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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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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

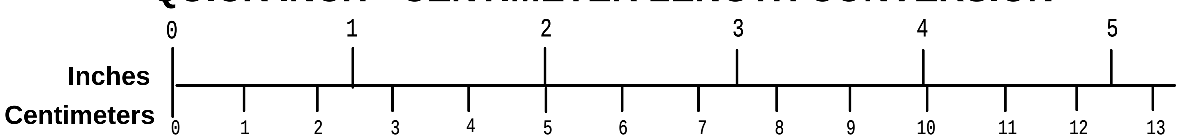
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

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 Model as of March 16, 2015; specifies the content, structure, and meaning of inputs and outputs; and provides instructions for the installation and use of the modeling system.

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

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

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.

Contents

Tables

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Abbreviations

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

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

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

Chapter One Introduction

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

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

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

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

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

In 2014, the system was adapted and expanded to allow NHTSA and Volpe Center staff to perform analysis in support of the medium duty rulemaking. As such, a new regulatory class, covering class 2b and class 3 pickups and vans, was introduced into the modeling system.

Although the revised model is capable of evaluating regulatory classes from prior modeling systems, the current revision is best suited for the medium duty analysis. Furthermore, to better illustrate the behavior of the industry, a feature allowing technologies to be inherited between vehicle platforms, engines, and transmissions has been reintroduced into the modeling system as the primary mode of operation.

Chapter Two System Design

Section 1 Overall Structure

The basic design of the CAFE Model 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 or vehicle class for the energy, carbon dioxide, criteria pollutant, and fatalities calculations. The system may be expanded in the future to represent CAFE-induced market responses (*i.e.*, mix shifting), in which case such calculations would group vehicles by market segment. Therefore, this system uses model-by-model categorization and accounting when calculating most effects, and aggregates results only as required for efficient reporting.

Section 2 CAFE Compliance Simulation

S2.1 Compliance Simulation Algorithm

Each time the modeling system is used, it evaluates one or more CAFE scenarios. Each of these scenarios is defined in the "scenarios" input file described in Section A.4 of Appendix A. Each scenario describes an overall CAFE program in terms of the program's coverage, applicability of multi-fuel vehicles, the structure and stringency of the standards applicable to passenger and nonpassenger automobiles, as well as other miscellaneous settings that may have an impact on compliance. The system is normally used to examine and compare at least two scenarios. The first scenario is identified as the baseline scenario, usually defined as the world in the absence of new CAFE standards (which itself can be considered in a variety of ways), providing results to which results for any other scenarios are compared. Although many scenarios can be examined with each run of the model, for simplicity in this overview, we will only describe one scenario occurring in one model year.

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

S2.1.1 Initial State of the Fleet

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

Vehicle Models Worksheet

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

Engine Worksheet

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

Transmission Worksheet

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

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

S2.2 Vehicle Technology Application within the CAFE Model

Vehicle technologies are a set of possible improvements available for the vehicle fleet. The vehicle technologies, referred to below simply as ‘technologies’, are defined by the user in the technology input file for the model (see Section A.2 in Appendix A). As a part of the definition for each technology there is an associated cost for the technology, an improvement factor (in terms of percent reduction of fuel consumption), the introduction year for the technology, whether it is applicable to a given class of vehicle, grouping (by technology group – engine, transmission, etc.), and phase-in parameters (the amount of fleet penetration allowed in a given year). Also defined in the technology inputs file are cost 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) for the 2021-2025 Notice of Proposed Rulemaking (NPRM) regarding CAFE standards for class 2b/3 trucks produced for sale in the United States in model years 2021-2025[1].

As discussed in the PRIA, the set of technologies, and the methods for considering their application, include those discussed in the 2017-2025 final rule documentation[2], albeit with updated fuel efficiency effectiveness estimates, as well as newly defined technologies for the 2021-2025 timeframe. The technologies discussed in 2012-2016 final rule were based on a 2002 National Academy of Sciences report.[3] That study estimated that the applicability of different technologies would vary based on vehicle type. Since the publication of the 2002 NAS study, NHTSA and EPA have agreed on technology-related estimates extending through MY2025, based on a range of newer studies and research, and NHTSA has developed corresponding inputs for use in the CAFE model. The development of these technology estimates is discussed in the preamble to the proposed rule, and in the supporting technical support document and regulatory impact analysis. Although the model now represents a wider range of technologies than the 2002 NAS study, and uses different logical sequences for considering their addition to manufacturers’ fleets, the model retains the ability for differentiation based on vehicle type.

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[1] *Available at* http://www.nhtsa.gov/fuel-economy.
[2] 75 FR 25324 (May 7, 2010).
[3] National Research Council, ‘‘Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards,’’ National Academy Press, Washington, DC (2002). *Available at* http://www.nap.edu/openbook.php?isbn=0309076013 (last accessed Nov. 13, 2011).

S2.2.1 Vehicle Technology Class

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

Table 1. CAFE Technology Vehicle Classes

Class	Description
Subcompact PC	Subcompact passenger car.
Subcompact Perf PC	Subcompact performance oriented passenger car
Compact PC	Compact passenger car
Compact Perf PC	Compact performance oriented passenger car
Midsize PC	Midsized passenger car
Midsize Perf PC	Midsized performance oriented passenger car
Large PC	Large passenger car
Large Perf PC	Large performance oriented passenger car
Minivan LT	Minivans
Small LT	Small sport utility vehicles and pickups
Midsize LT	Midsize sport utility vehicles and pickups
Large LT	Large sport utility vehicles and pickups
Truck 2b/3	Class 2b and class 3 pickups
Van 2b/3	Class 2b and class 3 cargo vans

S2.2.2 Technology Groups

The CAFE Model organizes technologies into groups, which allows the model to seek the next "best" technology application in any of these groups.[4] There are eight technology groups defined: engine, diesel engine, transmission, electrical accessory, mass reduction, low rolling resistance tires, dynamic load reduction, and aerodynamic load reduction. 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)

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

[5] Some technologies were evaluated during the initial development of the modeling system; however, they were later excluded from analysis. These technologies appear grayed out in the table. Additionally, technologies from previous rulemakings, which are represented within the system, but not applicable to this analysis, are grayed out as well.

	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) (TRBDS1) Stoichiometric Exhaust Gas Recirculation (SEGR) *Downspeeding (DWNSP)* Turbocharging and Downsizing - Level 2 (24 bar BMEP) (TRBDS2) *Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) (CEGR1)* • *Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) (CEGR2)* *Miller Cycle (MILLER)* Lean Burn GDI (LGDI) *CNG (CNG)* *LNG (LNG)* *LPG (LPG)* •
Vehicle Diesel Engine Technology Group (DslMod)	Diesel (DSL) Diesel Turbo Efficiency (DTURB) Diesel Engine Friction Reduction (EFRD) Diesel Downsizing (DDOWN)
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)	Aero Drag Reduction, Level 1 (AERO1) Aero Drag Reduction, Level 2 (AERO2)

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

Table 3. Technology Input Assumptions

Input	Definition
Applicable	If the technology is available for applicability.
Year Available/Retired	First and last model year the technology is available for applicability.
Technology Type	Technology group of which the technology is a member, as shown in Table 2 above.
FC	Fuel consumption improvement estimate of the technology.
Primary Fuel Share	Assumed percentage of miles driven by the vehicle on the primary fuel after being converted to a PHEV.
Off-Cycle Credit PC	Amount of off-cycle credit that the vehicles regulated as passenger automobiles incur as a result of applying the technology.
Off-Cycle Credit LT	Amount of off-cycle credit that the vehicles regulated as light trucks incur as a result of applying the technology.
Cost Table	Fully learned-out table of costs by model year[8] (in 2009 dollars).
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, as well as the technology group of which the technology is a member.

S2.2.3 Technology Availability

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

If *Applicability* is set to **TRUE**, the *Year Available* and *Year Retired* fields from the input assumptions are further considered in determining the technology's availability. Together, these

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

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

two fields define a range of model years during which the technology may be applied. If the year being evaluated by the CAFE Model is prior to the setting in the *Year Available* field or after the *Year Retired* field, then the technology will be unavailable for the particular class of vehicle.

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

S2.2.4 Technology Fuel Consumption Reduction Factors

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

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

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

For some technologies, the modeling system converts a vehicle or a vehicle's engine from operating on one type of fuel to another. For example, application of Compressed Natural Gas (CNG) technology converts a vehicle from gasoline operation to CNG operation. In such a case, the aforementioned equation still applies, however, the FE_{new} value is assigned to the vehicle's new fuel type, while the fuel economy on the original fuel is discarded.

Moreover, whenever the modeling system converts a vehicle model to a Plug-In Hybrid/Electric Vehicle (PHEV), that vehicle is assumed to operate simultaneously on its primary fuel (either gasoline or diesel) as well as on electricity. In this case, the *FC* field only influences the conversion from primary fuel to electricity, where the FE_{new} value is assigned to vehicle's fuel economy on electricity, while the fuel economy on the primary fuel remains unchanged.[9] For PHEVs, the *Primary Fuel Share* field specifies the assumed amount of miles driven by the vehicle in gasoline-only or diesel-only operation. The vehicle's overall rated fuel economy is

[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, the modeling system assumes that no such improvement exist.

then defined as the average of the fuel economy on its primary fuel and the fuel economy on electricity, weighted by the fuel shares.[10]

When the system further improves the vehicle, converting it from a PHEV to a pure electric vehicle (EV), the primary fuel component is removed, while the electric-operated portion remains. As such, given the PHEV's significantly higher fuel economy on electricity, the vehicle's overall fuel economy for an EV also increases. For this reason, the fuel consumption improvement for EV technology should typically be set at zero. Otherwise, the *FC* field should represent the additional improvements to the electric motor.

Lastly, for non-liquid fuel types, such as CNG and electricity, the *FC* improvement and the resulting FE_{new} are assumed to be specified in gasoline gallon equivalents of energy use.

S2.2.5 Technology Cost Tables

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

Some technology costs have a cost basis associated with them. For instance, for mass reduction technologies, the technology input costs must be multiplied by the reduction of vehicle curb weight, in pounds, to get the full cost of applying the technology. Similarly some engine technologies have costs determined on a per-cylinder or per-bank (configuration) basis. The cylinder-based technologies include EFR1, LUB2_EFR2, DVVLS, DVVLD, CVVL, SGDI, and SGDIO; while the configuration-based technologies include CCPS, ICP, DCP, and VVA.

Along with the base *Cost Table*, the input assumptions also define the *Maintenance Cost Table* and the *Repair Cost Table*. Both of these tables are specified for each model year and account for the learning effect, wherever applicable. The former identifies the changes in the amount buyers are expected to pay for maintaining a new vehicle[11], while the latter identifies the increases in non-warranty repair costs attributed to application of additional technology. Additionally, the input assumptions include *the Stranded Capital Table*, which associates a penalty cost for each technology that is replaced (or superseded) prior to fully amortizing the initial investment associated with that technology.

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

S2.2.6 Technology Synergies

[10] The overall fuel economy for PHEVs is the rated value achieved by the vehicle assuming on-road operation specified by the *Primary Fuel Share* field. For compliance purposes, the vehicle's overall fuel economy is determined by the *Multi-Fuel* and the *PHEV Share* parameters defined in the scenarios input file. The scenarios input file is further discussed in Section A.4 of Appendix A.

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

Technology synergies exist when the combination of two technologies yields a fuel consumption reduction which differs from the value that would be derived directly from equation (1). The synergy value may be positive (*i.e.*, increased reduction of fuel consumption) or negative (decreased reduction of fuel consumption). Along with the fuel consumption synergies, the modeling system also defines cost synergies to ensure correct cost accounting as it proceeds down the decision trees. In both cases, synergies are additive and are applied prior to evaluating the combined effect of multiple technologies.

The technology input assumptions provide separate tables for fuel consumption synergies and for cost synergies. In both tables, each new row defines a synergy relationship between two technologies, for each of the technology classes specified in Table 1. In some cases, a synergy relationship may apply to one technology class, but not to the other. When this occurs, a value of zero is used to indicate that no synergy exists for the specific class.

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

S2.2.7 Technology Applicability and Backfill

The modeling system determines the applicability of each technology to each vehicle model, engine, and transmission using the combination of technology input assumptions as well as the technology applicability settings defined for each vehicle, engine and transmission in the market data file. As discussed in Section S2.2.3 above, the technology input assumptions determine the general availability of a technology to a particular class of vehicles, while the applicability setting in the market data file determines if the technology is available for application on a specific vehicle model.[12] Since the modeling system relies heavily on the technology applicability settings, these sections must accurately and completely represent the initial state of each vehicle, engine, and transmission in order to avoid potential modeling errors.

In some cases, technologies may be bypassed because they are not cost-effective. If the modeling system applies a technology that resides later in the sequence, it will 'backfill' anything that was previously skipped in order to fully account for technology costs and improvements, each of which are specified on an incremental basis. This backfill, however, will not occur if a technology is not applicable to the vehicle. In the case where the backfill operation requires backtracking through branches in the sequence, the modeling system will first resolve any engineering constraints and limitations, as well as applicability issues to determine whether the branch still exists. If there is still a branch, the system will follow the technology path that would result in lower overall costs.[13]

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[12] The technology applicability section is described in Sections A.1.2, A.1.3, and A.1.4 of Appendix A.

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

S2.2.8 Application of Mass Reduction Technology

When the modeling system evaluates application of mass reduction technology, the fuel consumption reduction factor, as defined in the preceding section, is adjusted to represent the realized compliance benefit associated with the regulatory binning of vehicle test weights. For light-duty vehicles, test weight (TW) is derived from the loaded vehicle weight (LVW), which is computed as vehicle curb weight (CW) plus 300 pounds, whereas for class 2b/3 vehicles, test weight is based on the adjusted loaded vehicle weight (ALVW), computed as the average of gross vehicle weight rating (GVWR) and curb weight. Test weight values are then rounded, resulting in TW "bins" as follows:

LVW or ALVW ≤ 4,000 lb.: TW rounded to nearest 125 lb.
4000 lb. < LVW or ALVW ≤ 5,500 lb.: TW rounded to nearest 250 lb.
LVW or ALVW > 5,500 lb.: TW rounded to nearest 500 lb.

The calculation of vehicle test weight may be generalized by the following formula:

$$TW = MAX\left(1000, \left\lceil \frac{W}{R} - 0.5 \right\rceil \times R\right) \quad (2)$$

Here, W refers to the LVW or ALVW, depending on vehicle class, and R is the rounding factor equivalent to 125, 250, or 500 lbs. as defined above.

Taking into account the rounding of test weight, the new fuel consumption reduction factor, specific to mass reduction technology, becomes:

$$FC_{rounded\_TW} = \Delta TW \times \frac{FC_{unrounded\_TW}}{\Delta CW} \quad (3)$$

Where:

ΔCW = % change in curb weight (obtained from model input),
ΔTW = % change in test weight (calculated),
$FC_{unrounded\_TW}$ = % change in fuel consumption (from model input), without TW rounding, and
$FC_{rounded\_TW}$ = % change in fuel consumption (calculated), with TW rounding.

While the value for ΔCW is obtained directly from the model inputs, the value for ΔTW is calculated from vehicle's initial CW, vehicle's CW prior to application of mass reduction technology, and vehicle's CW after application of mass reduction technology. Computation of vehicle test weights (or, likewise, prior and future knowledge of TWs) at multiple stages is required, since the model inputs define ΔCW as incremental percent changes calculated from the vehicle's initial CW and applicable to the vehicle's present CW. That is:

$$CW_{NEW} = CW - CW_{INITIAL} \times \Delta CW \quad (4)$$

Hence, for each of the CW values, an appropriate TW value is obtained, with the ΔTW taking the following form:

$$\Delta TW = \frac{TW - TW_{NEW}}{TW_{INITIAL}} \quad \textbf{(5)}$$

On occasion, application of mass reduction technology may not yield a substantial decrease in CW necessary to push a vehicle into a new TW bin. For example, if a vehicle's present CW places it on the far edge of its TW bin, even larger amounts of weight reduction may not be enough to produce a CW that would move it into a new bin. As such, ΔTW and $FC_{rounded\_TW}$ become zero, consequently leading to no compliance benefit being realized on a vehicle. Conversely, if a vehicle starts with a CW that places it on the other side of its TW bin, even a small reduction in mass may lead to a new test weight. This leads to a higher calculated ΔTW value, ultimately inflating $FC_{rounded\_TW}$ and resulting in a high compliance benefit.

In addition to augmenting the fuel consumption reduction factor, application of mass reduction technology may also have an influence on the vehicle's new payload and towing capacity by way of adjusting the vehicle's GVWR and gross combined weight rating (GCWR) values. The degree by which GVWR and GCWR are affected is controlled in the scenarios input file through the "Payload Return" and "Towing Return" parameters. The calculation of new GVWR and GCWR are represented by the following formulas:

$$GVWR_{NEW} = \mathrm{MIN}\begin{pmatrix} GVWR - PayloadReturn \times (CW - CW_{NEW}), \\ CW_{NEW} * \left(\frac{GVWR}{CW}\right)_{MAX} \end{pmatrix} \quad \textbf{(6)}$$

$$GCWR_{NEW} = \mathrm{MIN}\begin{pmatrix} GCWR - TowingReturn \times (GVWR - GVWR_{NEW}), \\ GVWR_{NEW} * \left(\frac{GCWR}{GVWR}\right)_{MAX} \end{pmatrix} \quad \textbf{(7)}$$

Where:

CW and CW_{NEW} = vehicle's curb weight prior to and following application of mass reduction technology
GVWR and $GVWR_{NEW}$ = vehicle's GVWR prior to and following application of mass reduction technology
GCWR and $GCWR_{NEW}$ = vehicle's GCWR prior to and following application of mass reduction technology
PayloadReturn = % of CW reduction returned to payload capacity
TowingReturn = % of GVWR reduction returned to towing capacity
$\left(\frac{GVWR}{CW}\right)_{MAX}$ = limiting factor, defined for each input vehicle, preventing GVWR from increasing beyond levels observed among the majority of similar vehicles
$\left(\frac{GCWR}{GVWR}\right)_{MAX}$ = limiting factor, defined for each input vehicle, preventing GCWR from increasing beyond levels observed among the majority of similar vehicles

Since the current version of the model is tailored for analysis of class 2b and class 3 pickups and vans, the $GVWR_{NEW}$ is further capped to prevent decreasing below 8501 lbs. Additionally for class 2b/3 vehicles, given that TW is a derivative of the ALVW, application of mass reduction technology, and any subsequent effect on vehicle payload, further reflects on the resultant fuel consumption reduction factor.

S2.2.9 Technology Sequencing and Branching

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

S2.2.9.1 Sequencing and Branching within a Technology Group

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

S2.2.9.2 Bypassing a Technology

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

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

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

An example of the limitations would be within the engine technology group, as shown in Figure 2, below, where there is a separate path for vehicles with overhead valves (OHV) engines, single overhead cam engines (SOHC), and for engines with dual overhead cams (DOHC). Likewise, as shown in Figure 3 further down, the transmission technology group follows two distinct paths – one for manual transmissions and another for automatics.

S2.2.9.3 Engine Technology Sequencing and Branching

The engine technology sequence, shown in Figure 2, consists of two primary paths, one used for gasoline engines, and the other for diesel engines. The gasoline sequence is further subdivided into three paths: single overhead cam (SOHC); dual overhead cam (DOHC); and overhead valve (OHV). The technology applicability settings in the market data file aid the modeling system in determining which of the paths the system will follow for a given vehicle model. An additional branch, between DVVLD and CVVL technologies, exists within the DOHC branch. The model chooses which path to follow based on availability for the specific vehicle and the vehicle technology class, the technology phase-in constraints, and the technology cost-effectiveness.

