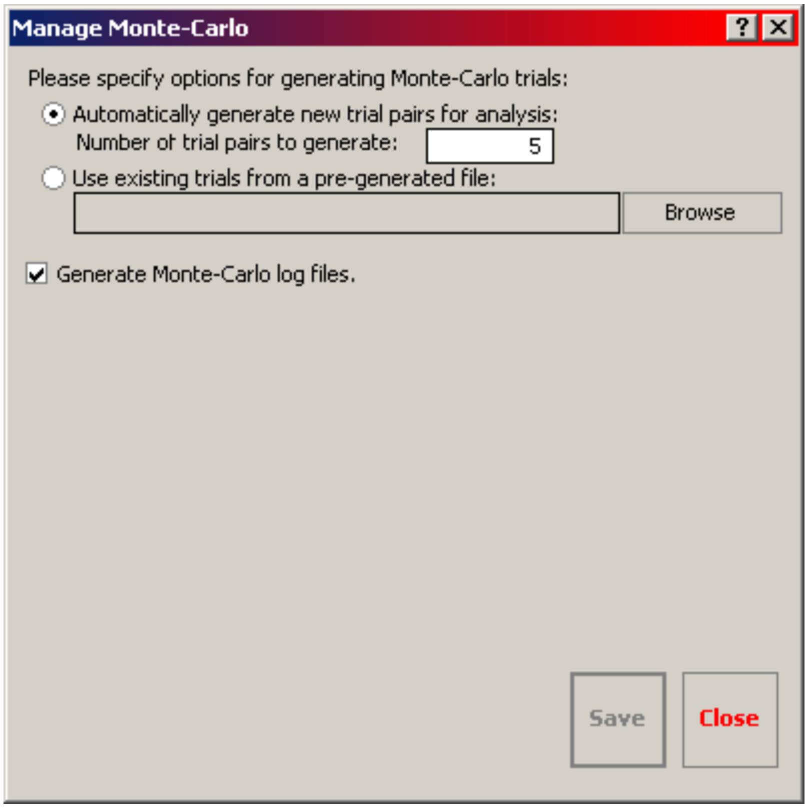
☑ Begin optimizing starting with the specified year: 2017

Figure 25. Manage Optimization Window

E.4.4 Manage Monte-Carlo Window

The **Manage Monte-Carlo** window (Figure 26) provides additional options necessary for configuring the system for Monte-Carlo modeling. During modeling, the system may automatically generate a new set of trial pairs to use for analysis, or use an input file that was previously generated during an earlier run. When generating trial pairs, each new trial pair may consist of multiple Monte-Carlo trials – one for each discount rate analyzed.

Upon completion of the modeling process, the system may also be configured to generate Monte-Carlo log files.



Please specify options for generating Monte-Carlo trials:

● Automatically generate new trial pairs for analysis:

Number of trial pairs to generate: 5

○ Use existing trials from a pre-generated file:

☑ Generate Monte-Carlo log files.

Figure 26. Monte-Carlo Model Settings Panel

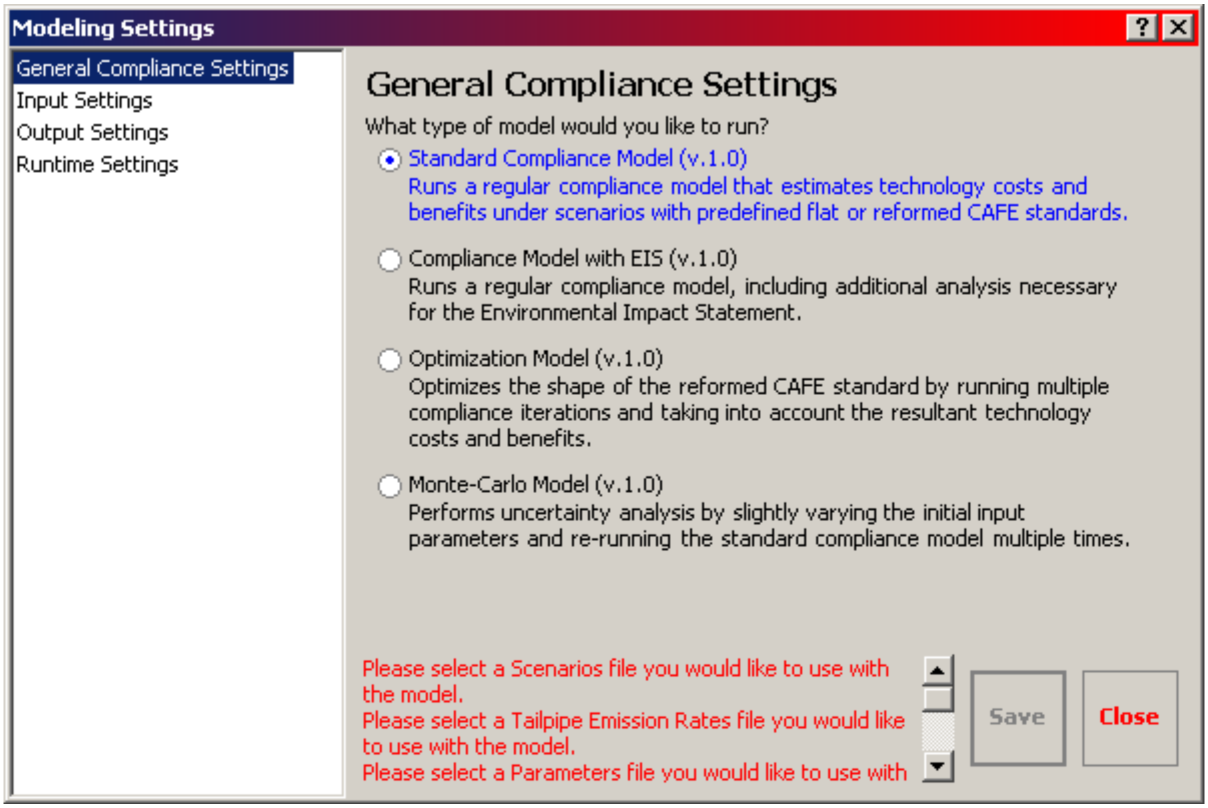
E.5 CAFE Model Usage Examples

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 in Figure 27 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.