Toward the completion of the gasoline engine technology sequence, the system encounters another branch, which culminates in a choice between conversion to LGDI engine, following a dieselization path, or following a strong hybrid path. Additionally, at the end of the dieselization sequence, the system will follow a strong hybrid path as well. The path that the model chooses is, again, based on availability for the specific vehicle and the vehicle technology class, the technology phase-in constraints, and the technology cost-effectiveness.

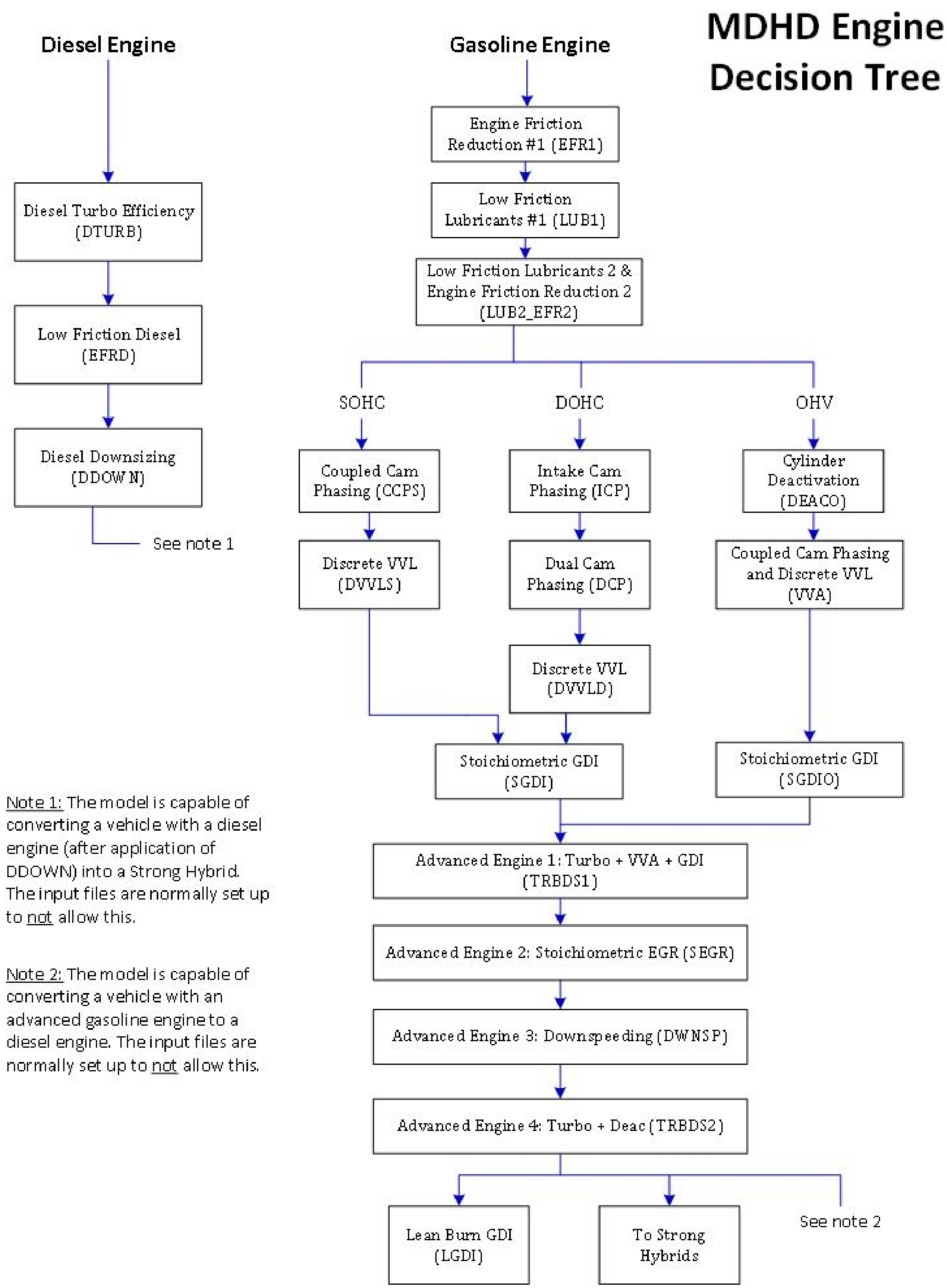

Figure 2. Engine Technology Group Technology Sequence

S2.2.9.4 Transmission Technology Sequencing

The MDHD transmission technology sequence, shown in Figure 3, contains 8-speed automatic transmissions as an advance available to vehicles with automatic transmissions with fewer than 8 forward speeds.

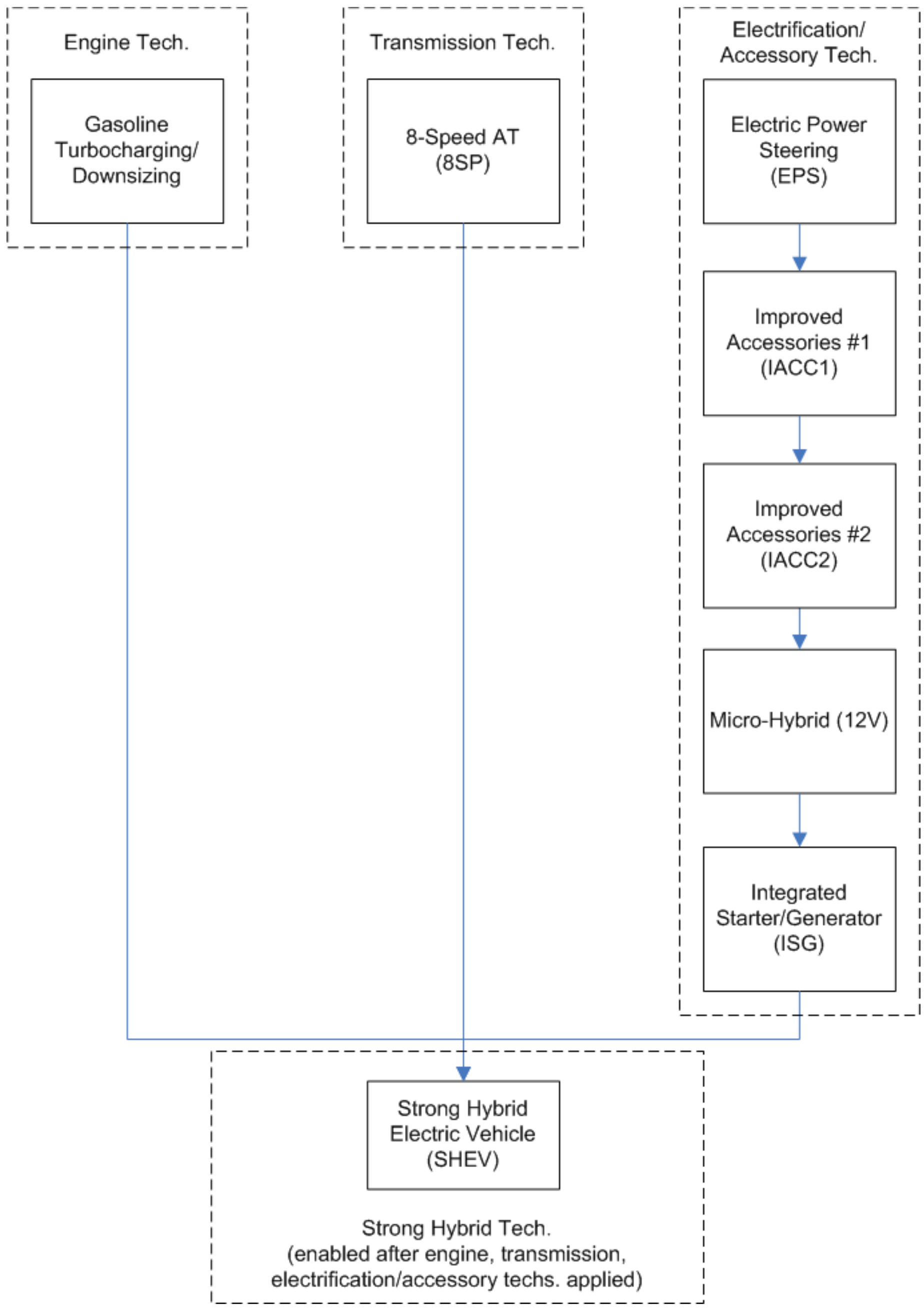

Figure 3. Transmission, Electrification/Accessory, and Hybrid Technology Decision Tree

S2.2.9.5 Electrical Accessory & Strong Hybrid Technology Sequencing

The electrical accessory technology sequence has no branches, as shown in Figure 3. 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 and transmission paths have been fully applied (excluding lean-burn direct injection). Furthermore, if a strong hybrid technology is applied before exhausting the electrification path, any preceding electrification technologies will be backfilled. Thus the engine, transmission, and (to a certain extent) electrification technologies are considered "enablers" that must be installed on a vehicle prior to the application of the strong hybrid technologies.

S2.2.9.6 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 4, 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.

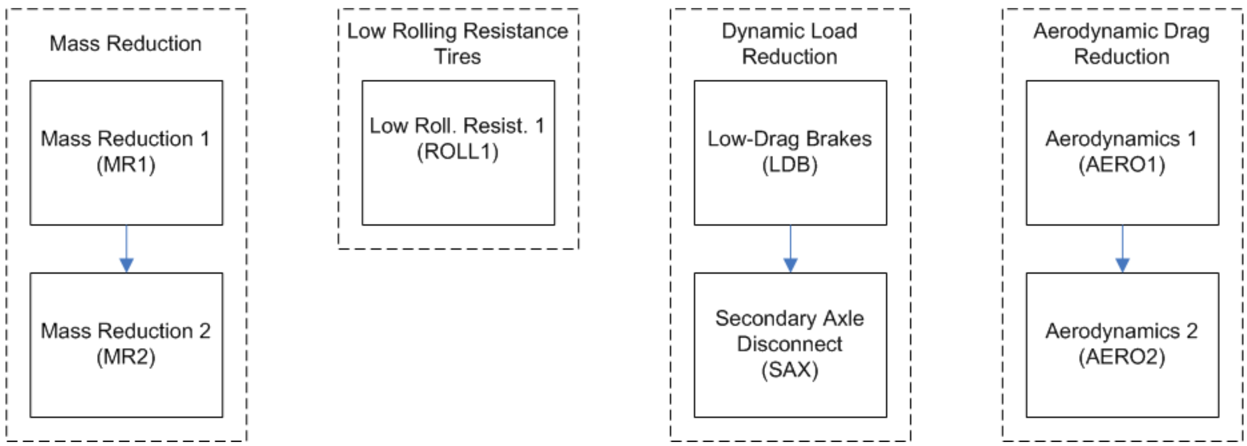

Figure 4. Vehicle Technology Decision Tree

S2.3 Compliance Simulation Loop

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 5 gives an overview of the process. If, considering all regulatory classes, the manufacturer owes no CAFE civil penalties, then the algorithm applies no technologies beyond any carried over from the previous model year, because the manufacturer is already in compliance with the standard. If the manufacturer does owe CAFE civil penalties, then the algorithm first finds the best next applicable technology in each of the technology groups (*e.g.*, engine technologies), and applies the same criterion to select the best among these. If this manufacturer is assumed to be unwilling to pay CAFE civil penalties (or, equivalently, if the user has set the system to exclude the possibility of paying civil penalties as long as some technology can still be applied), then the algorithm applies the technology to the affected vehicles. If the manufacturer is assumed to be willing to pay CAFE civil penalties and applying this technology would have a lower "effective cost" (discussed below) than simply paying penalties, then the algorithm also applies the technology. In either case, the algorithm then reevaluates the manufacturer's degree of noncompliance. If, however, the manufacturer is assumed to be willing to pay CAFE civil penalties and doing so would be less expensive than applying the best next technology, then the algorithm stops applying technology to this manufacturer's products. After, this process is repeated for each manufacturer. It is then repeated again for each modeling year. Once all modeling years have been processed, the compliance simulation algorithm concludes.

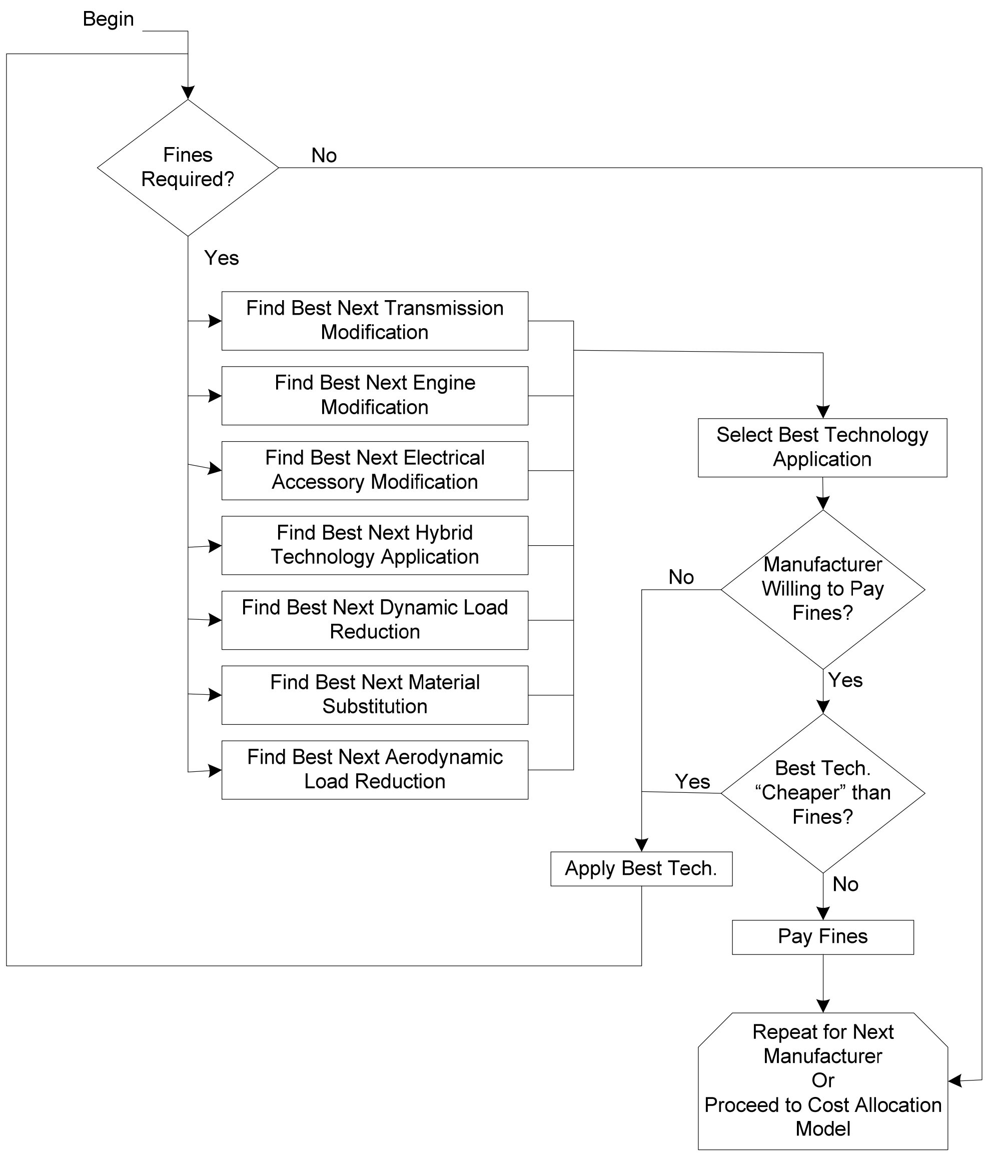

Figure 5. Compliance Simulation Algorithm

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.[14] The effective cost is used for evaluating the relative attractiveness of different technology applications, not for actual cost accounting. The effective cost is defined as the change in total technology costs incurred by the manufacturer plus the

[14] 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, which is regulated as a passenger car, and a minivan, which is regulated as a light truck. If the manufacturer's passenger car fleet complies with the corresponding standard, the algorithm accounts for the fact that upgrading this engine will incur costs and realize fuel savings for both of these vehicle models, but will only yield reductions of CAFE fines for the light truck fleet.

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

$$\boldsymbol{COST_{eff}} = \sum_{i=BaseMY}^{i=PresentMY} \frac{\Delta \boldsymbol{TECHCOST_i} + \Delta \boldsymbol{FINE_i} - (\boldsymbol{VALUE_{FUEL}})_i + \boldsymbol{WELFARELOSS_i}}{(\boldsymbol{N_j})_i} \quad \textbf{(8)}$$

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:[15]

$$\boldsymbol{VALUE_{FUEL}} = \sum_{i \in j} \left[\boldsymbol{N_i} \times \sum_{FT} \left(\left(\sum_{v=0}^{v=PB} \frac{(\boldsymbol{SURV_v})_i \times (\boldsymbol{MI_v})_i \times \boldsymbol{VMTGROWTH_{MY+v}} \times (\boldsymbol{PRICE_{FT}})_{MY}}{(\boldsymbol{1} - \boldsymbol{GAP_{FT}}) \times (\boldsymbol{1} + \boldsymbol{r})^{v}} \right) \times \left(\frac{(\boldsymbol{FS_{FT}})_i}{(\boldsymbol{FE_{FT}})_i} - \frac{(\boldsymbol{FS'_{FT}})_i}{(\boldsymbol{FE'_{FT}})_i} \right) \right) \right] \quad \textbf{(9)}$$

where $(SURV_v)_i$ is the probability that vehicle *i* of a given vintage *v* will remain in service, $(MI_v)_i$ is the average number of miles driven in a year by vehicle *i* 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, e85, 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 vehicle model *i* in the current model year *MY*, $(PRICE_{FT})_{MY}$ is the price of the specific fuel type in year *MY*, 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, $(SURV_v)_i$, $(MI_v)_i$, $VMTGROWTH_{MY+v}$, $(PRICE_{FT})_{MY}$, and GAP_{FT} are 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).

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[15] 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.

In equation (8), *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.[16] *FINE* is calculated by evaluating the following before and after the pending technology application, and taking the difference between the results:

$$FINE = -k_F \sum_C \text{MIN}(CREDIT_C + CREDITIN_C - CREDITOUT_C, 0) \qquad \textbf{(10)}$$

Here, k_F is in dollars per one credit of shortfall (*e.g.*, \$5.5/credit) and specified in the scenarios input file.

Within each regulatory class *C*, the 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 taking the difference between the CAFE level achieved by the class and the standard applicable to the class, and multiplying the result by the number of vehicles in that class. Taking into account attribute-based CAFE standards, for light duty regulatory classes, this is expressed as follows:

$$CREDIT_C = [\text{ROUND}(CAFE_C(\boldsymbol{V}_C), 1) - STD_C(\boldsymbol{V}_C)] \times N_C \times 10 \qquad \textbf{(11)}$$

while for the class 2b and class 3 regulatory classes, credits are computed as:

$$CREDIT_C = \left[\frac{100}{STD_C(\boldsymbol{V}_C)} - \text{ROUND}\left(\frac{100}{CAFE_C(\boldsymbol{V}_C)}, 2\right)\right] \times N_C \times 100 \qquad \textbf{(12)}$$

where $\boldsymbol{V}_C$ is a vector containing all vehicle models in regulatory class *C*, $CAFE_C(\boldsymbol{V}_C)$ is the CAFE level for regulatory class *C*, $\text{STD}_C(\boldsymbol{V}_C)$ is a function defining the standard applicable to regulatory class *C*, and N_C is the total sales volume for regulatory class *C*.