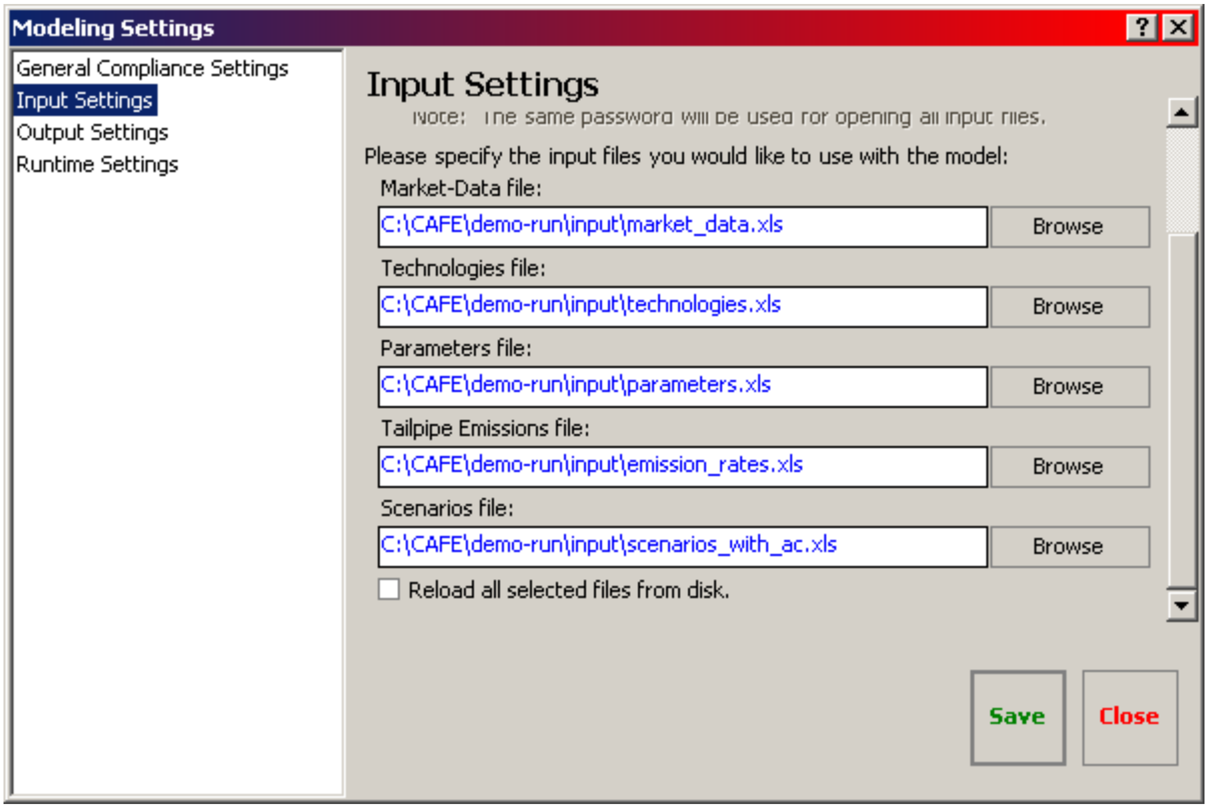
○ Optimization Model (v.1.0)
Optimizes the shape of the reformed CAFE standard by running multiple compliance iterations and taking into account the resultant technology costs and benefits.

○ 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

Figure 27. Select Standard Compliance Model

- Click on the **Input Settings** panel to select the input files to use for modeling (Figure 28). Note that once all the input files have been selected appropriately, the error messages disappear.



Input Settings

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

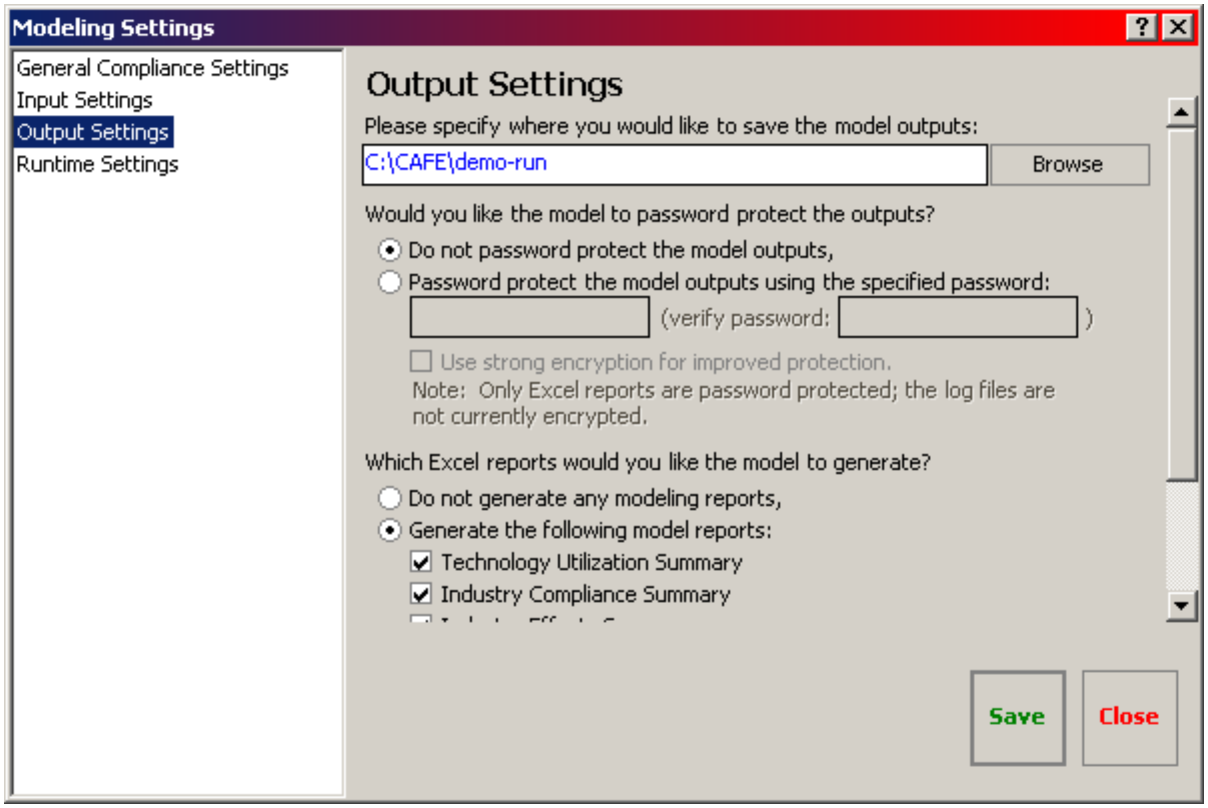
Tailpipe Emissions file: C:\CAFE\demo-run\input\emission_rates.xls

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

☐ Reload all selected files from disk.

Figure 28. Select Input Files

- On the **Output Settings** panel, select the location for output files and all of the available modeling reports (Figure 29).



Output Settings

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

C:\CAFE\demo-run

Would you like the model to password protect the outputs?

● Do not password protect the model outputs,

○ Password protect the model outputs using the specified password:

(verify password:)

☐ Use strong encryption for improved protection.

Note: Only Excel reports are password protected; the log files are not currently encrypted.

Which Excel reports would you like the model to generate?

○ Do not generate any modeling reports,

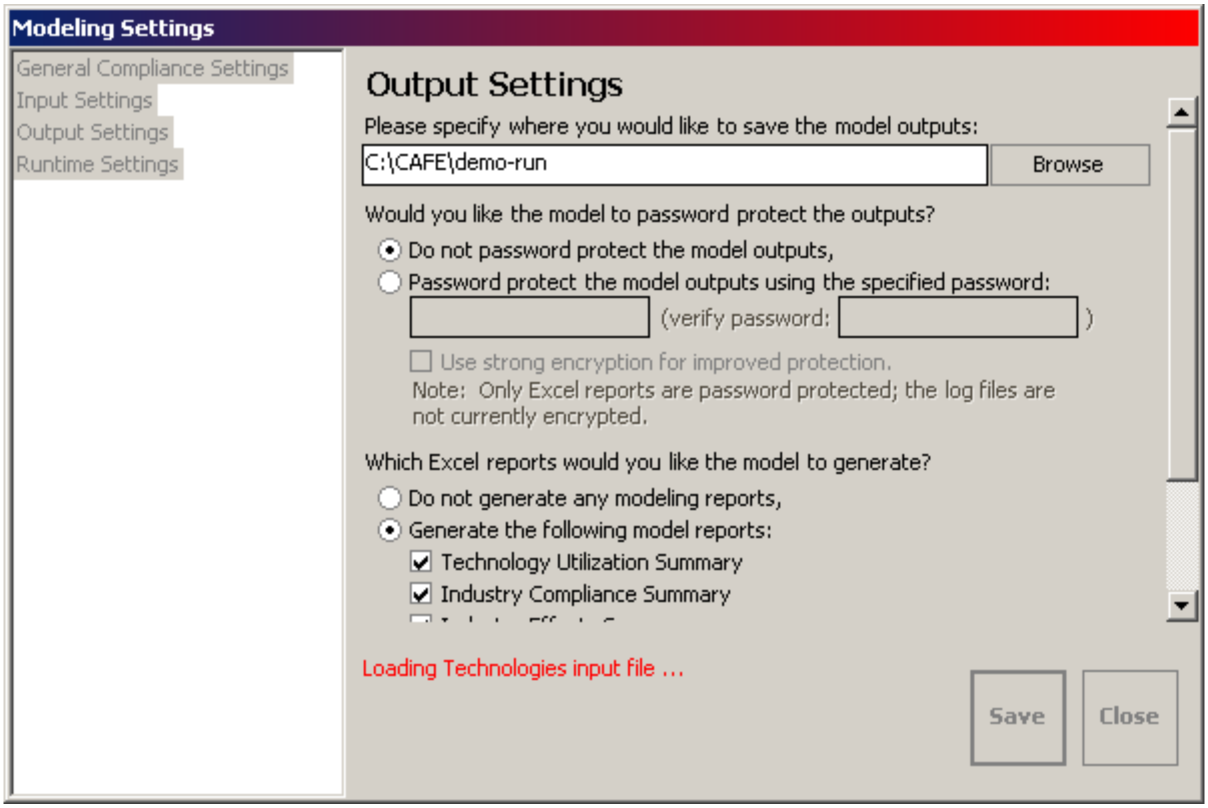
● Generate the following model reports:

☑ Technology Utilization Summary

☑ Industry Compliance Summary

Figure 29. Select Output Location and Modeling Reports

- 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 30).



Output Settings

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

C:\CAFE\demo-run

Would you like the model to password protect the outputs?

● Do not password protect the model outputs,

○ Password protect the model outputs using the specified password:

(verify password:)

☐ Use strong encryption for improved protection.

Note: Only Excel reports are password protected; the log files are not currently encrypted.

Which Excel reports would you like the model to generate?

○ Do not generate any modeling reports,

● Generate the following model reports:

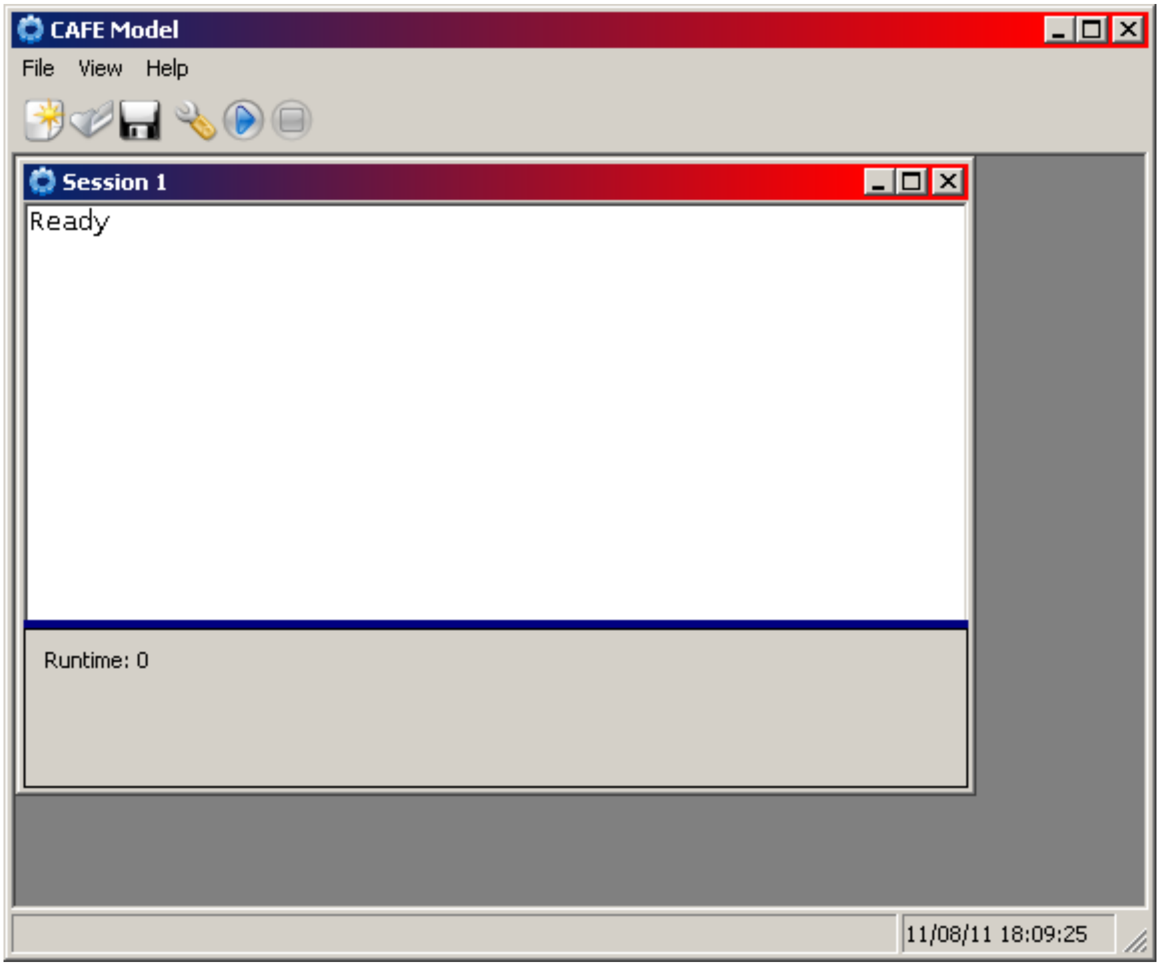
☑ Technology Utilization Summary

☑ Industry Compliance Summary

Loading Technologies input file ...

Figure 30. 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 31).