Additionally, in Equation (10) above, $CREDITIN_C$ is the amount of CAFE credit transferred into regulatory class *C* from another compliance category, while $CREDITOUT_C$ is the amount of CAFE credit transferred out of regulatory class *C* into another compliance category.

Figure 6 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.

[16] 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.

As shown in Figure 6, 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 (8), (9), and (10), irrespective of the manufacturer's willingness to pay fines.

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.

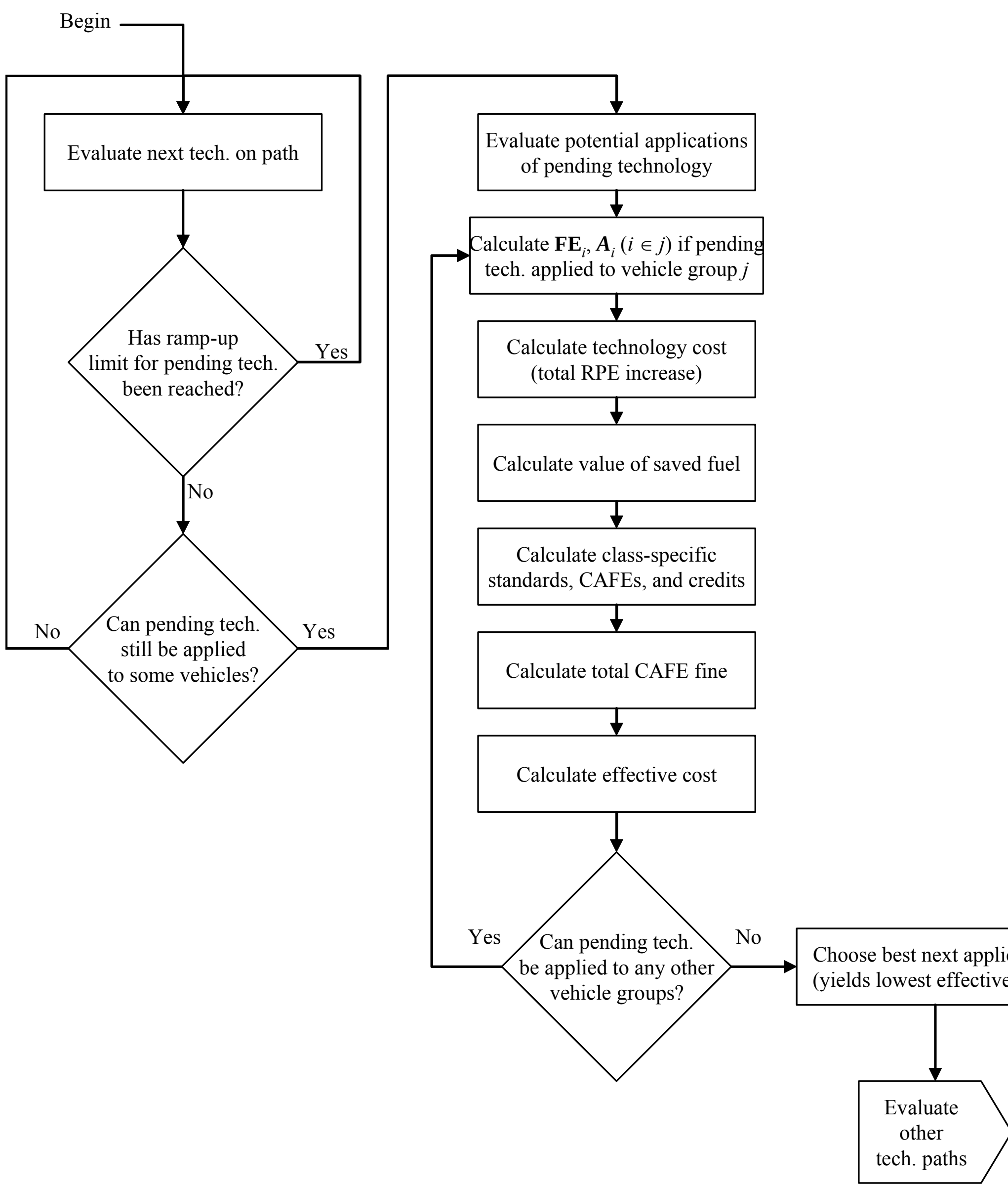

Figure 6. Determination of "Best Next" Technology Application

Chapter Three Calculation of Effects

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

The effects on energy use and emissions from tightening or reforming CAFE standards are estimated separately for each individual vehicle model and vintage (or model year) over its expected life span in the U.S. vehicle fleet. A vehicle model's life span extends from the initial model year when it is produced and sold, through the year when vehicles produced during that model year have reached the maximum age assumed in the CAFE model.[17] Each of the effects of raising CAFE standards is measured by the difference in the value of a variable – such as total gallons of fuel consumed by a vehicle model and vintage over its lifetime – with its baseline fuel economy level, and its estimated fuel economy if that model were instead required to comply with a stricter CAFE standard. A vehicle model's baseline fuel economy level is usually (but not necessarily) defined as the level of fuel economy it would be expected to have if the CAFE standard currently in effect for its vehicle class remained in effect for the future model year when it is produced.

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

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

Section 1 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:

$$n_{k,MY} = N_{MY} P_{k,MY} \tag{13}$$

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

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

$$n_{k,MY,t} = n_{k,MY} s_{k,a} \tag{14}$$

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:

$$a = t - MY.\text{[18]} \tag{15}$$

The CAFE model currently accommodates different schedules of survival rates by vehicle age for varying vehicle classes, where class 1/2a light trucks are further separated into vans, SUVs, and pickups, as reported in Section A.3.1 of Appendix A. Based on analysis of recent registration data, the maximum ages of passenger automobiles and light and medium duty trucks are estimated to be 30 years and 37 years, respectively.[19]

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

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

[19] 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.

electricity generated off-board and stored in on-board batteries).[20] 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.

[20] The system is also capable of handling additional fuel or technology types (namely, CNG, LNG, and LPG), provided the accompanying input assumptions are available to the model.

Section 2 Vehicle Use and Total Lifetime Mileage

The CAFE model employs the widely-documented relationship between vehicle age and declining average vehicle use to estimate the number of miles that individual vehicle models are driven annually and in total over their expected lifetimes. Separate schedules of average annual miles driven by age of vehicle were developed for passenger automobiles, light trucks (class 1 and 2a), and medium duty trucks (class 2b and 3), where light trucks are further separated into vans, SUVs, and pickups, as reported in Section A.3.1 of Appendix A. For passenger automobiles and light trucks, the initial estimates of the relationship between vehicle age and average annual miles driven were tabulated from the sample of approximately 140,000 households included in the 2009 National Household Travel Survey (NHTS).[21] For class 2b/3 trucks, these initial estimates were derived from a combination of the 2009 NHTS and the 2002 Vehicle In Use Survey (VIUS).

Two adjustments are applied to these mileage schedules to forecast the average number of miles that vehicles produced during future model years will be driven each year over their expected lifetimes. First, the estimates of annual miles driven by passenger cars and light trucks during 2008 are adjusted to reflect assumed future growth in average vehicle use.[22] The average number of miles driven by cars and light trucks of all ages is assumed to grow by 0.5% per year from 2008 on. For class 2b/3 trucks, however, this adjustment does not apply.

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 calendar year 2008 (for passenger cars and light trucks) or 2013 (for class 2b/3 trucks) and each subsequent calendar year. This adjustment employs actual gasoline prices for the years 2009-2013, forecasts for 2014-2040 reported in the U.S. Energy Information Administration's ***Annual Energy Outlook 2014***, and extrapolations of gasoline prices beyond the year 2040 developed by EPA.[23] This adjustment assumes an elasticity of annual vehicle use with respect to fuel cost per mile of -0.10, corresponding to a fuel economy rebound effect of 10%.

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

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

[22] 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.

[23] 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).

$$m_{k,MY,t} = m_{type,t-MY,MY'}(1+r)^{t-MY'}\left[1+\varepsilon_{m,cpm}\left(\frac{C_{k,MY,t}}{C_{k,t-MY,MY'}}-1\right)\right] \quad \textbf{(16)}$$

where $m_{type,t\text{-}MY,MY'}$ is the average annual mileage for a car or truck that was of age $t\text{-}MY$ during the VMT base year (2008 for car or class 1/2a truck, or 2013 for class 2b/3 truck), r is the rate of growth in average annual miles per vehicle beginning in 2008 or 2013, $t\text{-}MY'$ is the number of years that have elapsed between the base year and calendar year t, $\varepsilon_{m,cpm}$ is the elasticity of annual vehicle use with respect to fuel cost per mile, $C_{k,MY,t}$ is fuel cost per mile during year t for a car or truck model k, and $C_{k,t\text{-}MY,MY'}$ is fuel cost per mile for a car or truck that was of age $t\text{-}MY$ during the base year.

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 (16), 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,

$$C_{k,MY,t,CAFE} = \frac{P_t}{mpg_{k,MY,CAFE}(1-gap)} \quad \textbf{(17)}$$

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

Equations (16) and (17) 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.[24]

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:

$$M_{k,MY,t,CAFE} = n_{k,MY,t} m_{k,MY,t,CAFE} \quad \textbf{(18)}$$

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

[24] 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 (16) and (17) 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 forecast of MPG from the 2001 NHTS, and then adding the increase in use estimated by applying the rebound effect to the reduction in fuel cost per mile resulting from the increase in its fuel economy between the baseline forecast and a higher CAFE standard.

Section 3 Fuel Consumption and Savings

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

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

$$g_{k,MY,t,CAFE,fuel} = \frac{m_{k,MY,t,CAFE} s_{k,MY,CAFE,fuel}}{mpg_{k,MY,CAFE,fuel}\left(1 - gap_{fuel}\right)} \quad \textbf{(19)}$$

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.[25]

The CAFE model estimates use of eight different types of fuel energy: gasoline, diesel, E85 (blend of 85% ethanol and 15% gasoline), B20 (blend of 20% biodiesel and 80% petrodiesel), electricity, hydrogen, CNG, LNG, and LPG. However, only gasoline, diesel, E85, and electricity are presently used for analysis. 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 1% of their annual mileage each year over their lifetimes, while PHEVs are assumed to operate on electricity for 50% of their annual mileage and on gasoline for the remaining 50%. These values are inputs to the CAFE model, and can be adjusted by the user.

As equation (19) 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:

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

$$G_{MY,t,CAFE,fuel} = \sum_{k} g_{k,MY,t,CAFE,fuel} \qquad \textbf{(20)}$$

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:

$$G_{MY,CAFE,fuel} = \sum_{t} \sum_{k} g_{k,MY,t,CAFE,fuel} \qquad \textbf{(21)}$$

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:

$$\Delta G_{MY,t,CAFE,fuel} = G_{MY,t,CAFE,fuel} - G_{MY,t,BASE,fuel} \qquad \textbf{(22)}$$

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:

$$\Delta G_{MY,CAFE,fuel} = \sum_{t} G_{MY,t,CAFE,fuel} - \sum_{t} G_{MY,t,BASE,fuel} \qquad \textbf{(23)}$$

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

Section 4 Greenhouse Gas Emissions

Fuel savings from imposing stricter CAFE standards will result in lower emissions of carbon dioxide (CO_2), the primary greenhouse gas emitted during the refining, distribution, and combustion of transportation fuels.[26] 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.[27]

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:

$$CO2^{veh}{}_{MY,t,CAFE} = \sum_{fuel} \left(G_{MY,t,CAFE,fuel} d_{fuel} C_{fuel} \right) \left(\frac{44}{12} \right) \quad \textbf{(24)}$$

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:

$$CO2^{veh}{}_{MY,CAFE} = \sum_{t} CO2_{MY,t,CAFE} \quad \textbf{(25)}$$

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

[26] 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.

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

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

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

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

$$CO2^{ref}{}_{MY,t,CAFE} = \sum_{fuel} G_{MY,t,CAFE,fuel}\left(CO2^{f}{}_{fuel} + CO2^{r}{}_{fuel} + CO2^{d}{}_{fuel}\right) \qquad \textbf{(26)}$$

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

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

$$CO2^{ref}{}_{MY,CAFE} = \sum_{t} CO2_{MY,T,CAFE} \qquad \textbf{(27)}$$

where *t* again ranges from *MY* to *(MY+30)* for cars or *(MY+37)* for 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 trucks produced during model year *MY* are:

$$CO2^{tot}{}_{MY,CAFE} = CO2^{veh}{}_{MY,CAFE} + CO2^{ref}{}_{MY,CAFE} \qquad \textbf{(28)}$$

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

$$\Delta CO2^{tot}{}_{MY,CAFE} = CO2^{tot}{}_{MY,CAFE} - CO2^{tot}{}_{MY,BASE} \tag{29}$$

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

Section 5 Air Pollutant Emissions

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

The increased use of vehicle models with improved fuel economy that occurs through the fuel economy rebound effect causes increased emissions of most criteria pollutants, since federal standards regulate permissible emissions of these pollutants on a per-mile basis.[28] 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 passenger cars, light trucks, and class 2b/3 trucks operating on different fuel types; PHEVs when 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 trucks produced during model year *MY* during year *t* of their lifetimes, denoted $E^{veh}{}_{MY,t}$, are thus:

$$E^{veh}{}_{MY,t,CAFE} = \sum_{fuel}\sum_{k} M_{k,MY,t,CAFE}\, s_{k,MY,CAFE,fuel}\, e_{k,t-MY,fuel} \qquad \textbf{(30)}$$

where, as in equation (19) 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.[29]

In equation (30), $e_{k,t-MY,fuel}$ 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*).[30] Emission rates from vehicle use also depend on

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[28] 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.

[29] As in equation (19), 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.

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

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

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

$$E^{veh}{}_{MY,CAFE} = \sum_t E^{veh}{}_{MY,t,CAFE} \tag{31}$$

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

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

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

$$E^{ref}{}_{MY,CAFE} = \sum_t G_{my,t,CAFE,fuel} [e^f{}_{fuel} r_{fuel} f_{fuel}) + e^r{}_{fuel} r_{fuel} + e^d{}_{fuel}) \tag{32}$$

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

For vehicles operating on electricity, the bracketed expression in equation (32) 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:

$$E^{ref}{}_{MY,CAFE} = \sum_t E^{ref}{}_{MY,T,CAFE} \tag{33}$$

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

$$E^{tot}{}_{MY,CAFE} = E^{veh}{}_{MY,CAFE} + E^{ref}{}_{MY,CAFE} \quad \textbf{(34)}$$

Again, the presence of the CAFE subscript in equation (34) indicates that vehicles' lifetime emissions depend on the CAFE standard in effect during the model year they are produced, through its effect on their fuel economy, usage, and fuel consumption.

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

$$\Delta E^{tot}{}_{MY,CAFE} = E^{tot}{}_{MY,CAFE} - E^{tot}{}_{MY,BASE} \quad \textbf{(35)}$$

Section 6 Vehicle Safety Effects

As discussed in Section 2 above, vehicle miles traveled may increase due to the fuel economy rebound effect, resulting from improvements in vehicle fuel efficiency and cost of fuel, as well as the assumed future growth in average vehicle use. Increases in total lifetime mileage increase exposure to vehicle crashes, including those that result in fatalities. Consequently, the modeling system computes total fatalities attributed to vehicle use for vehicles of model year *MY*, belonging to safety class *SC* and weight threshold *T* as:

$$F_{MY,SC,T} = \frac{VMT_{MY,SC,T}}{1e9} \times BASE_{SC,T} \times FMVSS_{SC,T} \quad \textbf{(36)}$$

Where, $VMT_{MY,SC,T}$ is the lifetime vehicle miles traveled for vehicles of model year MY within a safety class *SC* and weight threshold *T*, $BASE_{SC,T}$ is the measure of base fatalities per billion miles for vehicles within a safety class *SC* and weight threshold *T*, and $FMVSS_{SC,T}$ is an adjustment for new Federal Motor Vehicle Safety Standards (FMVSS) for vehicles within a safety class *SC* and weight threshold *T*. The $FMVSS_{SC,T}$ adjustment in equation (36) above is employed to account for the fact that vehicles involved in future crashes will be certified to more stringent safety standards than those involved with past crashes upon which the base rates of involvement in fatal crashes were estimated.

Since the use of mass reducing technology is present within the model, safety impacts may also be observed whenever a vehicle's base weight decreases. Thus, in addition to computing total fatalities related to vehicle use, the modeling system also estimates changes in fatalities due to reduction in vehicle's curb weight. These changes are computed for vehicles of model year *MY*, belonging to safety class *SC* and weight threshold *T* as:

$$F^{\Delta CW}_{MY,SC,T} = \frac{VMT_{MY,SC,T}}{1e9} \times \frac{\Delta CW}{100} \times Effect_{SC,T} \times BASE_{SC,T} \times FMVSS_{SC,T} \quad \textbf{(37)}$$

Where, $VMT_{MY,SC,T}$, $BASE_{SC,T}$, and $FMVSS_{SC,T}$ are as defined for equation (36) above, ΔCW is the amount by which the vehicle's curb weight decreases, and $Effect_{SC,T}$ is the percentage by which fatalities change for every 100 lbs. that a vehicle's curb weight is reduced for vehicles within a safety class *SC* and weight threshold *T*. Equation (37) is applied directly as long as the vehicle's initial and final curb weights place it within the same weight threshold. In the event that mass reduction causes the vehicle to cross the threshold boundary, equation (37) is applied in two steps, where a portion of the ΔCW reduced (up to the threshold boundary) uses the $Effect_{MY,SC,T}$, $BASE_{SC,T}$, and $FMVSS_{SC,T}$ coefficients from the vehicle's initial weight threshold, and a portion of the ΔCW reduced (beyond the threshold boundary) uses the coefficients from the vehicle's new weight threshold.

The total fatalities attributed to vehicle use and vehicle weight change for vehicles of model year *MY*, belonging to safety class *SC* and weight threshold *T* are, hence, defined as the sum of the two components:

$$F^{Total}_{MY,SC,T} = F_{MY,SC,T} + F^{\Delta CW}_{MY,SC,T} \quad \textbf{(38)}$$

Lastly, total fatalities occurring within the industry in model year *MY* are accumulated across all vehicles belonging to safety classes *SC* and weight thresholds *T* as:

$$F_{MY}^{Total} = \sum_{SC,T} F_{MY,SC,T}^{Total} \quad \textbf{(39)}$$

The safety classes, weight thresholds, $Eff_{SC,CW}$, $FMVSS_{SC,CW}$ and $BASE_{SC,CW}$ variables are derived from Dr. Chuck Kahane's 2012 study and are specified as inputs to the model, defined in the parameters input file.[31]

In addition to using inputs to estimate the future involvement of modeled vehicles in crashes involving fatalities, the model also applies inputs defining other accident-related externalities estimated on a dollar per mile basis, as discussed below in S7.1.7.

[31] Kahane, C. J. (2012). "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs – Final Report," DOT HS 811-665 is in NHTSA-2010-0131-0336 and will also be in docket NHTSA-2010-0152. You can access the docket at http://www.regulations.gov/ by typing 'NHTSA-20100152' where it says "enter keyword or ID" and then clicking on "search."