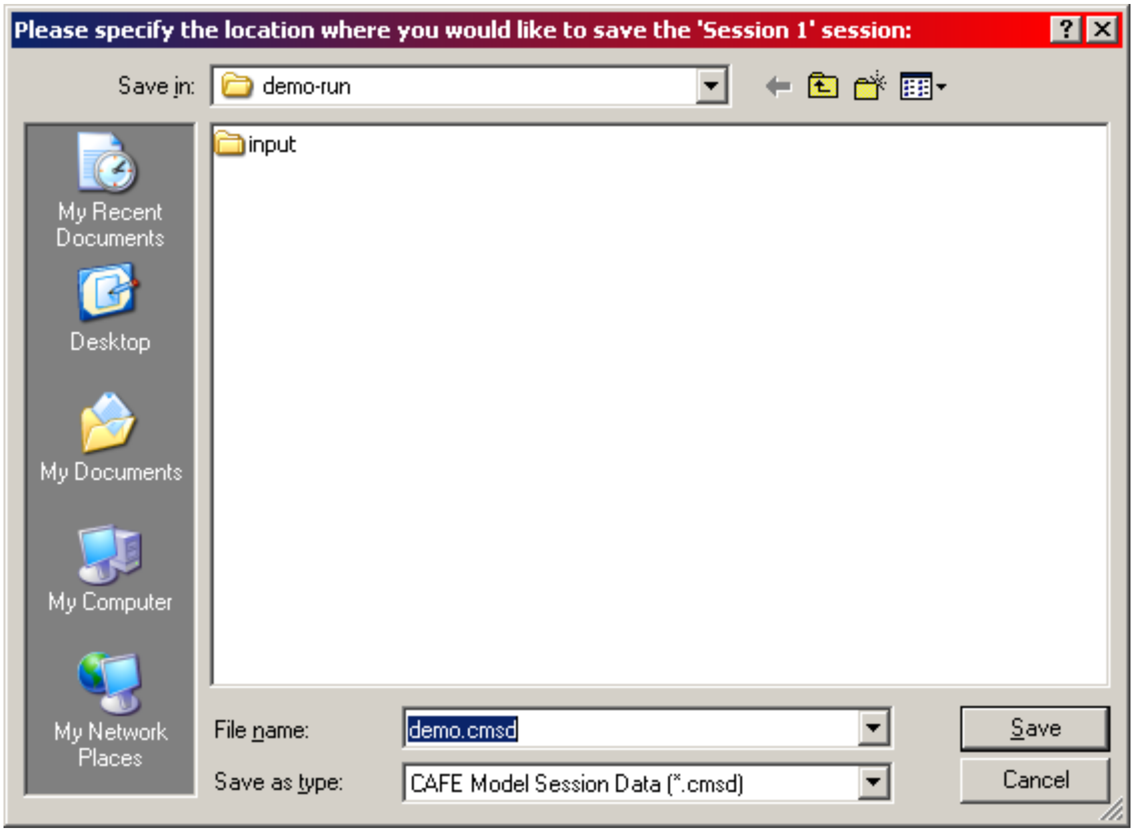
Ready

Runtime: 0

11/08/11 18:09:25

Figure 31. 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 32).


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

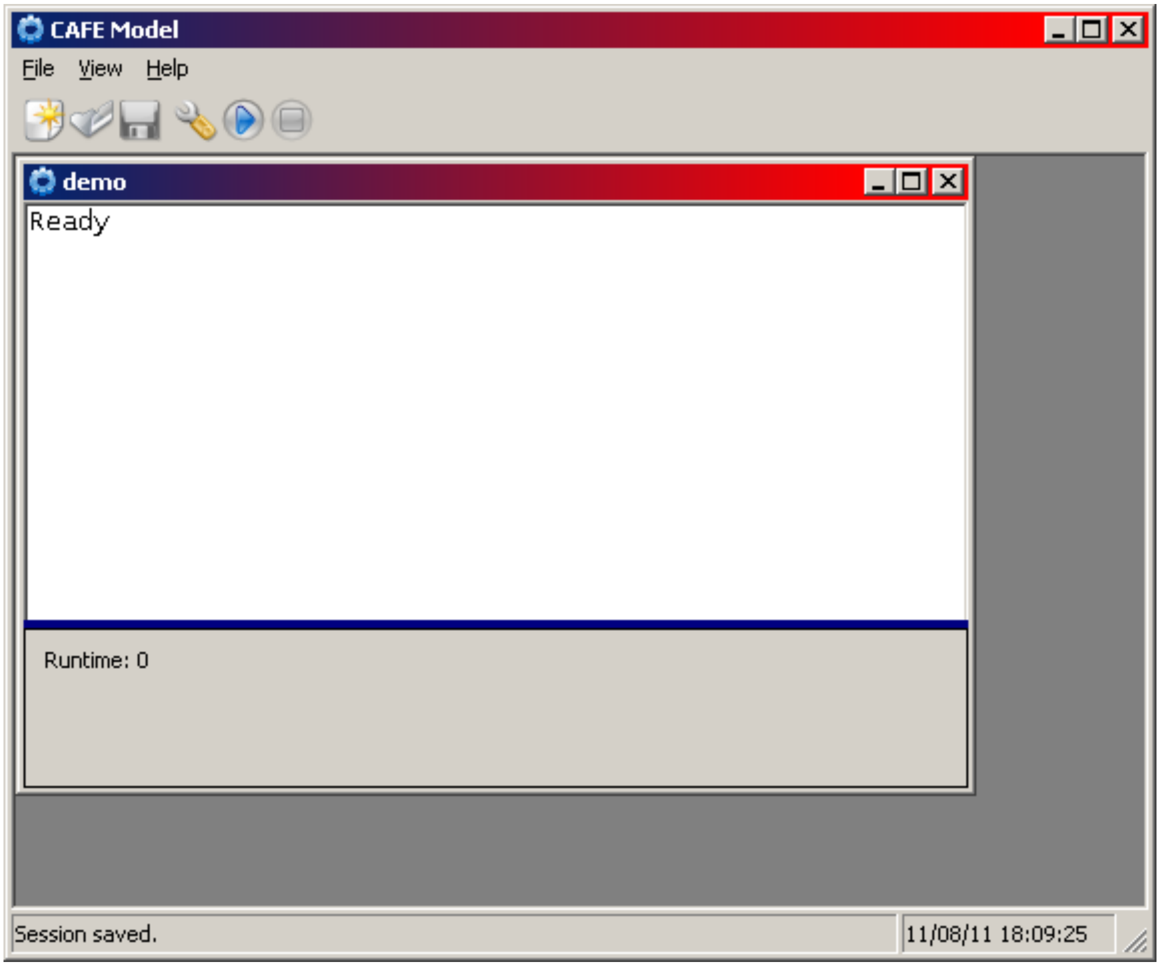
Save in: demo-run

File name: demo.cmsd

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

Figure 32. Save New Session

- After the session has been saved, notice the title of the session has changed to "demo" (Figure 33).



Ready

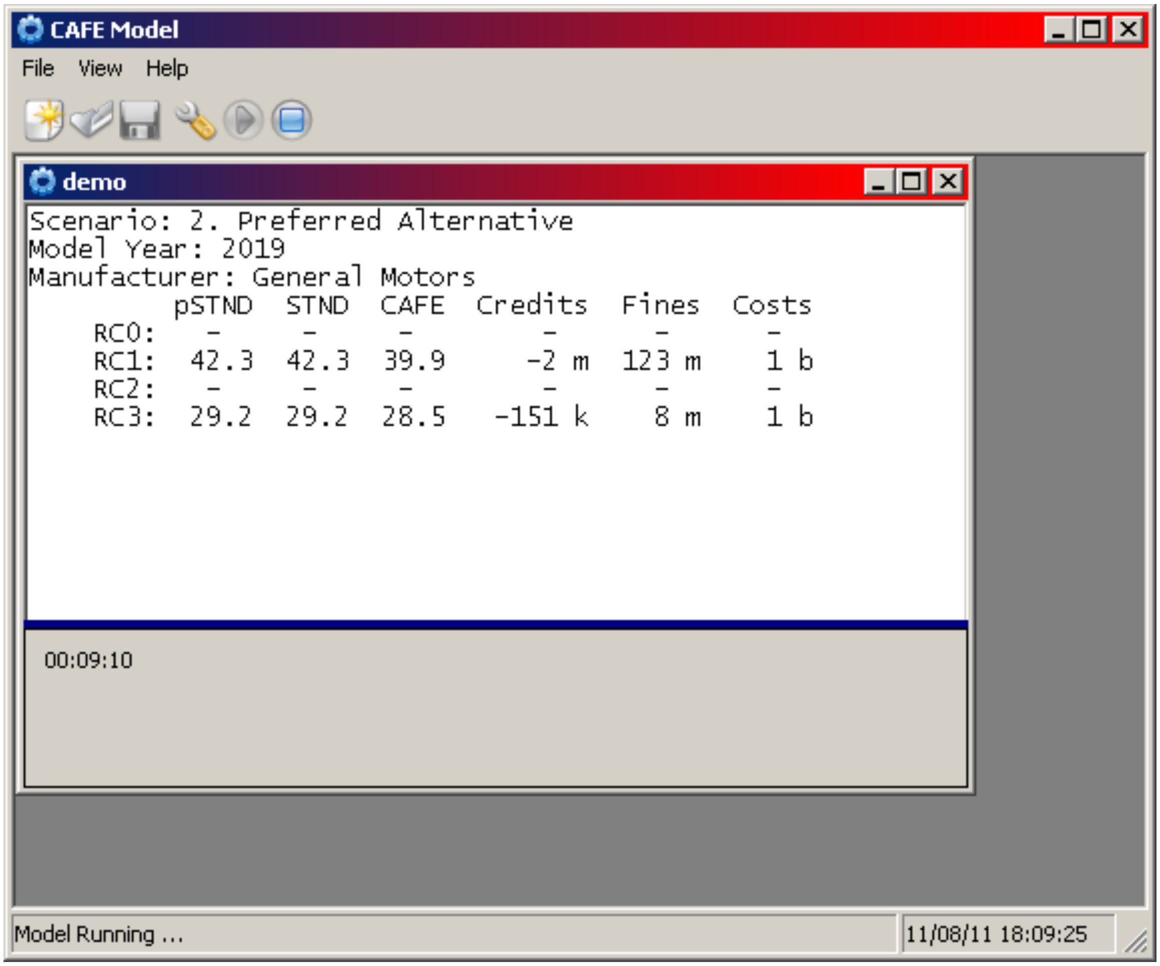
Runtime: 0

Session saved.

11/08/11 18:09:25

Figure 33. "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 34).



```
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
```

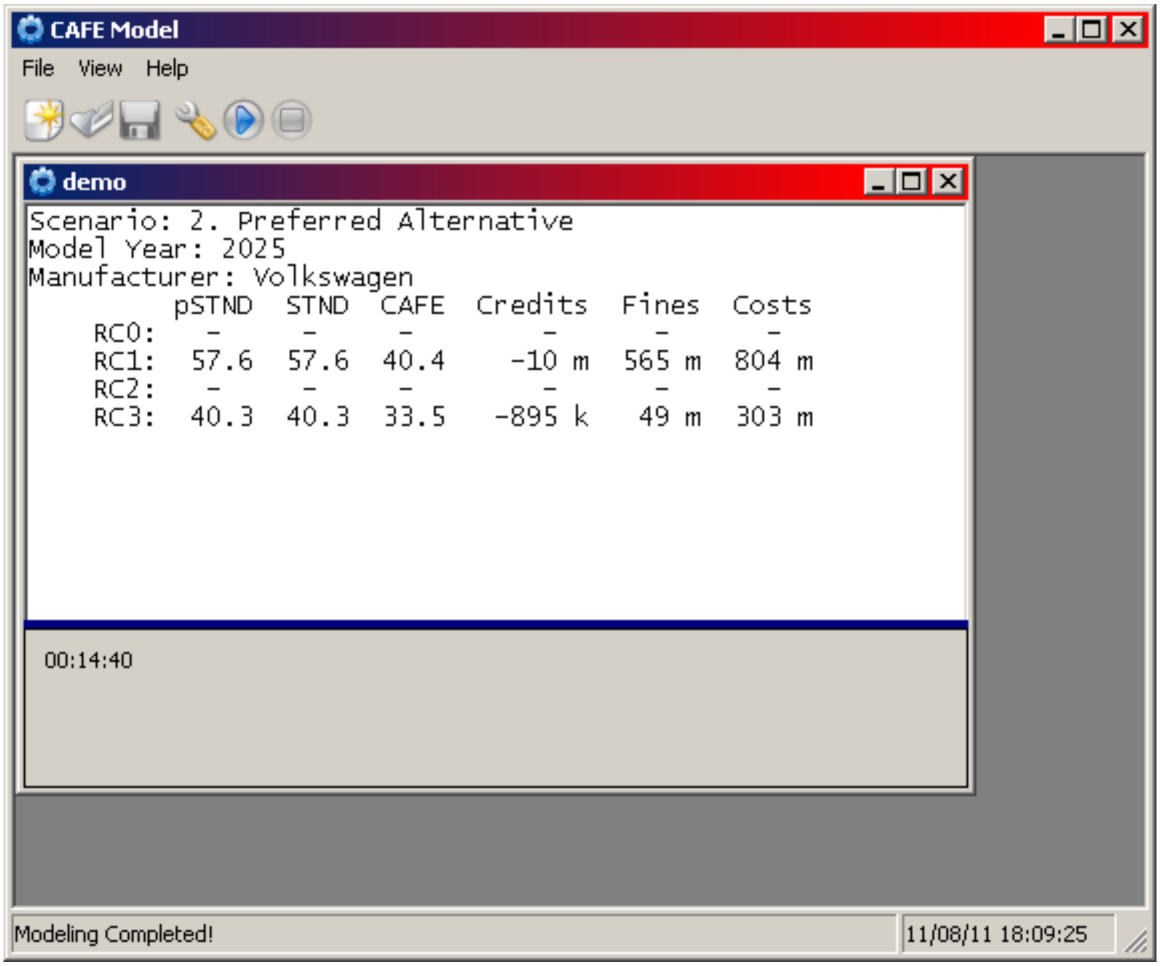
00:09:10

Model Running ...