Section 7 Private versus Social Costs and Benefits

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

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

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

S7.1 Benefits and Costs to New Vehicle Buyers

S7.1.1 Increases in New Vehicle Prices

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

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

S7.1.2 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.

S7.1.3 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.

S7.1.4 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.[32] 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.

S7.1.5 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.

S7.1.6 Social Benefits and Costs from Increased Fuel Economy

S7.1.6.1 The "Social Value" of Fuel Savings

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

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

S7.1.6.2 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

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

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

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

S7.1.6.3 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.

S7.1.7 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.

In addition to external costs, the modeling system also computes costs associated with the cleanup of fatal crashes, attributed to increases in total miles driven and the application of mass reduction technology.

Appendix A Model Inputs

The CAFE Model 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 4 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 4. 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, regulatory classification, references to specific engines and transmissions used, and settings related to technology applicability.
Market Data (Engines Worksheet)	Contains an indexed list of engines available during the study period, along with various engine attributes and 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 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 (upstream and downstream), and economic externalities related to highway travel and petroleum consumption. Additionally, starting with this revision of the model, the parameters input file contains inputs necessary for performing fleet analysis for the EIS.
Scenarios	Specifies coverage, structure, and stringency of CAFE standards for scenarios to be simulated.

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 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 can be used or the cell can be left blank.

Table 5. Manufacturers Worksheet

Category	Column	Units	Definition/Notes
General	Manufacturer Code	integer	Unique number assigned to each manufacturer.
	Manufacturer Name	text	Name of the manufacturer.
	Cost Allocation Strategy	integer	The cost allocation strategy the manufacturer will use for allocating costs. 0 = allocate technology costs on an as-incurred basis 1 = distribute technology costs and fines based on the share of aggregate sales revenue 2 = not used 3 = distribute technology costs and fines evenly
	Discount Rate	number	Represents the manufacturer specific discount rate, which factors into the effective cost calculation.
	Payback Period	number	The number of years required for an initial investment to be repaid in the form of future benefits or cost savings.
	Payback Period (After Compliance)	number	The payback period to use after the manufacturer reached compliance.
	Optimize	text	Y = consider the manufacturer during optimization N = do not consider the manufacturer during optimization
Willingness to Pay CAFE Fines	2011	text	Represents the manufacturer's willingness to pay fines. Y = pay fines instead of applying ineffective technologies N = apply ineffective technologies instead of paying fines
	2012	text	
	…		
	2029	text	
	2030	text	
Available Passenger Car Credits (mpg)	2011	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Passenger Cars.
	2012	vehicle-mpg	
	…		
	2029	vehicle-mpg	
	2030	vehicle-mpg	
Available Light Truck Credits (mpg)	2011	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Light Trucks.
	2012	vehicle-mpg	
	…		
	2029	vehicle-mpg	
	2030	vehicle-mpg	
Available Light Truck 2b/3 Credits (mpg)	2011	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as class 2b/3 Trucks.
	2012	vehicle-mpg	
	…		
	2029	vehicle-mpg	
	2030	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 6 and Table 7 list the different columns of information specified in the vehicle models file. To make the information readable, the Vehicle Models tables are divided into sections.

Table 6. 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.
	Platform	text	The platform 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 (by Fuel Type[33])	number	The CAFE fuel economy rating of the vehicle for each fuel type.
	Fuel Share (by Fuel Type[33])	number	The percent share that the vehicle runs on each fuel type. This value indicates the amount of miles driven by the vehicle on each fuel type. The sum of all fuel shares for any given vehicle must add up to one.
Sales	MY2010	units	Vehicle's projected production for sale in the US.
	MY2011	units	
	…		
	MY2029	units	
	MY2030	units	
MSRP	MY2010	dollars	Vehicle's projected average MSRP (sales-weighted, including options).
	MY2011	dollars	
	…		
	MY2029	dollars	
	MY2030	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 LT2b3 = the vehicle should be regulated as a class 2b/3 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
Vehicle Information	Class	text	Vehicle class.
	Style	text	Vehicle style.
	Structure	text	Vehicle structure (ladder or unibody).
	Drive	text	Vehicle drive (A=all-wheel drive, F=front-wheel drive, R=rear-wheel drive, 4=four-wheel drive).
	Footprint	sq. feet	The vehicle footprint; wheelbase times average track width.
	Curb Weight	pounds	Total weight of the vehicle, including batteries, lubricants, and other expendable supplies, but excluding the driver, passengers, and other payloads (SAE J1100).
	GVWR	pounds	Gross Vehicle Weight Rating; weight of loaded vehicle, including passengers and cargo.
	GCWR	pounds	Gross Combined Weight Rating; weight of loaded vehicle, including passengers and cargo, as well as the mass of the trailer and cargo in the trailer.
	Max GVWR/CW	proportion	Maximum ratio of GVWR to Curb Weight allowed for the vehicle. During application of mass reduction technology, vehicle's GVWR will be adjusted such that its GVWR/CW ratio does not exceed this value.
	Max GCWR/GVWR	proportion	Maximum ratio of GCWR to GVWR allowed for the vehicle. During application of mass reduction technology, vehicle's GVWR will be adjusted such that its GVWR/CW ratio does not exceed this value.

[33] For each vehicle, fuel economies and fuel shares are reported independently for each of the following fuel types: gasoline, E85, diesel, B20, electricity, hydrogen, CNG, LNG, and LPG. If the vehicle does not use a specific fuel type, the associated fuel economy and fuel share values will be zero.

	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	List of previous and future refresh years of the vehicle, separated by a semicollon.
	Redesign Year	model year	List of previous and future redesign years of the vehicle, separated by a semicollon.
	Employment Hours per Vehicle	hours	Employment hours associated with the production of each vehicle model.

The applicability of technologies considered on a vehicle model basis (as opposed, for example, on an engine basis) can be controlled for each vehicle model by using the "Technology Applicability" category. Since the modeling system relies heavily on these settings when determining the initial usage and availability of technology to a vehicle, this section must be complete and accurate in order to avoid modeling errors.

Table 7. Vehicles Worksheet (2)

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

A.1.3 Engines Worksheet

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

Table 8. 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).
Classifications	Engine Size	text	The relative size of the engine, with respect to technology application. Allowed values are: SD or Small = a small sized engine MD or Medium = a medium sized engine LD or Large = a large sized engine
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	text	
	SEGR	text	
	DWNSP	text	
	TRBDS2	text	
	CEGR1	text	
	CEGR2	text	
	MILLER	text	
	LGDI	text	
	CNG	text	
	LNG	text	
	LPG	text	
	DSL	text	
	DTURB	text	
	EFRD	text	
	DDOWN	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. As in the vehicles worksheet, the technology applicability for any transmission technology must be complete and accurate for any specific transmission.

Table 9. 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, large pickups and SUVs, class 2b/3 pickups, and class 2b/3 vans. Input assumptions that are common among all technology classes are listed on a separate technologies definitions tab. Table 10 shows the contents of a technologies definitions tab for all classes while Table 11 shows the contents of the technology assumptions tabs.

Table 10. Technologies Definitions

Category	Column	Units	Definition/Notes
General	Num.	integer	Unique number assigned to each technology.
	Technology	text	Name of the technology.
	Abbr.	text	Abbreviation of the technology.
	TechType	text	The group of a technology: EngMod = the type of the technology is engine modification DslMod = the type of the technology is diesel engine modification TrnMod = the type of the technology is transmission modification ELEC = the type of the technology is electric system improvement MR = the type of the technology is mass reduction ROLL = the type of the technology is rolling resistance tires DLR = the type of the technology is dynamic load reduction AERO = the type of the technology is aerodynamics modification
Off-Cycle Credits	Off-Cycle Credit PC	gram per mile	Amount of off-cycle credit that the vehicles incur as a result of applying the technology. Specified in grams per mile of CO2 for each regulatory class.
	Off-Cycle Credit LT		
	Off-Cycle Credit LT 2b/3		
Phase-in Values	PV-1	percentage	Percentage of the entire fleet to which the technology may be applied.
	PV-2	percentage	
	…		
	PV-16	percentage	
	PV-17	percentage	

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

Table 11. Technologies Assumptions

Category	Column	Units	Definition/Notes
General	Num.	integer	Unique number assigned to each technology.
	Abbr.	text	Abbreviation of the technology. For engine technologies that differ based on the relative size of the engine, an "_SD", "_MD", or "_LD" suffix may be used to indicate the technology cost and effectiveness values are specified for a small, medium, or large engine.
	TechType	text	The group of a technology.
Availability	Applicable	boolean	TRUE = the technology is available for applicability in a technology class FALSE = the technology is not available for applicability in a technology class
	Year Avail.	model year	First year the technology is available for applicability.
	Year Retired	model year	Last year the technology is available for applicability.
Misc Attributes	Electric Range	number	What the range, in miles, of an electric vehicle would be when operating on a battery, as a result of applying the technology; applies to PHEV and EV technologies only.
	Delta Weight (%)	percentage	Percentage by which the vehicle's weight changes as a result of applying the technology.
	Delta Weight (lbs)	number	Amount of pounds by which the vehicle's weight changes as a result of applying the technology.
	Loss of Value	dollars	The consumer welfare loss associated with application of the technology.
FC Improvements	FC	percentage	Fuel consumption improvement estimate of the technology.
	Primary Fuel Share	percentage	Percentage of miles the vehicle is expected to travel on the primary fuel after applying the technology (applicable when a vehicle is being converted into a plug-in HEVs or another form of dual fuel vehicle).
Cost Table	Cost 2009	dollars	Table of learned out cost estimates for the technology, per model year.
	Cost 2010	dollars	
	…		
	Cost 2024	dollars	
	Cost 2030	dollars	
Maint. Table	Maint. 2009	dollars	Table of learned out maintenance cost estimates for the technology, per model year.
	Maint. 2010	dollars	
	…		
	Maint. 2024	dollars	
	Maint. 2030	dollars	
Repair Table	Repair 2009	dollars	Table of learned out repair cost estimates for the technology, per model year.
	Repair 2010	dollars	
	…		
	Repair 2024	dollars	
	Repair 2030	dollars	
Stranded Capital Table	SC-1	dollars	Penalty costs associated with replacing (or superseding) a technology early.
	SC-2	dollars	
	…		
	SC-9	dollars	
	SC-10	dollars	

A.2.1 Technology Synergies

Technology synergies occur when the combined effect of two technologies is greater than (or less than) the fuel consumption reduction for the two technologies combined. To support synergies, the technology input file has synergy sections for cost and fuel improvements. Contents of the synergy tables are shown in Table 12 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 12. Technology Synergies

Category	Column	Units	Definition/Notes
General	Type	text	The synergy type relation between two technologies. The "accounting" type indicates that the synergy relation between two technologies is to provide accounting adjustments for the decision trees and is the only synergy type applied to technology costs. The "physical" type indicates that the synergy relation between two technologies is to address physical energy losses.
	Technology A	text	Abbreviation of the first technology in a synergy pair. For engine technologies that differ based on the relative size of the engine, an "_SD", "_MD", or "_LD" suffix may be used to indicate the technology synergy values are specified for a small, medium, or large engine.
	Technology B	text	Abbreviation of the second technology in a synergy pair. For engine technologies that differ based on the relative size of the engine, an "_SD", "_MD", or "_LD" suffix may be used to indicate the technology synergy values are specified for a small, medium, or large engine.
Technology Class	Subcompact PC	percentage	Values to offset the technology cost or fuel consumption when either of technology A or B is being applied when the other is already installed.
	Subcompact Perf. PC		
	Compact PC		
	Compact Perf. PC		
	Midsize PC		
	Midsize Perf. PC		
	Large PC		
	Large Perf. PC		
	Minivan LT		
	Small LT		
	Midsize LT		
	Large LT		
	Truck 2b3		
	Van 2b3		

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 13. Vehicle Age Data Worksheet

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

Separate survival fractions and annual miles driven are used for cars, vans, SUVs, pickups, and class 2b/3 trucks. The survival fractions measure the proportion of vehicles originally produced during a model year that remain in service at each age, 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 14. Forecast Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Forecast Data	Retail Fuel Prices (low, average, high)	$/gallon	2012 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-1975.
	Fuel Taxes	$/gallon	2012 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-2000.

A.3.3 Fuel Economy Data

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

Table 15. Fuel Economy Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Fuel Economy Data	Fuel Economy (by Fuel Type and Fleet)	mpg	Historic and projected fuel economy levels for each available fuel type and fleet type.
	Fuel Share (by Fuel Type and Fleet)	percentage	Historic and projected fuel shares for each available fuel type and fleet type.

A.3.4 Economic Values

The Economic Values worksheet contains an estimate of the magnitude of the “rebound effect”, as well as the rates used to compute the economic value of various direct and indirect impacts of CAFE standards, and the discount rate to apply when calculating present value. As mentioned above, the user can define and edit all inputs. For example, although the economic values in Table 16 were obtained from various sources of information, the system does not require that the user rely on these sources.

Table 16. Economic Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
Economic Values	Rebound Effect	percentage	Increase in the annual use of vehicle models in response to lower per-mile cost of driving a more fuel-efficient vehicle.
	Discount Rate	percentage	Percent rate by which the dollar value of a benefit or cost is reduced when its receipt or payment is postponed by one additional year into the future; used for calculating socially-valued benefits.
	Base Year for Discounting	percentage	The calendar year to use for "present year" discounting. If a base year value is used, social discounting is assumed, with all costs and benefits being discounted to that year. If no value is specified, private discounting is implied, with all costs and benefits being discounted to the model year being analyzed.
	Annual Growth Rate for Average VMT per Vehicle	***various***	Annual growth rate for average VMT per vehicle.
	Base Year for Average Annual Usage Data	model year	Base year for annual growth rate for average VMT per vehicle.
	Growth Rate at Low Fuel Price	percentage	Annual growth rate for average VMT per vehicle, when using low fuel prices.
	Growth Rate at Average Fuel Price	percentage	Annual growth rate for average VMT per vehicle, when using average fuel prices.
	Growth Rate at High Fuel Price	percentage	Annual growth rate for average VMT per vehicle, when using high fuel prices.
	"Gap" between Test and On-Road MPG (by Fuel Type)	percentage	Difference between a vehicle's EPA fuel economy rating and its actual on-road fuel economy.
	Fixed Component of Average Refueling Time in Minutes (by Fuel Type)	minutes	Average refueling time a spent by a consumer refueling the vehicle tank or recharging the vehicle electric battery.
	Average Tank Volume Refueled	percentage	Average tank volume refilled during a refueling stop.
	Value of Travel Time per Vehicle	$/hour	Amount that the driver of a vehicle would be willing to pay to reduce the time required to make a trip.
	External Costs from Additional Vehicle Use Due to "Rebound" Effect	***$/vehicle-mile***	Estimates intended to represent costs per vehicle-mile of increased travel compared to approximately current levels, assuming current distribution of travel by hours of the day and facility types.
	Congestion	$/vehicle-mile	Congestion component of external costs from additional vehicle use.
	Accidents	$/vehicle-mile	Accidents component of external costs from additional vehicle use.
	Noise	$/vehicle-mile	Noise component of external costs from additional vehicle use.
	Ownership and Operating Costs		
	Taxes & Fees (% of final vehicle MSRP)	percentage	Average percentage of the vehicle's final MSRP the consumer pays in taxes and fees when purchasing a new vehicle.
	Financing (% of final vehicle MSRP)	percentage	Average percentage of the vehicle's final MSRP the consumer would pay for financing a new vehicle.
	Insurance (% of final vehicle MSRP)	percentage	Average percentage of the vehicle's final MSRP the consumer would pay for insuring a new vehicle.
	Relative Value Loss (% of final vehicle MSRP, pure EVs only)	percentage	Average percentage of the vehicle's final MSRP, which translates into relative value loss to consumer due to decreased operating life of pure electric vehicles.
	Resale Value	percentage	Average percentage of the vehicle's final MSRP the consumer recoups after selling the vehicle.
	Economic Costs of Oil Imports		
	"Monopsony" Component	$/gallon	Demand cost for imported oil; increasing domestic petroleum demand that is met through higher oil imports can cause the world price of oil to rise, and conversely that declining imports can reduce the world price of oil; determined by a complex set of factors, including the relative importance of U.S. imports

			in the world oil market and demand to its world price among other participants in the international oil market.
	Price Shock Component	$/gallon	Expected value of costs to U.S. economy from reduction in potential output resulting from risk of significant increases in world petroleum price; includes costs resulting from inefficiencies in resource use caused by incomplete adjustments to industry output levels and mixes of production input when world oil price changes rapidly.
	Military Security Component	$/gallon	Costs of taxpayers for maintaining a military presence to secure the supply of oil imports from potentially unstable regions of the world and protect the nation against their interruption.

A.3.5 Fleet Analysis Values

The Fleet Analysis Values worksheet contains fine tuning parameters for performing fleet analysis calculations. The Forecast of Sales contains projected vehicle production for sale in the U.S. between model years 2014 and 2064 and is used to estimate additional car and truck fleet values, beyond what is available on the Historic Fleet Data worksheet (discussed below). When fleet analysis is used, the system evaluates modeling effects for historic and forecast model years, producing outputs required for the EIS.

Table 17. Fleet Analysis Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
Fleet Analysis Values	***Fuel Economy Growth Rates***		
	Baseline Scenario (by Fleet Type)	percentage	Growth rates used to estimate additional fuel economy growth beyond the last model year covered during the study period for the baseline scenario.
	Action Alternatives (by Fleet Type)	percentage	Growth rates used to estimate additional fuel economy growth beyond the last model year covered during the study period for the action alternatives.
	CAFE Start Year (by Fleet Type)	model year	The model year when Fuel Economy regulations were first introduced. This value is useful when evaluating the fuel use and environmental effects assuming the absence of CAFE standards. This value is not used in this version of the model.
	Forecast of Sales (by Fleet Type)	units	The forecast of total industry sales by model year. The first model year specified should be immediately following the last model year from the Historic Fleet Data. Forecast of Sales are used to scale individual vehicle sales, after the last compliance model year, in order to evaluate the fuel use and environmental effects of future years during Fleet Analysis.

A.3.6 Historic Fleet Data

The Historic Fleet Data worksheet provides historic data of vehicles remaining on the road, specified by model year for each vehicle age, for the car, class 1/2a truck, and class 2b/3 truck fleets. The period of years covered is between 1975 and 2013.

Table 18. Historic Fleet Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Historic Fleet Data	Fleet Data (by Fleet Type)	units	Historic car and truck fleet data for each fleet type and model year, specified by vehicle age.

A.3.7 Safety Values

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

Table 19. Safety Values Worksheet

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

A.3.8 Credit Trading Values

The Credit Trading Values worksheet contains fine tuning parameters for enabling credit transfers and credit carry forward within the model.