11/08/11 18:09:25

Figure 34. 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 35).



```
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 35. 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 36).

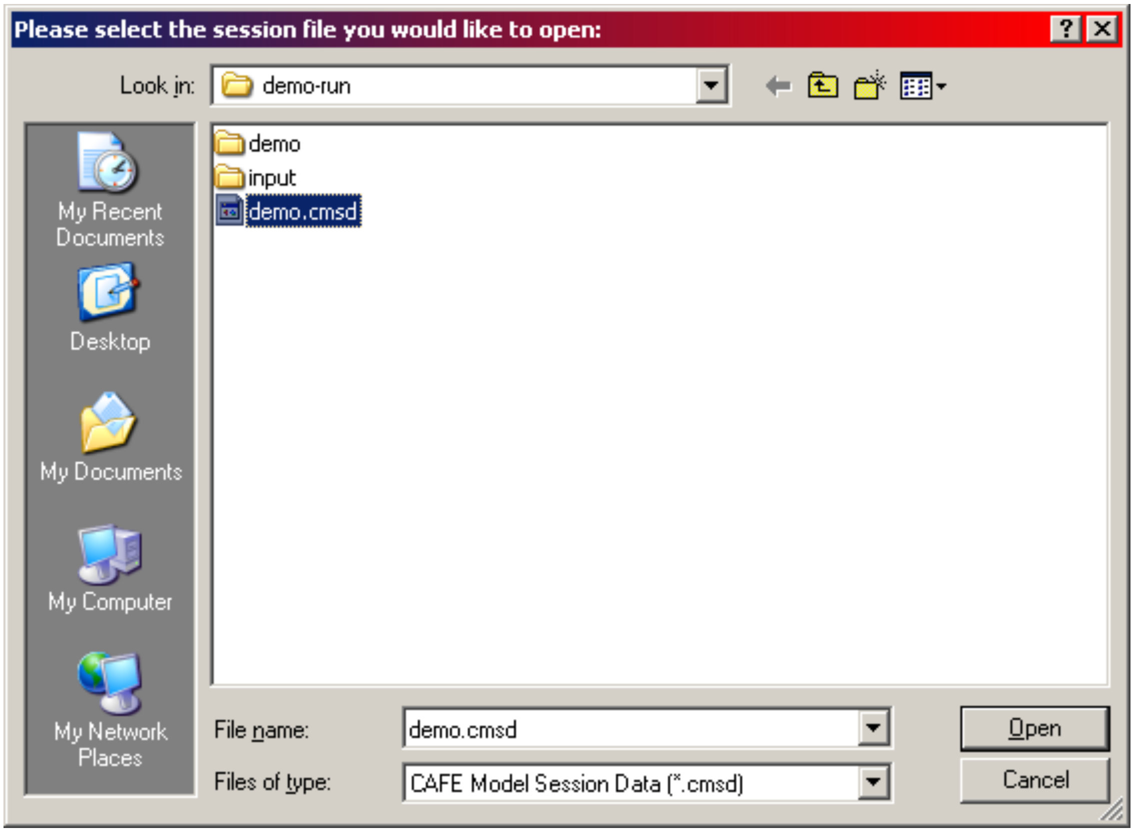
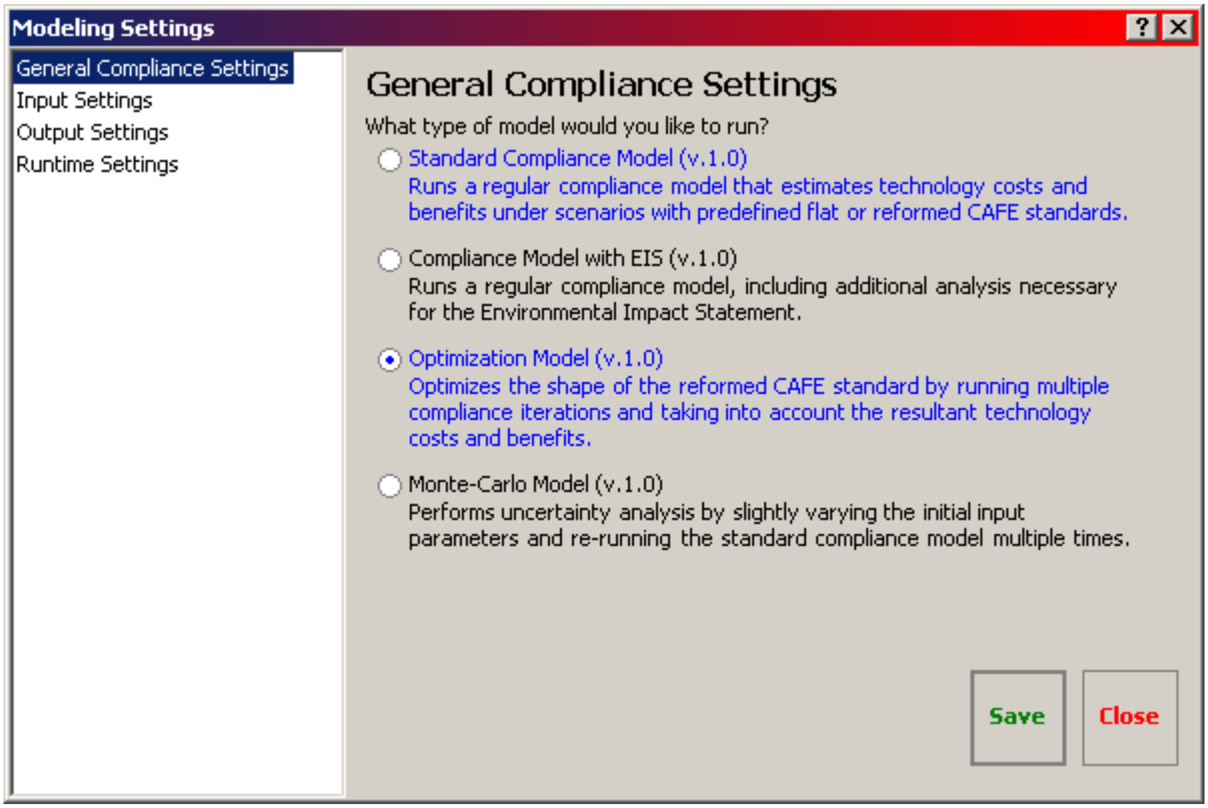


Figure 36. Open "demo" Session

- 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 37.



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.

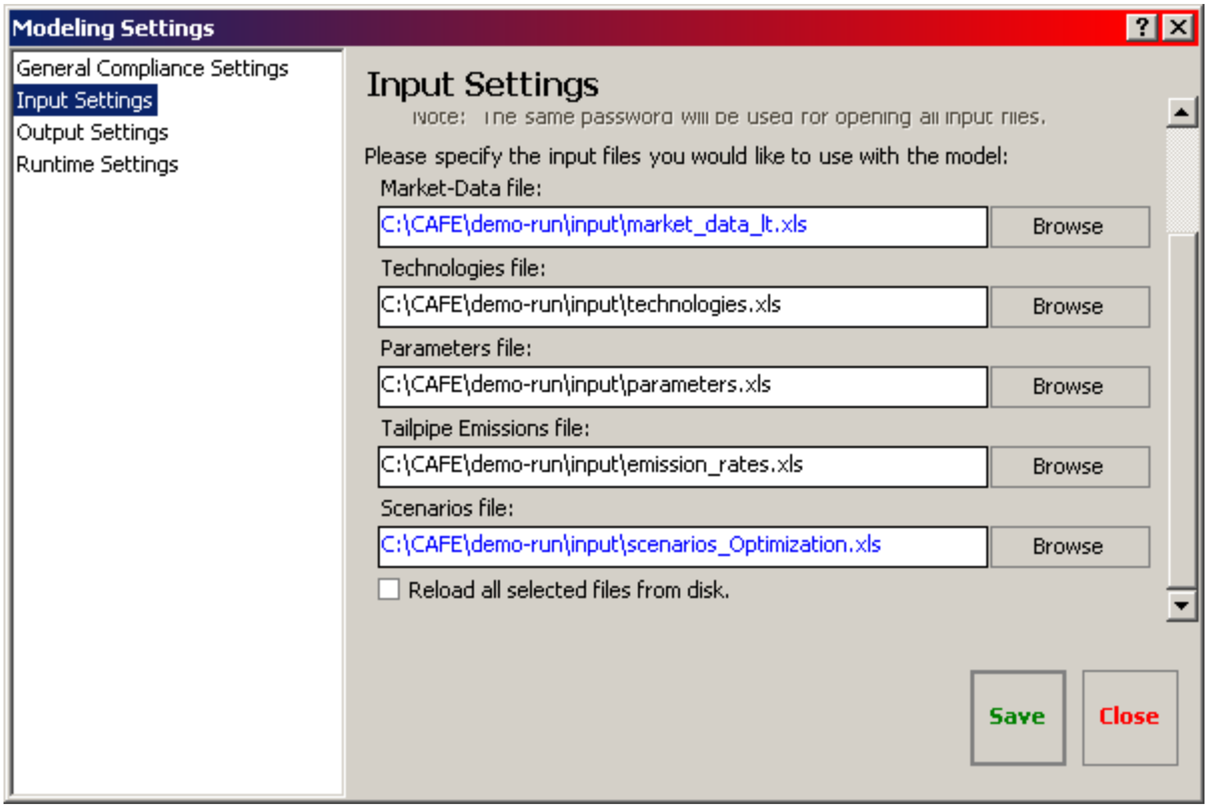
○ Compliance Model with EIS (v.1.0)
Runs a regular compliance model, including additional analysis necessary for the Environmental Impact Statement.

● 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 37. 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 38).



Input Settings

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

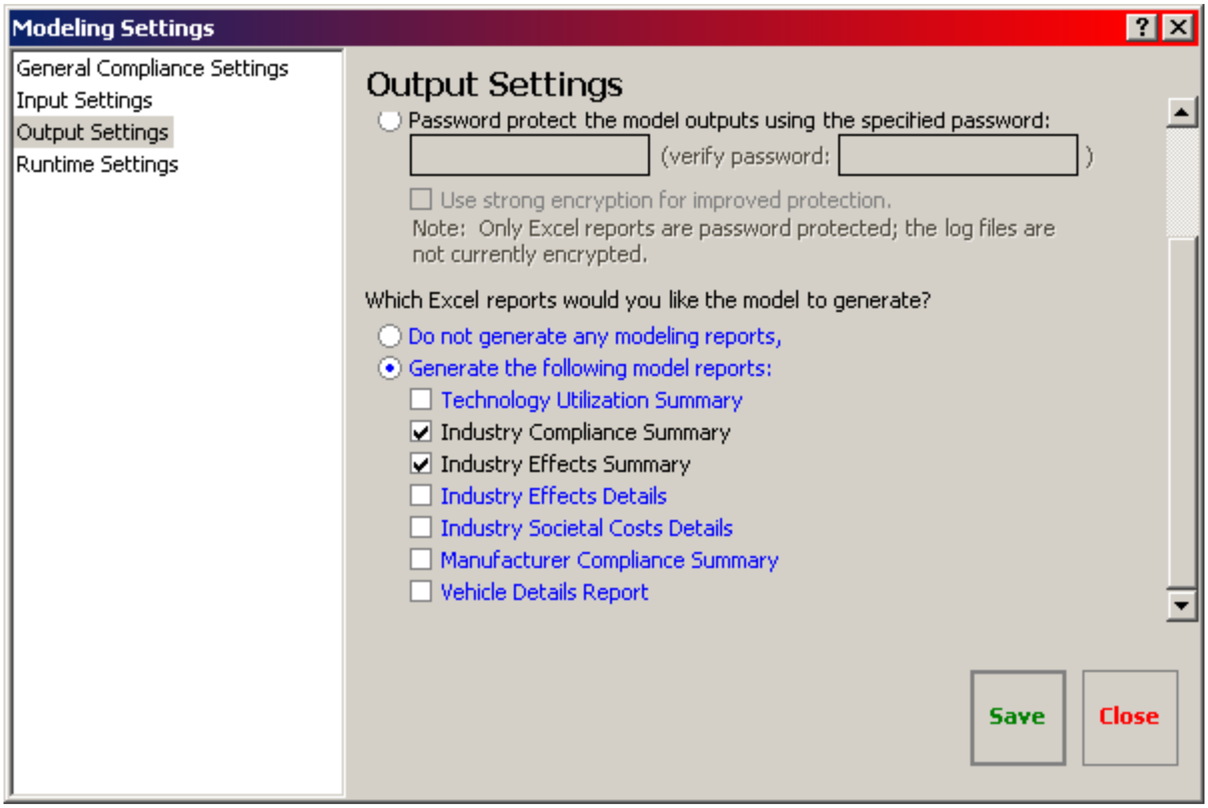
Tailpipe Emissions file: C:\CAFE\demo-run\input\emission_rates.xls

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