Table 20. Credit Trading Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
Credit Trading Values	***Credit Trading Options***		Fine Tuning Parameters for using Credit Trading option in the model.
	Trade credits between manufacturers	boolean	Whether to allow credit trading between manufacturers within the same compliance category (i.e., regulatory class) and model year. This option is not supported in this version of the model.
	Transfers credits between regulatory classes	boolean	Whether to allow credit transfers between regulatory class within the same manufacturer and model year.
	Carry credits forward into future model years	boolean	Whether to allow carrying of credits forward into the analysis year from earlier model years within the same manufacturer and compliance category.
	Maximum number of years to carry forward	integer	Maximum number of model years to look forward.
	Carry credits backward into past model years	boolean	Whether to allow carrying of credits backward into the analysis year from future model years within the same manufacturer and compliance category. This option is not supported in this version of the model.
	Maximum number of years to carry backward	integer	Maximum number of model years to look backward. This option is not supported in this version of the model.
	Transfer Caps (mpg)	mpg	Transfer caps corresponding to the maximum amount of credits that may be transferred into a compliance category for each model year. The cap from the latest model year is carried forward for all subsequent years.
	Assumed Lifetime VMT by Regulatory Class	miles	Assumed lifetime VMT to use when credits are transferred between compliance categories.

A.3.9 DFS Model Values

This option is not supported in this version of the model.

A.3.10Fuel 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 21. Fuel Properties Worksheet

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

A.3.11 Emission Costs

The Emission Costs Worksheet contains emission damage costs arising from various pollutants.

Table 22. Emission Costs Worksheet

Category	Model Characteristic	Units	Definition/Notes
Emission Costs	***Emission Damage Costs***		
	Carbon Monoxide	$/metric-ton	Economic costs arising from Carbon Monoxide damage.
	Volatile Organic Compounds	$/metric-ton	Economic costs arising from Volatile Organic Compounds damage.
	Nitrogen Oxides	$/metric-ton	Economic costs arising from Nitrous Oxides damage.
	Particulate Matter	$/metric-ton	Economic costs arising from Particulate Matter damage.
	Sulfur Dioxide	$/metric-ton	Economic costs arising from Sulfur Oxides damage.
	Methane	scalar	Economic costs arising from Methane damage, specified as GWP-scalar of CO-2 Costs.
	Nitrous Oxide	scalar	Economic costs arising from Nitrous Oxide damage, specified as GWP-scalar of CO-2 Costs.
	CO-2 Damage		
	CO-2 Discount Rates	percentage	Discount rates to apply to low, average, high, or very high Carbon Dioxide estimates.
	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.

A.3.12 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 23. Upstream Emissions Worksheet

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

A.3.13 Tailpipe Emissions

The Tailpipe Emissions is a set of multiple worksheets that contain vehicular criteria pollutant emission factors specified by vehicle age, fuel type, and vehicle class (LDV, LDT1/2a, and LDT2b/3), with each worksheet representing a different pollutant.

Table 24. Tailpipe Emissions Worksheet

Category	Model Characteristic	Units	Definition/Notes
Tailpipe Emission Rates (multiple tabs by Pollutant)	Emission Rates (by Fuel Type and Fleet)	grams/mile	Vehicle operation emission rate for each fuel type and fleet, specified for historic and future model years, and for each vehicle age. Emission rates may specified for the following fuel types: Gasoline, Gasoline reformulated, E85, Diesel, B20, CNG, LNG, and LPG; and for the following fleets: LDV (passenger cars), LDT1/2a (weighted average of class 1/2a trucks), LDT2b/3 (weighted average of class 2b/3 trucks), and MDT4/5/6 (weighted average of class 4/5/6 trucks; this value is not used by the model).

A.4 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
Passenger Car	All passenger automobiles
Light Truck	Class 1 and class 2a trucks
Light Truck 2b/3	Class 2b and class 3 trucks

The "Regulatory Class" column on the vehicles worksheet discussed above is used to indicate whether the vehicle is regulated as a Passenger Car (PC), Light Truck (LT), or Light Truck 2b/3 (2b3).

Within each scenario worksheet, the specifications for each regulatory class are defined separately, using the parameters described in Table 26 below.

Table 26. Scenarios Worksheet

Category	Column	Units	Definition/Notes
Function Definition	Function	integer	Functional form to use for computing the vehicle target.
	A - J (function coefficients)	number	Coefficients associated with the functional form to use for computing the vehicle target.
	Min (mpg)	mpg	Minimum CAFE standard that each manufacturer must attain, specified as a flat-standard in miles/gallon, or 0 if not applicable.
	Min (%)	percentage	Minimum CAFE standard that each manufacturer must attain, specified as a percentage of the average requirement under the function-based standard, or 0 if not applicable.
Supplemental Options	Fine Rate	number	The CAFE fine rate for non-compliance in dollars per one credit of shortfall.
	Multi-Fuel	integer	The applicability of multi-fuel vehicles for compliance calculations (does not apply to single-fuel vehicles): 0 = only gasoline fuel economy value is considered (gasoline fuel share is assumed to be 100%); 1 = for Gasoline/Ethanol-85 vehicles, only the gasoline fuel economy value is considered (gasoline fuel share is assumed to be 100%); for Gasoline/Electricity vehicles, both fuel economy values are considered; 2 = for Gasoline/Ethanol-85 and Gasoline/Electricity vehicles, both fuel economy values are considered.
	FFV Share	percentage	The statutory fuel share to use for compliance for flex-fuel vehicles (FFVs), whenever the Multi-Fuel mode is 2. This fuel share applies only to vehicles operating on gasoline and ethanol-85 fuel types. If 0 or <blank> is used, the vehicle's assumed on-road fuel share will be used for compliance.
	PHEV Share	percentage	Specifies the statutory fuel share to use for compliance for plug-in hybrid/electric vehicles (PHEVs), whenever the Multi-Fuel mode is either 1 or 2. This fuel share applies only to vehicles operating on gasoline and electricity fuel types. If 0 or <blank> is used, the vehicle's assumed on-road fuel share will be used for compliance.
	Include AC	boolean	Whether to include adjustments for improvements in air conditioning (AC adjustments) for compliance and effects calculations: TRUE = include AC credits for compliance and effects calculations (credits, fines, and whether mfr is in compliance); FALSE = do not include AC credits for compliance and effects calculations (the achieved CAFE in modeling reports will still show "CAFE w/o AC" as well as "CAFE with AC").
	AC Adjustment	number	The AC adjustment factor in grams/mile of CO2.
	AC Cost ($)	dollar	The cost of AC adjustment in dollars per unit.
	Off-Cycle Cap	number	The maximum amount of credit a manufacturer may accrue from Off-Cycle technology improvements, specified in grams/mile of CO2.

	FFV Cap	number	The maximum amount of credit a manufacturer may accrue from flex-fuel vehicles (FFVs), specified in vehcle-miles/gallon. This option is not supported in this version of the model.
	SHEV Tax Credit	dollar	The amount of Federal tax credits a buyer receives for purchasing a strong hybrid/electric vehicle (SHEV).
	PHEV Tax Credit	dollar	The amount of Federal tax credits a buyer receives for purchasing a plug-in hybrid/electric vehicle (PHEV).
	EV Tax Credit	dollar	The amount of Federal tax credits a buyer receives for purchasing a pure electric vehicle (EV).
	TW Function	integer	The functional form to use for computing the vehicle's test weight.
	Payload Return	percentage	The percentage of curb weight reduction returned to payload capacity. This setting applies whenever mass reduction technology is installed to a vehicle. For example, if payload return is 0%, the vehicle's payload capacity remains the same; if payload return is 100%, the vehicle's reduction in curb weight goes entirely to payload.
	Towing Return	percentage	The percentage of GVWR reduction returned to towing capacity. This setting applies whenever mass reduction technology is installed to a vehicle. For example, if towing return is 0%, the vehicle's towing capacity remains the same; if towing return is 100%, the vehicle's reduction in GVWR goes entirely to towing.

Appendix B Model Outputs

The system produces seven output files in comma separate values (CSV) format. The system places all files in the "reports" folder, located in the user selected output path (ex: **C:\cafe\demo-run\demo\reports-csv**). Table 27 lists the available output types and their contents. With this revision of the modeling system, the structure of all outputs generated has changed from earlier versions. The "raw" modeling results are stored as plain text (without any additional formatting), in a "database-like" style. Most of the modeling reports have been extended to include additional information, while some were scaled down to contain only the relevant portions. As discussed earlier, the first scenario appearing in the scenarios file is assigned to Scenario 0 and is treated as the baseline. The action alternatives are then assigned to Scenario 1, 2, and so on, in order of appearance. For all modeling reports, the baseline scenario always shows absolute values, while, for the majority of reports, the action alternatives include relative changes compared to the baseline, as discussed in the sections below.

Table 27. Output Files

Output File	Contents
Technology Utilization Report	Contains manufacturer-level and industry-wide technology application and penetration rates for each technology, model year, and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
Compliance Report	Contains manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
Societal Effects Report	Contains industry-wide summary of energy and emissions effects for each model year and scenario analyzed. The model produces two versions of this output file, where the results are disaggregated by either the vehicle class and fuel type or the regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
Societal Costs Report	Contains industry-wide summary of consumer and social costs for each model year and scenario analyzed. The model produces two versions of this output file, where the results are disaggregated by either the vehicle class and fuel type or the regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
Annual Societal Effects Report	This output file is similar to the *Societal Effects Report*, except it further disaggregates the results by calendar year.
Annual Societal Costs Report	This output file is similar to the *Societal Costs Report*, except it further disaggregates the results by calendar year.
Vehicles Report	Contains disaggregate vehicle-level summary of compliance model results, providing a detailed view of the final state of each vehicle examined by the model, for each model year and scenario analyzed.

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

B.1 Technology Utilization Report

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

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

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

Table 28. Technology Utilization Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period.
Manufacturer	text	Manufacturers analyzed during the study period. A value of "TOTAL" is used to represent industry-wide results.
Reg-Class	text	The regulatory class for which the application and penetration rates are reported. When multiple regulatory classes are present in the output, a value of "TOTAL" is used to represent the sum across all classes.
Technology (abbreviation)	text	The technology for which the application and penetration rates are reported. Some of the discrete technology entries, which represent the same technology, but are modeled separately given the differences in costs and fuel improvements attributed to different engine sizes, were merged in the output. For example, TRBDS1_SD, TRBDS1_MD, and TRBDS1_LD, all represent the same technology, and the application and penetration rates of these three technologies were summed and reported as TRBDS1.
App-Rate	number	The application rate of the technology, specified as a proportion of total sales. The application rates represent the amount of technology that was applied by the modeling system during analysis. If a technology was applied to a vehicle, but later superseded during the modeling process by another technology (for example, DCP superseding ICP), the superseded technology on that vehicle will not count toward the application rate.
Pen-Rate	number	The penetration rate of the technology, specified as a proportion of total sales. The penetration rates represent the amount of technology that was either on the baseline vehicle at the start of the analysis, or applied by the modeling system during analysis. If a technology was present on or applied to a vehicle, but later superseded during the modeling process by another technology (for example, DCP superseding ICP), the superseded technology on that vehicle will not count toward the penetration rate.
Incr.AR	number	The incremental application rate of the technology, which represents the difference between the action alternative and the baseline scenario.
Incr.PR	number	The incremental penetration rate of the technology, which represents the difference between the action alternative and the baseline scenario.

B.2 Compliance Report

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

Table 29. Compliance Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "TOTAL" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Manufacturer	text	Manufacturers analyzed during the study period. A value of "TOTAL" is used to represent industry-wide results.
Reg-Class	text	The regulatory class for which the compliance results are reported. When multiple regulatory classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Sales	units	Total production of vehicles for sale for a specific model year, manufacturer, and regulatory class (as well as sum across any of the attributes, where applicable).
k.Labor Hours	hours (k)	Thousands of employment hours associated with the production of vehicle models. (The modeling system applies any employment hours specified in the input file; however, the system reflects no predetermined assumptions regarding the context for these inputs.)
Prelim-Stnd	mpg	Preliminary value of the required CAFE standard (before the "alternative minimum CAFE standard", as outlined in the scenarios input section, is applied).
Standard	mpg	The value of the required CAFE standard.
CAFE (2-cycle)	mpg	The value of the achieved CAFE standard, using a 2-bag test cycle, not including the adjustment for improvements in air conditioning or off-cycle credits.
CAFE	mpg	The value of the achieved CAFE standard, including the adjustment for improvements in air conditioning and off-cycle credits. This value is used for compliance purposes.
Average CW	lbs.	Average curb weight of analyzed vehicles.
Average FP	sq.ft.	Average footprint of analyzed vehicles.
Average WF	lbs.	Average work-factor of analyzed vehicles. This value is reported only when the vehicles analyzed are subject to the work-factor based functional standards.
CO2 Required	grams per mile	The value of the required CO-2 standard.
CO2 Achieved	grams per mile	The value of the achieved CO-2 standard.
Tech Cost	dollars[1]	Total amount of technology costs accrued by all vehicles for a specific model year, manufacturer, and regulatory class.
Fines	dollars[1]	Total amount of fines paid by a manufacturer for a specific model year and regulatory class.
Reg-Cost	dollars[1]	Total amount of regulatory costs accrued by all vehicles for a specific model year, manufacturer, and regulatory class. The regulatory costs are the sum of technology costs and fines.
Disc Cost	dollars[1]	Total amount of technology costs accrued by all vehicles for a specific model year, manufacturer, and regulatory class. If social discounting is used, the technology costs are discounted to the "Base Year for Discounting" value specified in the parameters file. If private discounting is used, the discounted costs are the same as technology costs.
Value Loss	dollars[1]	Total loss in value to the consumer due to decreased range of pure electric vehicles.
Rel. Value Loss	dollars[1]	Total relative loss in value to the consumer due to due to decreased operating life of pure electric vehicles.
Maint Cost	dollars[1]	Total maintenance costs accrued due to application of additional technologies.
Repair Cost	dollars[1]	Total repair costs accrued due to application of additional technologies.
Taxes/Fees	dollars[1]	Total amount of taxes & fees paid by the consumers for purchasing new vehicles for a specific model year, manufacturer, and regulatory class.
Financing	dollars[1]	Total amount paid by the consumers for financing new vehicles for a specific model year, manufacturer, and regulatory class.
Insurance	dollars[1]	Total amount paid by the consumers for insuring new vehicles for a specific model year, manufacturer, and regulatory class.
Total Consumer Costs	dollars[1]	The total consumer costs accumulated by the manufacturer for a specific model year and regulatory class. The consumer costs are the sum of: discounted technology costs, fines, taxes & fees, financing costs, insurance

		costs, maintenance costs, repair costs, loss of value, and relative loss of value.
Total Social Costs	dollars[1]	The total social costs accumulated by the manufacturer for a specific model year and regulatory class. The social costs are the sum of: discounted technology costs, maintenance costs, repair costs, loss of value, and relative loss of value.
Avg Tech Cost	dollars[1]	Average technology costs per single vehicle unit.
Avg Fines	dollars[1]	Average fines paid per single vehicle unit.
Avg Reg-Cost	dollars[1]	Average regulatory costs per single vehicle unit.
Avg Disc Cost	dollars[1]	Average technology costs per single vehicle unit. If social discounting is used, the technology costs are discounted to the "Base Year for Discounting" value specified in the parameters file. If private discounting is used, the average discounted costs are the same as average technology costs.
Avg Value Loss	dollars[1]	Average loss in value per single vehicle unit.
Avg Rel. Value Loss	dollars[1]	Average relative loss in value per single vehicle unit.
Avg Maint Cost	dollars[1]	Average maintenance costs per single vehicle unit.
Avg Repair Cost	dollars[1]	Average repair costs per single vehicle unit.
Avg Taxes/Fees	dollars[1]	Average taxes & fees per single vehicle unit.
Avg Financing	dollars[1]	Average financing costs per single vehicle unit.
Avg Insurance	dollars[1]	Average insurance costs per single vehicle unit.
Avg Consumer Costs	dollars[1]	Average consumer costs per single vehicle unit.
Avg Social Costs	dollars[1]	Average social costs per single vehicle unit.
Credits Earned	credits[2]	Total credits accumulated by the manufacturer for a specific model year and regulatory class. Manufacturers earn compliance credits whenever their achieved value of the CAFE standard is above the required value of the CAFE standard (in mpg).
Credits Out	credits[2]	Total credits transferred out of a specific regulatory class (such as from domestic passenger automobiles to light trucks) or carried forward from a previous model year.
Credits In	credits[2]	Total credits transferred into a specific regulatory class or carried forward into the present model year.

In the above table, note that:

(1) For the baseline scenario, all costs are specified as absolutes; for the action alternatives, all costs are incremental and are specified as the difference between the action alternative and the baseline scenario.

(2) For light duty vehicles (passenger cars, class-1 light duty trucks, and class-2a light duty trucks), one credit equates to one mile per 10 gallons. For medium duty vehicles (class-2a light duty trucks and class-3 light duty trucks), one credit equates to one gallon per 10k miles.

B.3 Societal Effects Report and Societal Costs Report

The *Societal Effects Report* contains industry-wide summary of energy and emissions effects, while the *Societal Costs Report* contains corresponding industry-wide summary of consumer and social costs for each model year and scenario analyzed. The modeling system generates two versions of each report, where in one, the results are reported by vehicle class (LDV, LDT12a, LDT2b3), while in the other, the results are reported by regulatory class (PC, LT, LT2b3). In each case, the results are aggregated for the entire fleet as well. Most of the metrics, which are reported independently by model year, are further summed (or averaged) over the entire analysis period.

The *Societal Effects Report* also disaggregates energy and emissions effects by fuel type, as well as providing aggregate totals across all fuels. The report contains calculated levels of energy consumed by fuel type in quads, thousands of gallons, and thousands of native units during the full useful life of all vehicles sold in each model year. For liquid fuel types (gasoline, diesel, E85, and B20), amount of gallons consumed is specified in their native units (for example, gallons of E85). For non-liquid fuel types (electricity, hydrogen, CNG), amount of gallons consumed is specified in gasoline equivalent gallons. Additionally, energy consumption in native units is specified for electricity in mW-h, and for hydrogen and CNG in Mcf. Full useful life travel (in thousands of miles) and average fuel economy levels are also presented to provide a basis for comparison. The rated fuel economy levels reported are not comparable to the value of achieved CAFE standard shown in the compliance report. The values contained in the Societal Effects Report are computed as total VMT divided by total gallons (with the effect of the on-road gap backed out), and do not incorporate some of the compliance credits.

The *Societal Effects Report* also presents estimates of full fuel cycle carbon dioxide and criteria pollutant emissions by fuel type. As shown in Table 30 below, carbon dioxide emissions are reported in million metric tons of carbon-equivalent emissions (one metric ton of carbon dioxide is equivalent to 12/44 of a metric ton of carbon), and all criteria pollutants are reported in metric tons.

In the *Societal Effects Report*, for the baseline scenario, VMT, energy use, fatalities, and all emissions are specified as absolutes. For the action alternatives, these values are incremental and are specified as the difference between the action alternative and the baseline scenario.

The *Societal Costs Report* contains monetized consumer and social costs including fuel expenditures, travel and refueling value, economic and external costs arising from additional vehicle use, as well as owner and societal costs associated with emissions damage. In all cases, these costs are calculated for the fleet of vehicles sold in each model year over their full useful lives, discounted using the rate specified in the benefits model parameters file, and reported in thousands of constant year-2012 dollars. Chapter Three, Section 6 of the primary text discusses these types of costs and benefits in greater detail, and Appendix A (Model Inputs) discusses corresponding input assumptions.

In the *Societal Costs Report*, for the baseline scenario, all costs are specified as absolutes. For the action alternatives, all costs are incremental and are specified as the difference between the action alternative and the baseline scenario.

Table 30 below lists the full contents of the *Societal Effects Report* and Table 31 lists the full contents of the *Societal Costs Report*.