☐ Reload all selected files from disk.

Figure 38. Select Scenarios File for Optimization

- On the **Output Settings** panel, deselect all report types except for “Industry Compliance Summary” and “Industry Effects Summary” (Figure 39).
    - ****Note**: the ***Optimized Industry Report*** is generated automatically as long as the “Do not generate any modeling reports” option is not selected.



Output Settings

○ Password protect the model outputs using the specified password:

(verify password:)

☐ Use strong encryption for improved protection.

Note: Only Excel reports are password protected; the log files are not currently encrypted.

Which Excel reports would you like the model to generate?

○ Do not generate any modeling reports,

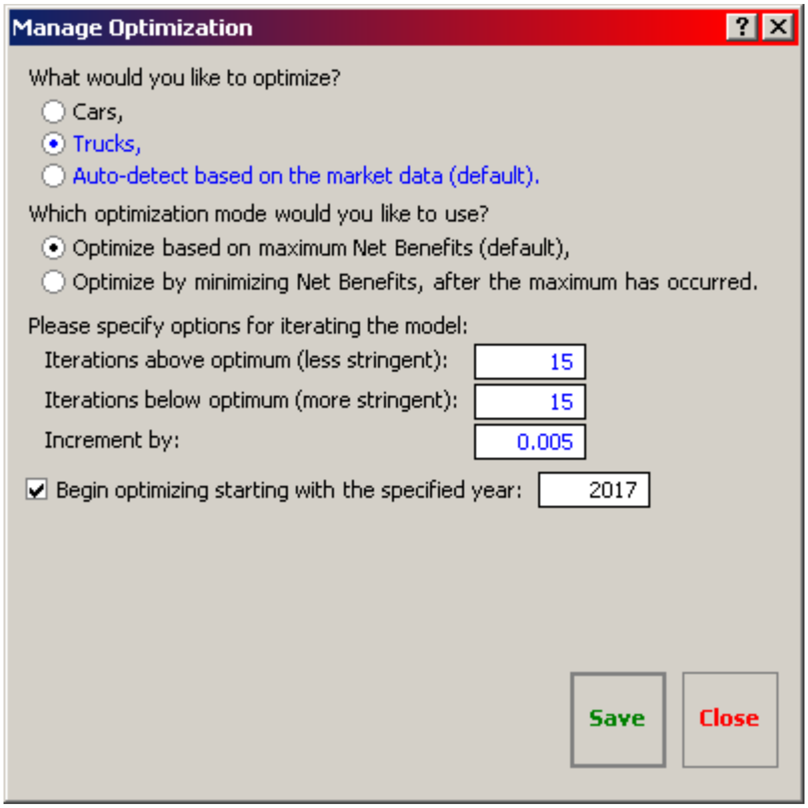
● Generate the following model reports:

☐ Technology Utilization Summary
☑ Industry Compliance Summary
☑ Industry Effects Summary
☐ Industry Effects Details