Table 30. Societal Effects Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "TOTAL" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Reg-Class	text	The regulatory class for which the societal effects are reported. When multiple regulatory classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Veh-Class	text	The vehicle class for which the societal effects are reported. When multiple vehicle classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all vehicle classes for some of the outputs, where applicable.
Fuel Type	text	The fuel type for which the societal effects are reported. A value of "TOTAL" is used to represent the sums (or averages) across all fuel types for some of the outputs, where applicable.
Rated FE	mpg	The average fuel economy rating of vehicles. Note, this value is not comparable to the value of achieved CAFE standard shown in the compliance report; this value is computed as total VMT divided by total gallons (with the effect of the on-road gap backed out), and does not incorporate some of the compliance credits.
On-road FE	mpg	The average on-road fuel economy rating of vehicles.
Fuel Share	ratio	The average fuel share, indicating the amount of miles driven by all vehicles on each fuel type.
Curb Weight	lbs.	Average curb weight of analyzed vehicles.
Footprint	sq.ft.	Average footprint of analyzed vehicles.
Work Factor	lbs.	Average work-factor of analyzed vehicles. This value is reported only when the vehicles analyzed are subject to the work-factor based functional standards.
Sales	units	Total production of vehicles for sale for a specific model year, regulatory or vehicle class, and fuel type (as well as sum across any of the attributes, where applicable).
kVMT	miles (k)	Thousands of miles traveled by all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Quads	quads	Energy used by all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
kGallons	gallons (k)	Amount of gallons of liquid fuel consumed, or amount of gasoline equivalent gallons of fuel consumed (for non-liquid fuel types), by all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
kUnits	varies	Amount of energy consumed by all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type, where the units of measure vary based on fuel type. For liquid fuel types (gasoline, e85, diesel, b20, LNG, LPG), the units are specified in thousands of gallons; for electricity, the units are specified in mW-h; for hydrogen and CNG, the units are specified in Mcf.
Fatalities	units	Amount of fatalities resulting from reduction in vehicle curb weight and increases in VMT due to the rebound effect, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
CO (t)	metric-tons	Amount of Carbon Monoxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
VOC (t)	metric-tons	Amount of Volatile Organic Compounds emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
NOx (t)	metric-tons	Amount of Nitrogen Oxides emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
SO2 (t)	metric-tons	Amount of Sulfur Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
PM (t)	metric-tons	Amount of Particulate Matter (diameter of ~2.5 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
CO2 (mmt)	million	Amount of Carbon Dioxide emissions generated from domestic crude petroleum extraction, transportation, and

	metric-tons	refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
CH4 (t)	metric-tons	Amount of Methane emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
N2O (t)	metric-tons	Amount of Nitrous Oxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Acetaldehyde (t)	metric-tons	Amount of Acetaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Acrolein (t)	metric-tons	Amount of Acrolein emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Benzene (t)	metric-tons	Amount of Benzene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Butadiene (t)	metric-tons	Amount of 1,3-Butadiene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Formaldehyde (t)	metric-tons	Amount of Formaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
DPM10 (t)	metric-tons	Amount of Diesel Particulate Matter (diameter of ~10 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
MTBE (t)	metric-tons	Amount of Methyl Tertiary Butyl Ether emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.

Table 31. Societal Costs Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "TOTAL" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Reg-Class	text	The regulatory class for which the societal costs are reported. When multiple regulatory classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Veh-Class	text	The vehicle class for which the societal costs are reported. When multiple vehicle classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all vehicle classes for some of the outputs, where applicable.
Fuel Type	text	The fuel type for which the societal costs are reported. A value of "TOTAL" is used to represent the sums (or averages) across all fuel types for some of the outputs, where applicable.
Disc-Rate	number	Social discount rate applied to future benefits. A value of 0 indicates undiscounted costs.
Pre-Tax Fuel Cost	dollars (k)	Total pre-tax fuel expenditures accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Fuel Tax Cost	dollars (k)	Total fuel tax revenues accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Retail Fuel Costs	dollars (k)	Total retail fuel expenditures (pre-tax fuel cost + fuel tax cost) accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Drive Surplus	dollars (k)	Benefits from the additional driving that results from improved fuel economy, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Refuel Surplus	dollars (k)	Benefits from reduced refueling frequency due to the extended vehicle range and improved fuel economy, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Market Externalities	dollars (k)	Economic costs of oil imports not accounted for by price, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Congestion Costs	dollars (k)	Congestion costs from additional vehicle use, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Accident Costs	dollars (k)	Accident costs from additional vehicle use, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Noise Costs	dollars (k)	Noise costs from additional vehicle use, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Fatality Costs	dollars (k)	Cost from additional fatalities resulting from reduction in vehicle curb weight, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
CO Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Monoxide damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
VOC Damage Costs	dollars (k)	Owner and societal costs arising from Volatile Organic Compounds damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
NOx Damage Costs	dollars (k)	Owner and societal costs arising from Nitrogen Oxides damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
SO2 Damage Costs	dollars (k)	Owner and societal costs arising from Sulfur Dioxide damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
PM Damage Costs	dollars (k)	Owner and societal costs arising from Particulate Matter damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
CO2 Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Dioxide damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
CH4 Damage Costs	dollars (k)	Owner and societal costs arising from Methane damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
N2O Damage Costs	dollars (k)	Owner and societal costs arising from Nitrous Oxide damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Total Consumer Costs	dollars (k)	Total consumer costs accumulated by the industry for a specific model year, regulatory or vehicle class, and fuel type. The consumer costs are the sum of: retail fuel costs, drive surplus, and refueling surplus.
Total Social Costs	dollars (k)	Total social costs accumulated by the industry for a specific model year, regulatory or vehicle class, and fuel type. The social costs are the sum of: pre-tax fuel costs, drive surplus, refueling surplus, market externalities, congestion costs, accident costs, noise costs, fatality costs, and emissions damage costs (CO, VOC, NOx, SO2, PM, CO2, CH4, and N2O).

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

The *Annual Societal Effects Report* and the *Annual Societal Costs Report* contain similar results as the *Societal Effects Report* and the *Societal Costs Report*, except these outputs further disaggregate the results by calendar year. Table 32 lists the full contents of the *Annual Societal Effects Report* and Table 33 lists the full contents of the *Annual Societal Costs Report*. The annual reports produce results as absolutes for the baseline and action alternatives.

Table 32. Annual Societal Effects Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. When "Fleet Analysis" option is enabled during modeling, the range of years is extended to include historic and future model years.
Age	integer	The vehicle's vintage, ranging from 0 to 39, where 0 corresponds to a vehicle's first year on the road.
Calendar Year	calendar year	Calendar years analyzed for the effects calculations.
Veh-Class	text	The vehicle class for which the societal costs are reported. When multiple vehicle classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all vehicle classes for some of the outputs, where applicable.
Fuel Type	text	The fuel type for which the societal costs are reported. A value of "TOTAL" is used to represent the sums (or averages) across all fuel types for some of the outputs, where applicable.
Fleet	units	Total on-road fleet for a specific model year, vehicle age, vehicle class, and fuel type.
kVMT	miles (k)	Thousands of miles traveled by all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Quads	quads	Energy used by all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
kGallons	gallons (k)	Amount of gallons of liquid fuel consumed, or amount of gasoline equivalent gallons of fuel consumed (for non-liquid fuel types), by all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
kUnits	varies	Amount of energy consumed by all vehicles for a specific model year, vehicle age, vehicle class, and fuel type, where the units of measure vary based on fuel type. For liquid fuel types (gasoline, e85, diesel, b20, LNG, LPG), the units are specified in thousands of gallons; for electricity, the units are specified in mW-h; for hydrogen and CNG, the units are specified in Mcf.
Fatalities	units	Amount of fatalities resulting from reduction in vehicle curb weight and increases in VMT due to the rebound effect, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO Upstream (t)	metric-tons	Amount of Carbon Monoxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
VOC Upstream (t)	metric-tons	Amount of Volatile Organic Compounds emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
NOx Upstream (t)	metric-tons	Amount of Nitrogen Oxides emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
SO2 Upstream (t)	metric-tons	Amount of Sulfur Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
PM Upstream (t)	metric-tons	Amount of Particulate Matter (diameter of ~2.5 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO2 Upstream (mmt)	million metric-tons	Amount of Carbon Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CH4 Upstream (t)	metric-tons	Amount of Methane emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
N2O Upstream (t)	metric-tons	Amount of Nitrous Oxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acetaldehyde Upstream (t)	metric-tons	Amount of Acetaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acrolein	metric-	Amount of Acrolein emissions generated from domestic crude petroleum extraction, transportation, and

Upstream (t)	tons	refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Benzene Upstream (t)	metric-tons	Amount of Benzene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Butadiene Upstream (t)	metric-tons	Amount of 1,3-Butadiene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Formaldehyde Upstream (t)	metric-tons	Amount of Formaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
DPM10 Upstream (t)	metric-tons	Amount of Diesel Particulate Matter (diameter of ~10 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
MTBE Upstream (t)	metric-tons	Amount of Methyl Tertiary Butyl Ether emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO Tailpipe (t)	metric-tons	Amount of Carbon Monoxide emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
VOC Tailpipe (t)	metric-tons	Amount of Volatile Organic Compounds emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
NOx Tailpipe (t)	metric-tons	Amount of Nitrogen Oxides emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
SO2 Tailpipe (t)	metric-tons	Amount of Sulfur Dioxide emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
PM Tailpipe (t)	metric-tons	Amount of Particulate Matter (diameter of ~2.5 micrometers) emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO2 Tailpipe (mmt)	million metric-tons	Amount of Carbon Dioxide emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CH4 Tailpipe (t)	metric-tons	Amount of Methane emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
N2O Tailpipe (t)	metric-tons	Amount of Nitrous Oxide emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acetaldehyde Tailpipe (t)	metric-tons	Amount of Acetaldehyde emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acrolein Tailpipe (t)	metric-tons	Amount of Acrolein emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Benzene Tailpipe (t)	metric-tons	Amount of Benzene emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Butadiene Tailpipe (t)	metric-tons	Amount of 1,3-Butadiene emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Formaldehyde Tailpipe (t)	metric-tons	Amount of Formaldehyde emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
DPM10 Tailpipe (t)	metric-tons	Amount of Diesel Particulate Matter (diameter of ~10 micrometers) emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
MTBE Tailpipe (t)	metric-tons	Amount of Methyl Tertiary Butyl Ether emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO Total (t)	metric-tons	Amount of Carbon Monoxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
VOC Total (t)	metric-tons	Amount of Volatile Organic Compounds emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
NOx Total (t)	metric-tons	Amount of Nitrogen Oxides emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
SO2 Total (t)	metric-tons	Amount of Sulfur Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
PM Total (t)	metric-tons	Amount of Particulate Matter (diameter of ~2.5 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO2 Total (mmt)	million metric-tons	Amount of Carbon Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CH4 Total (t)	metric-	Amount of Methane emissions generated from domestic crude petroleum extraction, transportation, and

	tons	refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
N2O Total (t)	metric-tons	Amount of Nitrous Oxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acetaldehyde Total (t)	metric-tons	Amount of Acetaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acrolein Total (t)	metric-tons	Amount of Acrolein emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Benzene Total (t)	metric-tons	Amount of Benzene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Butadiene Total (t)	metric-tons	Amount of 1,3-Butadiene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Formaldehyde Total (t)	metric-tons	Amount of Formaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
DPM10 Total (t)	metric-tons	Amount of Diesel Particulate Matter (diameter of ~10 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
MTBE Total (t)	metric-tons	Amount of Methyl Tertiary Butyl Ether emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.

Table 33. Annual Societal Costs Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. When "Fleet Analysis" option is enabled during modeling, the range of years is extended to include historic and future model years.
Age	integer	The vehicle's vintage, ranging from 0 to 39, where 0 corresponds to a vehicle's first year on the road.
Calendar Year	calendar year	Calendar years analyzed for the effects calculations.
Veh-Class	text	The vehicle class for which the societal costs are reported. When multiple vehicle classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all vehicle classes for some of the outputs, where applicable.
Fuel Type	text	The fuel type for which the societal costs are reported. A value of "TOTAL" is used to represent the sums (or averages) across all fuel types for some of the outputs, where applicable.
Disc-Rate	number	Social discount rate applied to future benefits. A value of 0 indicates undiscounted costs.
Pre-Tax Fuel Cost	dollars (k)	Total pre-tax fuel expenditures accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Fuel Tax Cost	dollars (k)	Total fuel tax revenues accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Retail Fuel Costs	dollars (k)	Total retail fuel expenditures (pre-tax fuel cost + fuel tax cost) accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Drive Surplus	dollars (k)	Benefits from the additional driving that results from improved fuel economy, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Refuel Surplus	dollars (k)	Benefits from reduced refueling frequency due to the extended vehicle range and improved fuel economy, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Market Externalities	dollars (k)	Economic costs of oil imports not accounted for by price, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Congestion Costs	dollars (k)	Congestion costs from additional vehicle use, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Accident Costs	dollars (k)	Accident costs from additional vehicle use, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Noise Costs	dollars (k)	Noise costs from additional vehicle use, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Fatality Costs	dollars (k)	Cost from additional fatalities resulting from reduction in vehicle curb weight, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Monoxide damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
VOC Damage Costs	dollars (k)	Owner and societal costs arising from Volatile Organic Compounds damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
NOx Damage Costs	dollars (k)	Owner and societal costs arising from Nitrogen Oxides damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
SO2 Damage Costs	dollars (k)	Owner and societal costs arising from Sulfur Dioxide damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
PM Damage Costs	dollars (k)	Owner and societal costs arising from Particulate Matter damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO2 Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Dioxide damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CH4 Damage Costs	dollars (k)	Owner and societal costs arising from Methane damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
N2O Damage Costs	dollars (k)	Owner and societal costs arising from Nitrous Oxide damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Total Consumer Costs	dollars (k)	Total consumer costs accumulated by the industry for a specific model year, vehicle age, vehicle class, and fuel type. The consumer costs are the sum of: retail fuel costs, drive surplus, and refueling surplus.
Total Social Costs	dollars (k)	Total social costs accumulated by the industry for a specific model year, vehicle age, vehicle class, and fuel type. The social costs are the sum of: pre-tax fuel costs, drive surplus, refueling surplus, market externalities, congestion costs, accident costs, noise costs, fatality costs, and emissions damage costs (CO, VOC, NOx, SO2, PM, CO2, CH4, and N2O).

B.5 Vehicles Report

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

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

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

Table 34 below list the full contents of the *Vehicles Report*.

Table 34. Vehicles Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period.
Manufacturer	text	Manufacturers analyzed during the study period.
Veh Index	integer	Unique index assigned to each vehicle by the modeling system during runtime.
Veh Code	integer	Index of the vehicle (unique per manufacturer), as read from the input file.
Model	text	Vehicle model.
Name Plate	text	Vehicle nameplate.
Platform	text	Name of the platform used by a vehicle.
Plt Version	text	Revision of the platform used by a vehicle. This field lists the platform version as "baseline", if the vehicle is using an original and unmodified platform. Alternatively, this field shows the model year, signifying the revision of the intial platform that the vehicle has inherited.
Eng Code	integer	Index of the engine used by a vehicle.
Eng Fuel Initial	text	Fuel used by the starting engine, before any modifications were made by the modeling system. Available options are: G for gasoline, D for diesel, G+E85 for gasoline/E85 flex fuel vehicles, and D+B20 for diesel/B20 flex fuel vehicles.
Eng Type Initial	text	Brief information about the starting engine, before any modifications were made by the modeling system. The field includes: engine horsepower, displacement, configuration, number of cylinders, and aspiration.

Eng Version	text	Revision of the engine used by a vehicle. This field lists the engine version as "baseline", if the vehicle is using an original and unmodified engine. Alternatively, this field shows the model year, signifying the revision of the intial engine that the vehicle has inherited.
Eng Fuel	text	Fuel used by the engine in a specific model year.
Eng Type	text	Brief information about the engine in a specific model year. At present, only the aspiration of the engine is shown, since other attributes are assumed to remain unchanged.
Trn Code	integer	Index of the transmission used by a vehicle.
Trn Type Initial	text	Brief information about the starting transmission, before any modifications were made by the modeling system. This field includes: transmission type (A=automatic, M=manual, CVT=continuously variable transmission, AMT=automated manual transmission, DCT=dual-clutch transmission) and number of gears (if applicable).
Trn Version	text	Revision of the transmission used by a vehicle. This field lists the transmission version as "baseline", if the vehicle is using an original and unmodified transmission. Alternatively, this field shows the model year, signifying the revision of the intial transmission that the vehicle has inherited.
Trn Type	text	Brief information about the transmission in a specific model year. This field includes: transmission type (A=automatic, M=manual, CVT=continuously variable transmission, AMT=automated manual transmission, DCT=dual-clutch transmission) and number of gears (if applicable).
FE Initial (by Fuel Type[1])	mpg	Vehicle's initial fuel economy rating when operating on a specific fuel type. This represents the starting value as read from the input file.
FE Initial	mpg	Vehicle's overall initial fuel economy rating, before any modifications were made by the modeling system. For FFVs (gasoline/E85 and diesel/B20) and PHEVs (gasoline/electricity), the overall fuel economy rating may be harmonically averaged based on the share of each fuel type, according to the "Multi-Fuel" setting defined in the scenarios input file.
FS Initial (by Fuel Type[1])	ratio	Vehicle's initial fuel share, indicating the amount of miles driven by the vehicle on each fuel type. This represents the starting value as read from the input file.
Fuel Initial	text	All fuel types initially used by the vehicle, before any modifications were made by the modeling system.
FE Rated (by Fuel Type[1])	mpg	Vehicle's fuel economy rating when operating on a specific fuel type, in a specific model year, taking into account the effect of technology additions made by the modeling system. This value does not include adjustment for improvements in air conditioning or off-cycle credits.
FE Rated	mpg	Vehicle's overall fuel economy rating in a specific model year, taking into account the effect of technology additions made by the modeling system. For FFVs (gasoline/E85 and diesel/B20) and PHEVs (gasoline/electricity), the overall fuel economy rating may be harmonically averaged based on the share of each fuel type, according to the "Multi-Fuel" setting defined in the scenarios input file. This value does not include adjustment for improvements in air conditioning or off-cycle credits.
FE Compliance (by Fuel Type[1])	mpg	Vehicle's fuel economy rating when operating on a specific fuel type, in a specific model year, taking into account the effect of technology additions made by the modeling system, adjusted for improvements in air conditioning and off-cycle credits.
FE Compliance	mpg	Vehicle's overall fuel economy rating in a specific model year, taking into account the effect of technology additions made by the modeling system, adjusted for improvements in air conditioning and off-cycle credits. For FFVs (gasoline/E85 and diesel/B20) and PHEVs (gasoline/electricity), the overall fuel economy rating may be harmonically averaged based on the share of each fuel type, according to the "Multi-Fuel" setting defined in the scenarios input file. This value is used for compliance purposes.
FS (by Fuel Type[1])	ratio	Vehicle's fuel share, indicating the amount of miles driven by the vehicle on each fuel type in a specific model year.
Fuel	text	All fuel types used by the vehicle in a specific model year.
Veh Class	text	Vehicle's general classification (passenger vehicle: LDV; light duty truck: LDT1, LDT2a, LDT2b, LDT3; medium duty truck: MDT4, MDT5, MDT6; heavy duty truck: HDT7, HDT8). Only the passenger vehicle and light duty truck classifications are supported by the modeling system.
Reg Class	text	Vehicle's regulatory class (PassengerCar, LightTruck, or LightTruck2b3).
Tech Class	text	Vehicle's technology class (used for technology selection and application).
Safety Class	text	Vehicle's safety class (PC=Passenger Car, CM=CUV/Minivan, LT=Light Truck/SUV; used for safety calculations).
Redesign State	text	Vehicle's redesign state, whether the vehicle is being redesigned in the current model year.
Refresh State	text	Vehicle's refresh state, whether the vehicle is being refreshed in the current model year.
Platform Leader	text	A flag indicating whether a vehicle serves as the leader of the engine (E), transmission (T), and/or platform (P) that it uses. During modeling, engine, transmission, and platform technologies are first applied to a leader vehicle during the leaders redesign or refresh, and subsequently inherited on all other vehicles during their redesign/refresh years.
Sales Initial	units	Vehicle's production volumes in a specific model year. This represents the starting value as read from the input file.
Sales	units	Vehicle's final production volumes in a specific model year. If modeling options for sales mixing are used (such as the Dynamic Fleet Share Model), this value will differ from the initial production volumes; otherwise, this value will be the same the initial one.
MSRP Initial	dollars	Vehicle's initial MSRP value in a specific model year. This represents the starting value as read from the input file.
MSRP	dollars	Vehicle's final MSRP value in a specific model year, including additional costs arising from technology application or fine payment.
k.Labor Hours	hours (k)	Thousands of employment hours associated with the production of the vehicle models in a specific model year.

CW Initial	lbs.	Vehicle's initial curb weight. This represents the starting value as read from the input file.
CW	lbs.	Vehicle's final curb weight in a specific model year, taking into account any mass reduction technology applied by the modeling system.
TW Initial	lbs.	Vehicle's initial test weight, before any modifications were made by the modeling system.
TW	lbs.	Vehicle's final test weight in a specific model year, taking into account any mass reduction technology applied by the modeling system.
GVWR Initial	lbs.	Vehicle's initial GVWR, before any modifications were made by the modeling system.
GVWR	lbs.	Vehicle's final GVWR in a specific model year, taking into account any mass reduction technology applied by the modeling system.
GCWR Initial	lbs.	Vehicle's initial GCWR, before any modifications were made by the modeling system.
GCWR	lbs.	Vehicle's final GCWR in a specific model year, taking into account any mass reduction technology applied by the modeling system.
Footprint	sq.ft.	Vehicle's initial footprint. This represents the starting value as read from the input file. The vehicle's footprint does not change during the analysis.
Work Factor	lbs.	Vehicle's work factor in a specific model year. This value is reported only for vehicles that are subject to the work-factor based functional standard.
FE Target	gallons per mile	Vehicle's fuel economy target in a specific model year.
CO2 Target	grams per mile	Vehicle's CO-2 target in a specific model year.
CO2 Rating	grams per mile	Vehicle's CO-2 rating in a specific model year.
Tech Cost	dollars	Unit costs accumulated by the vehicle model from technology application in a specific model year.
Price Increase	dollars	Increase in vehicle price accumulated by the vehicle model from technology application and fine payment in a specific model year.
Tax Credit	dollars	Amount of Federal tax credits a buyer receives for purchasing this vehicle. Tax credits are specified for strong hybrid, plug-in hybrid, and electric vehicles, only when the applicable "Tax Credit" settings are defined in the scenarios input file.
Value Loss	dollars	Loss in value to the consumer due to decreased range of pure electric vehicles. This value does not apply if the vehicle is not an EV.
Rel. Value Loss	dollars	Relative loss in value to the consumer due to due to decreased operating life of pure electric vehicles. This value does not apply if the vehicle is not an EV.
Maint Cost	dollars	Unit maintenance costs accumulated by the vehicle model from technology application in a specific model year.
Repair Cost	dollars	Unit repair costs accumulated by the vehicle model from technology application in a specific model year.
Taxes/Fees	dollars	Taxes & fees paid by the consumers for purchasing a new vehicle model in a specific model year.
Financing	dollars	Financing costs paid by the consumers for purchasing a new vehicle model in a specific model year.
Insurance	dollars	Insurance costs paid by the consumers for purchasing a new vehicle model in a specific model year.
LUB1 EFR1 LUB2_EFR2 CCPS DVVLS DEACS ICP DCP DVVLD CVVL DEACD SGDI DEACO VVA SGDIO TRBDS1 SEGR DWNSP TRBDS2 CEGR1 CEGR2 MILLER LGDI CNG LNG LPG DSL DTURB EFRD	text	The utilization of technologies on a vehicle model in a specific model year. The following define the utilization codes used by the modeling system: U = technology was initially in use on a base vehicle before modeling began A = technology was applied to a vehicle by the modeling system US = technology was in use on a base vehicle, but was later superseded when another technology was applied by the modeling system AS = technology was applied to a vehicle by the modeling system, but was later superseded when another technology was applied PA = technology has exceed its phase-in threshold in the current model year, however, it was still applied by the modeling system in order to satisfy backfilling constraints of another technology P = technology has exceed its phase-in threshold in the current model year, and thus was not applied by the modeling system X = technology is not available for application on a vehicle in the current model year <blank> = technology is available for application on a vehicle in the current model year, but the modeling system has not yet applied it

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<tr><td>6MAN</td><td rowspan="8">text</td><td rowspan="8">(same as above)</td></tr>
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<tr><td>FCV</td></tr>
<tr><td>MR1</td><td rowspan="12">text</td><td rowspan="12">(same as above)</td></tr>
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<tr><td>AERO2</td></tr>
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In the above table, note that:

(1) For each vehicle, fuel economies and fuel shares are reported independently for each of the following fuel types: G for gasoline, E85, D for diesel, B20, E for electricity, H for hydrogen, CNG, LNG, and LPG. If the vehicle does not use a specific fuel type, the associated fuel economy and fuel share values will be zero.

Appendix C Monte Carlo Analysis

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

The results of the analysis are located in the output folder selected during modeling. During Monte-Carlo simulation, the CSV outputs that are typically produced with regular compliance modeling are omitted. In their place, a unifying Monte-Carlo specific report is generated, summarizing the results of individual trials. Multiple Monte-Carlo reports are created, one for each scenario analyzed, with the first scenario (Sn0) being the baseline to which all others are compared. Additionally, plain text Monte-Carlo log files can be found under the "MC-logs" subdirectory. The following outputs are produced at the end of the Monte-Carlo simulation:

- ***MC_trials.csv***: Contains Monte-Carlo trials used as input to the analysis. The contents of this file are summarized in Table 35 below.
- ***MC_tech_costs.csv***: Specifies the sales-weighted average technology costs for each technology, adjusted by the randomized cost scales from the **MC_trials.csv** file. The average costs for a technology are computed across all model years and 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 model years and 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.

- ***monte_carlo_report_sn*.csv***: Includes the results of pseudo-randomly generated Monte-Carlo trials for all scenarios. The report for the results of the baseline scenario (Sn0) provides the totals accrued during that scenario. The report for the results of the non-baseline scenario (Sn1) contains changes compared to the baseline. The contents of the file are summarized in Table 36 below.

C.1 Monte-Carlo Input Sampling

In the past versions of the CAFE Model, the sampling of trials for Monte-Carlo analysis was performed internally by the modeling system. Starting with the previous revision, the Monte-Carlo trials are generated externally and are fed into the system in the form of an input file. The "MC trials" file is provided as part of the current rulemaking analysis, and may be obtained to perform additional modeling by users. Alternatively, users wishing to experiment with various distributions and sampling techniques may generate their own trials, provided the resulting input file is congruent with the original used for the analysis. The sampling procedure employed for generating the Monte-Carlo trials is outlined Chapter 10 of the NHTSA Preliminary Regulatory Impact Analysis for the 2021–2027 CAFE standards.

The CAFE model requires entries for each of the variables in Table 35 (below) for every trial, as well as the set of input files necessary to produce a normal run (*i.e.*, those specifying technology and fleet inputs, economic assumptions, and regulatory scenarios). For the "MC trials" file that was used in the final analysis of the 2017–2025 CAFE program, a number of different distributions and technology groupings were used to produce the set of trials.

Table 35. Monte-Carlo Input Data

Column	Contents
Index	Unique index of the trial.
FuelPriceScalar	A randomized scalar used for adjusting the ratio of previous and present model year fuel prices.
PaybackPeriod_OC	Randomized value of the post-compliance payback period that manufacturers use with voluntary overcompliance.
ReboundEffect	Randomized value of the rebound effect.
OnRoadGap_Gasoline	Randomized value of the on-road gap for gasoline fuel.
OnRoadGap_Diesel	Randomized value of the on-road gap for diesel fuel.
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.

C.2 Monte-Carlo Output Data

The modeling system produced two modeling reports as part of the Monte-Carlo analysis: monte_carlo_report_sn0.csv and monte_carlo_report_sn1.csv. The former contains results of the baseline scenario (Sn0), which are specified as the totals accrued during analysis of the baseline, while the latter contains results of the alternative scenario (Sn1), which, for the most part, are presented as incremental changes over the baseline. In both output files, results are provided for each trial, model year analyzed, and regulatory class (according to the regulatory classification of vehicles), as well as aggregated across the entire industry (combining multiple regulatory classes) and all model years (providing a total cost of the program). Some of the outputs reported do not apply to the baseline scenario. In particular, since the "net benefits" is the direct result of improvements realized in the alternative scenario over the baseline scenario, this value would appear as "0" in the baseline's output file.

The following table lists the full contents of the *Monte-Carlo Report*.

Table 36. Monte-Carlo Report

Column	Units	Contents
Trial	integer	Unique index of the trial.
Model Year	model year	Model years analyzed during the study period.
Reg-Class	text	The regulatory class for which the compliance results are reported.
Standard	mpg	The value of the required CAFE standard.
CAFE	mpg	The value of the achieved CAFE standard.
Average CW	lbs.	Average curb weight of analyzed vehicles.
Average WF	lbs.	Average work-factor of analyzed vehicles.
Avg.Tech Costs	dollars	Average technology costs per single vehicle unit.
Avg.Incr Costs	dollars	Average incremental technology costs per single vehicle unit.
Avg.Payback	years	Average payback.
Tech Costs	dollars	Incremental technology costs accrued by the industry (million-$).
Disc Tech Costs	dollars	Incremental discounted technology costs accrued by the industry (million-$).
Fines	dollars	Incremental fines owed by the industry (million-$).
Total Tech Costs	dollars	Incremental compliance costs accrued by the industry including: discounted technology costs, maintenance costs, repair costs, loss of value, and relative loss of value (million-$).
VMT	miles	Incremental billions of miles traveled by all vehicles over their lifetime for a specific model year and regulatory class.
Fuel Consumption	gallons	Incremental billions of gallons of fuel consumed by all vehicles over their lifetime for a specific model year and regulatory class.
CO2 Emissions	million metric-tons	Amount of incremental Carbon Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
Fatalities	units	Incremental fatalities resulting from reduction in vehicle curb weight and increases in VMT due to the rebound effect, aggregated over the lifetime of all vehicles for a specific model year and regulatory class.
Pre-Tax Fuel Costs	dollars	Incremental pre-tax fuel expenditures accumulated across all vehicles over their lifetime for a specific model year and regulatory class (million-$).
Social Costs	dollars	Incremental social costs accumulated by the industry for a specific model year and regulatory class including: pre-tax fuel costs, drive surplus, refueling surplus, market externalities, congestion costs, accident costs, noise costs, fatality costs, and emissions damage costs (million-$).
Net Benefits	dollars	Net benefits for a specific model year and regulatory class (million-$). Net benefits are computed as: -Social_Costs - Total_Tech_Costs
Tech Use LGDI	number	The penetration rate of the technology, specified as a proportion of total sales. The penetration rates represent the amount of technology that was either on the baseline vehicle at the start of the analysis, or applied by the modeling system during analysis. If a technology was present on or applied to a vehicle, but later superseded during the modeling process by another technology (for example, DCP superseding ICP), the superseded technology on that vehicle will not count toward the penetration rate.
Tech Use ISG	number	
Tech Use SHEV	number	
Tech Use ROLL1	number	
Tech Use MR2	number	

Appendix D CAFE Model Software Manual

D.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.

D.2 Notice

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

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

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

D.3 Installation and System Requirements

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

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

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

Table 37. CAFE Model System Requirements

Intel compatible processor (1 GHz or faster recommended)
1 GB RAM (2 GB recommended)
10 MB hard drive space for installation (additional disk space will be required during runtime)
Microsoft® Windows XP/Vista/7/8 Microsoft® Windows Server 2003/2008
Microsoft® .NET Framework 3.5
Microsoft® Excel 2010 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 as a stand-alone executable and does not require installation. To operate the model, place the "CAFE Model.exe" file on the desktop and execute it[39].

D.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.[40] 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 7). The user must read and understand the warnings listed prior to using the modeling system.

[39] 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).

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

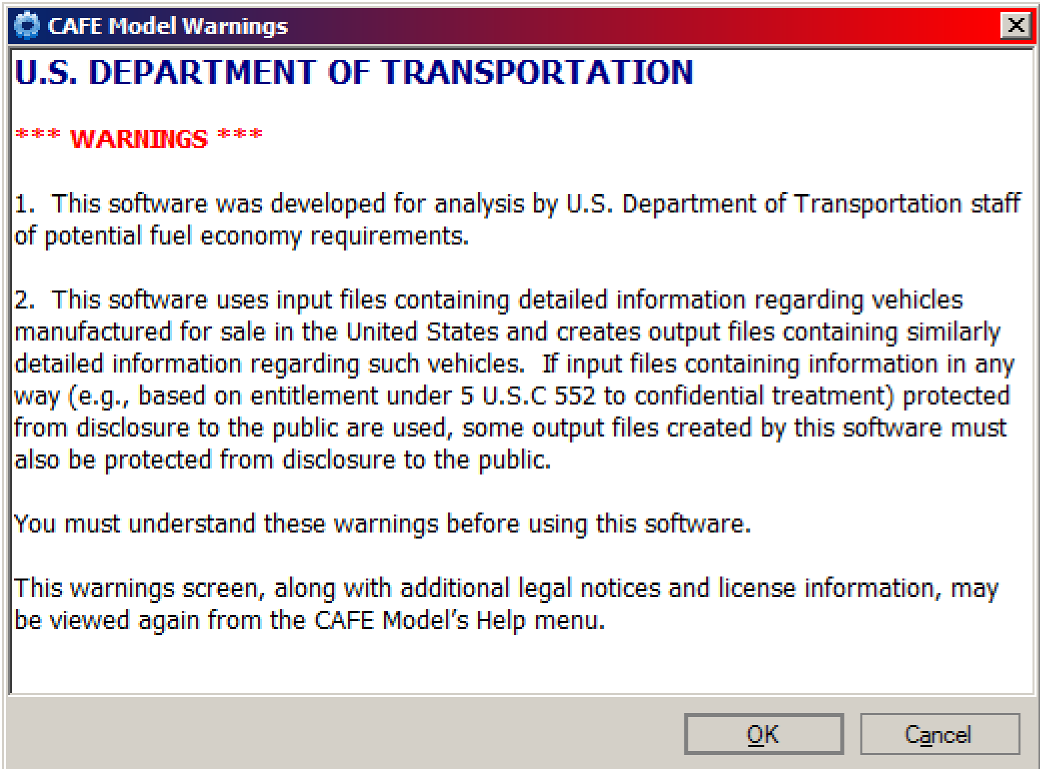

Figure 7. Warnings Dialog Box

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

D.4.1 CAFE Model Window

The main **CAFE Model** window (Figure 8) 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.

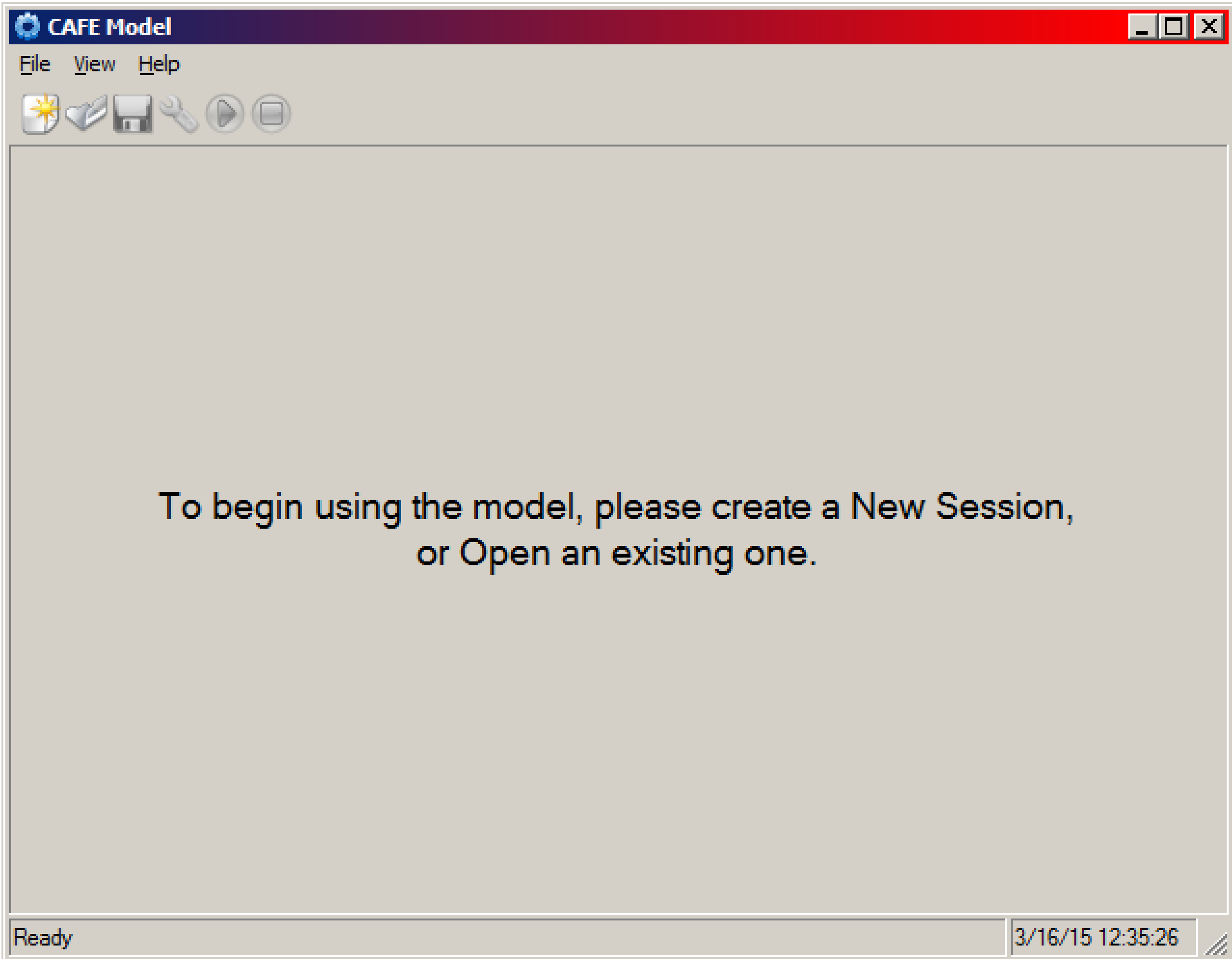

Figure 8. CAFE Model Window

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 9), with most commonly used shortcuts also available on the model toolbar (Figure 10). For user convenience, most of the menu entries may also be controlled using keyboard shortcuts.