☐ Industry Societal Costs Details
☐ Manufacturer Compliance Summary
☐ Vehicle Details Report

Figure 39. Select Reports for Optimization Modeling

- 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 40. (****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.)



Manage Optimization

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:

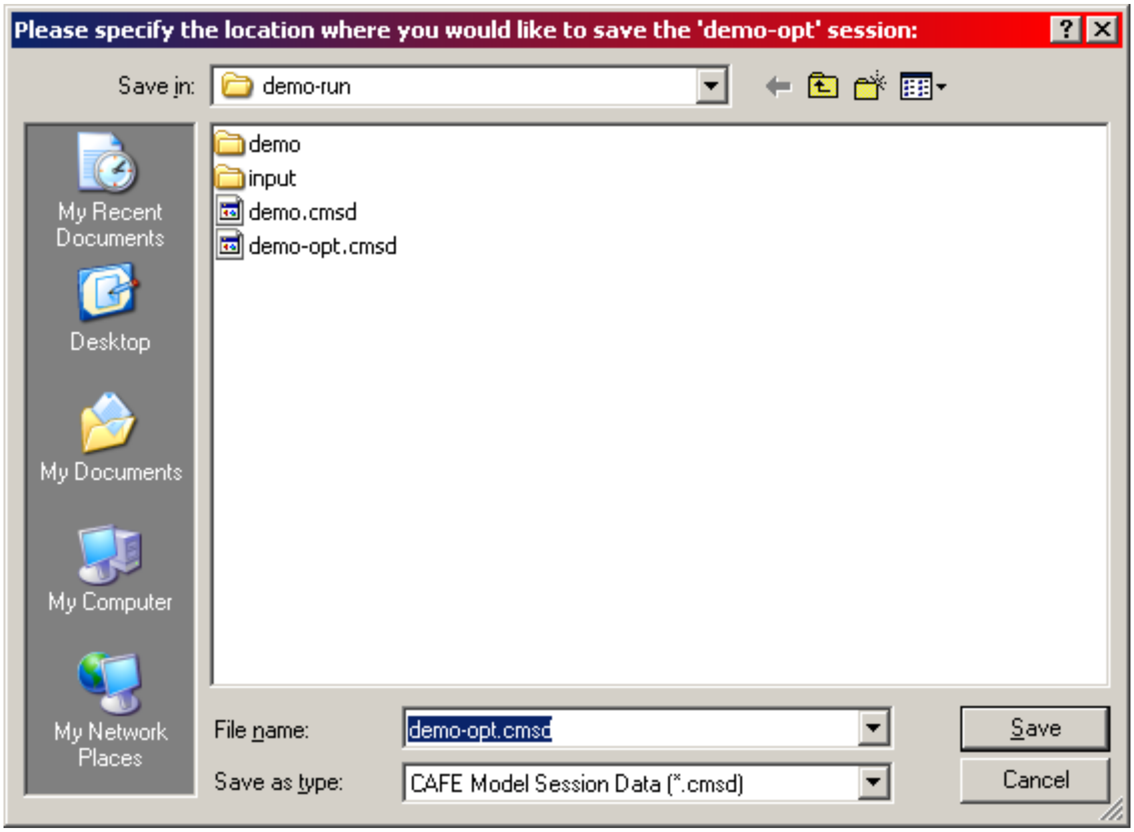
Iterations above optimum (less stringent): 15
Iterations below optimum (more stringent): 15
Increment by: 0.005

☑ Begin optimizing starting with the specified year: 2017

Figure 40. 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 41).

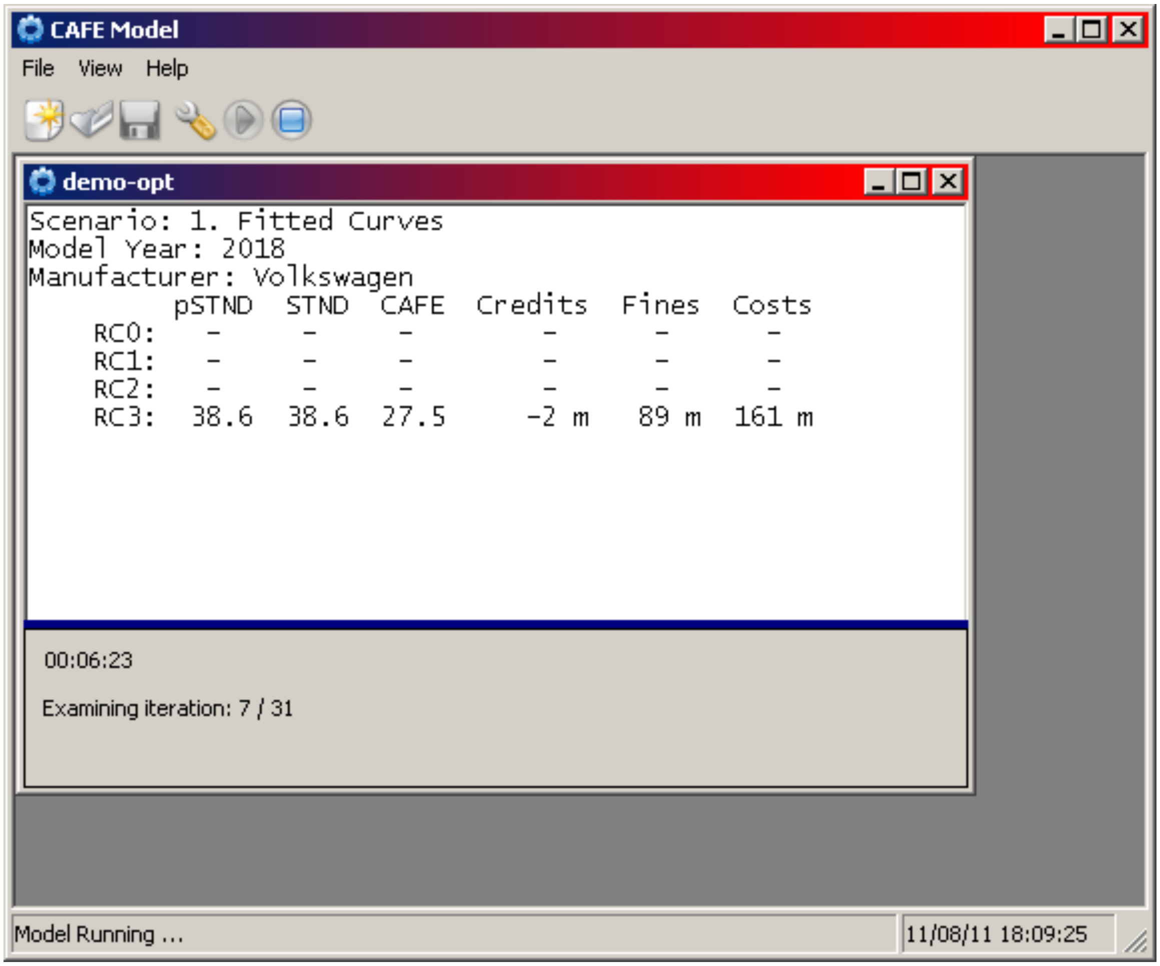


File name: demo-opt.cmsd

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

Figure 41. 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 42).



```
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 42. 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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