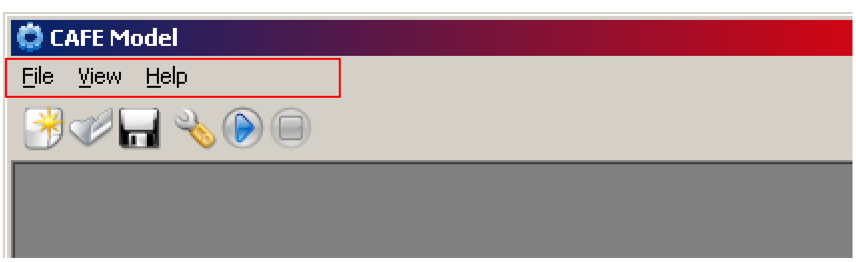

Figure 9. CAFE Model File Menu

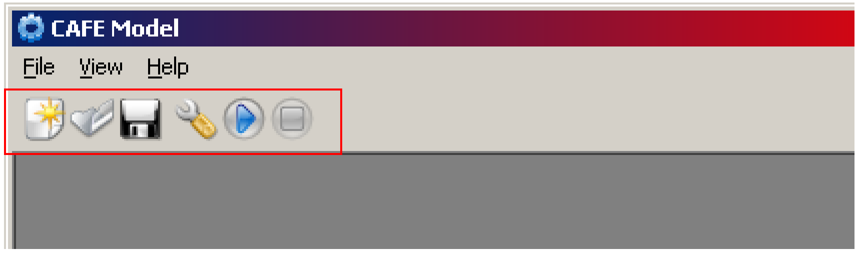

Figure 10. CAFE Model Toolbar

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*** > ***Output Location***: Opens the Windows Explorer and browses to the location where the output files and reports of the active session are saved.

D.4.2 Modeling Settings Window

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

D.4.2.1 General Compliance Settings Panel

The **General Compliance Settings** panel (Figure 11) 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, two 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.

- ***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.

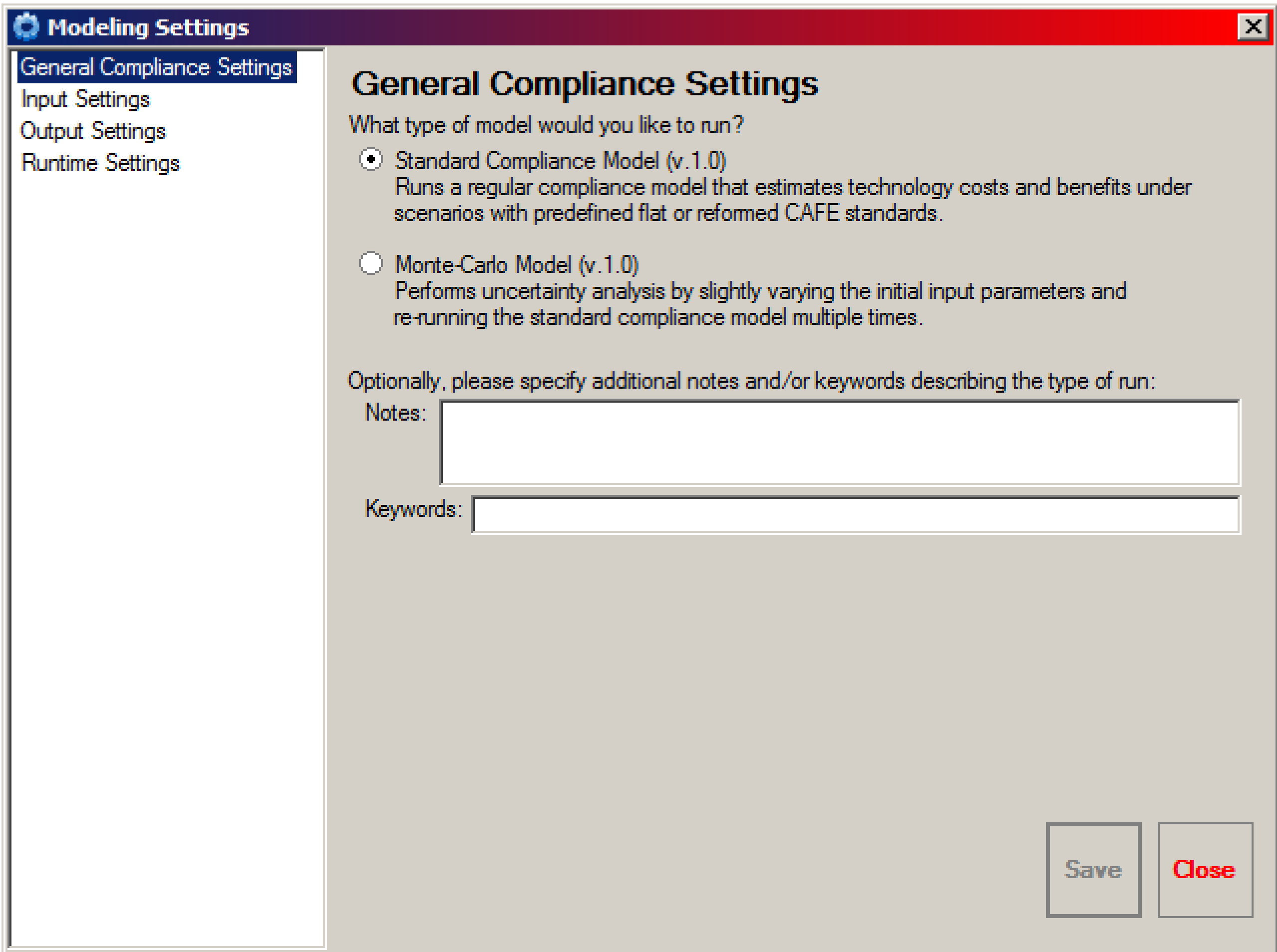

Figure 11. General Compliance Settings Panel

D.4.2.2 Input Settings Panel

On the **Input Settings** panel (Figure 12), the user can select the input data files for use with the modeling system.

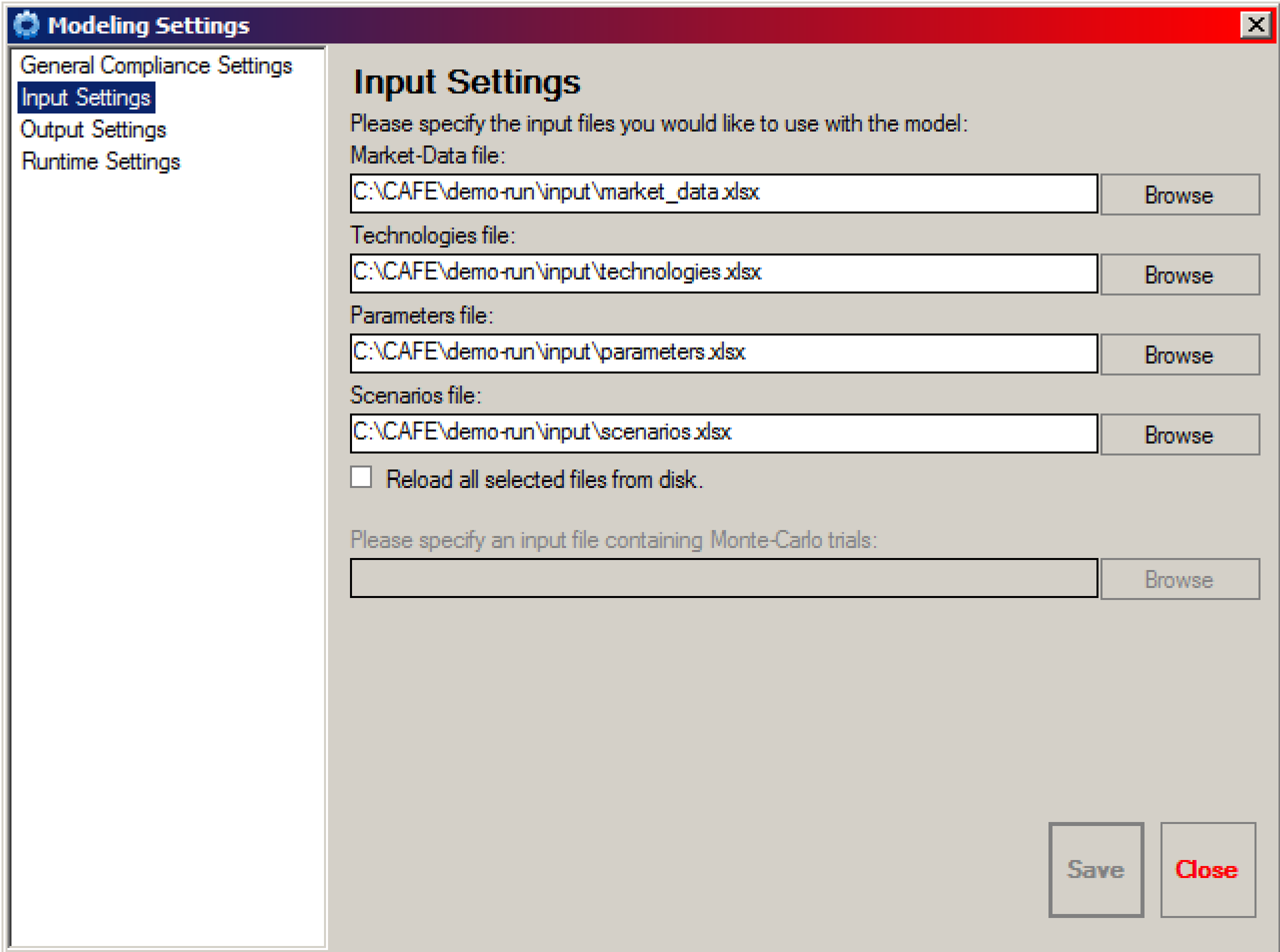

Figure 12. Input Settings Panel (1)

When selecting input files, the model will attempt to verify if an appropriate file was used. If incorrect file path is entered, an error message will be displayed (Figure 13).

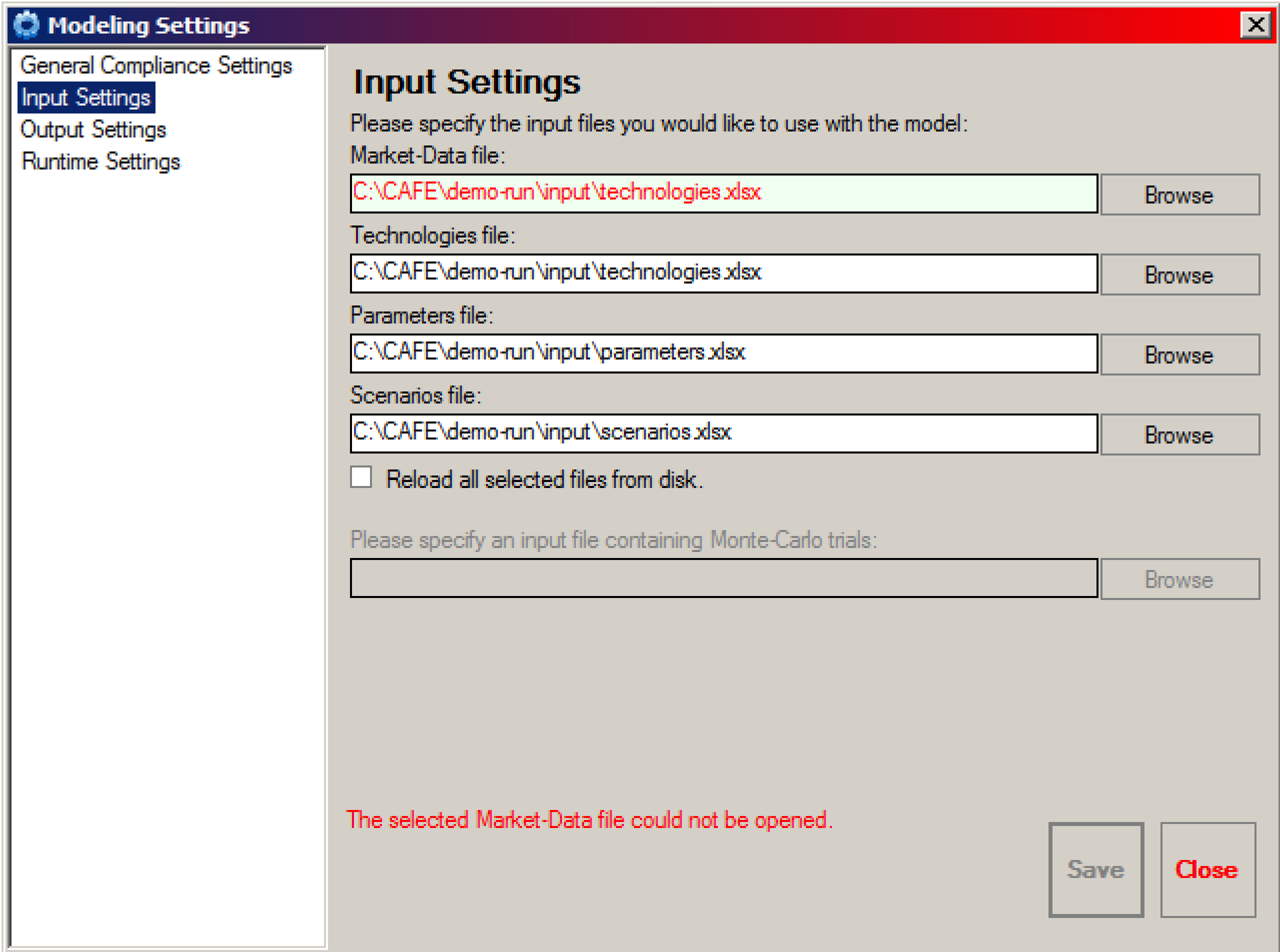

Figure 13. Input Settings Panel (2)

D.4.2.3 Output Settings Panel

The **Output Settings** panel (Figure 14) is used to configure the location where modeling results will be saved.

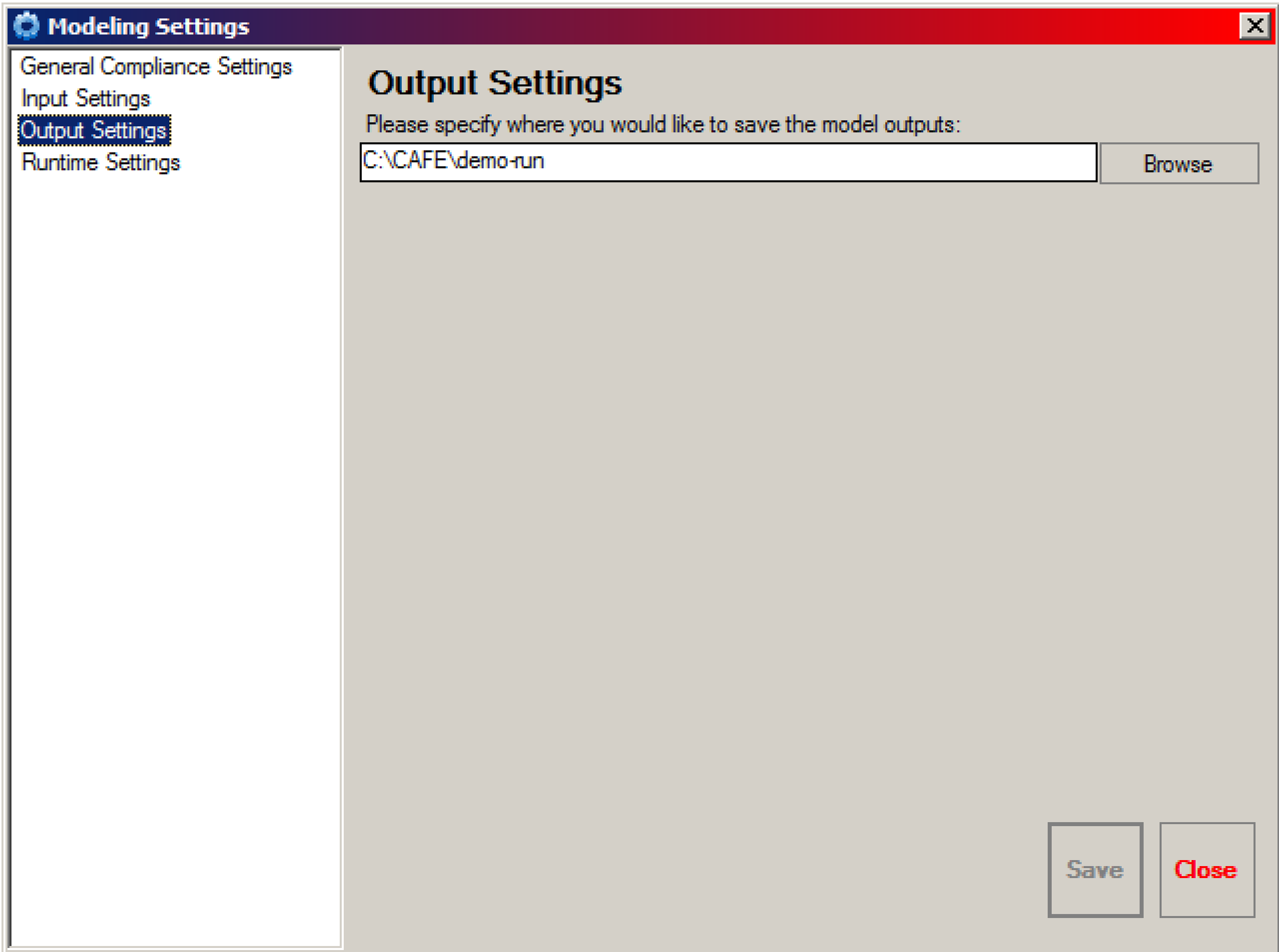

Figure 14. Output Settings Panel

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

- ***Technology Utilization Report***: Provides manufacturer-level and industry-wide technology application and penetration rates for each technology, model year, and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
- ***Compliance Report***: Provides manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
- ***Societal Effects Report***: Provides industry-wide summary of energy and emissions effects for each model year and scenario analyzed. The model produces two versions of this output file, where the results are disaggregated by either the vehicle class and fuel type or the regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
- ***Societal Costs Report***: Provides industry-wide summary of consumer and social costs for each model year and scenario analyzed. The model produces two versions of this output file, where the results are disaggregated by either the vehicle class and fuel type or the

regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.

- ***Annual Societal Effects Report***: This output file is similar to the *Societal Effects Report*, except it further disaggregates the results by calendar year.
- ***Annual Societal Costs Report***: This output file is similar to the *Societal Costs Report*, except it further disaggregates the results by calendar year.
- ***Vehicles Report***: Provides a detailed view of the final state of each vehicle examined by the model, for each model year and scenario analyzed.

D.4.2.4 Runtime Settings Panel

The **Runtime Settings** panel (Figure 15) provides additional modeling options to further customize the model behavior, beyond what is available in the input files:

- ***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.
- ***CO2 Price Estimates***: Specifies whether to use low, average, high, or very-high carbon dioxide cost estimates from the parameters input file. By default, average CO2 price estimates are used.
- ***Scale Consumer Benefits***: Specifies whether the model should scale the private consumer benefits by a specific percentage during the effects calculations. Valid values are between 0 and 100.
- ***Perform Fleet Analysis Calculations***: Specifies whether the model should perform fleet analysis calculations, evaluating modeling effects for historic and forecast model years (before the first compliance model year as well as after the last compliance model year).

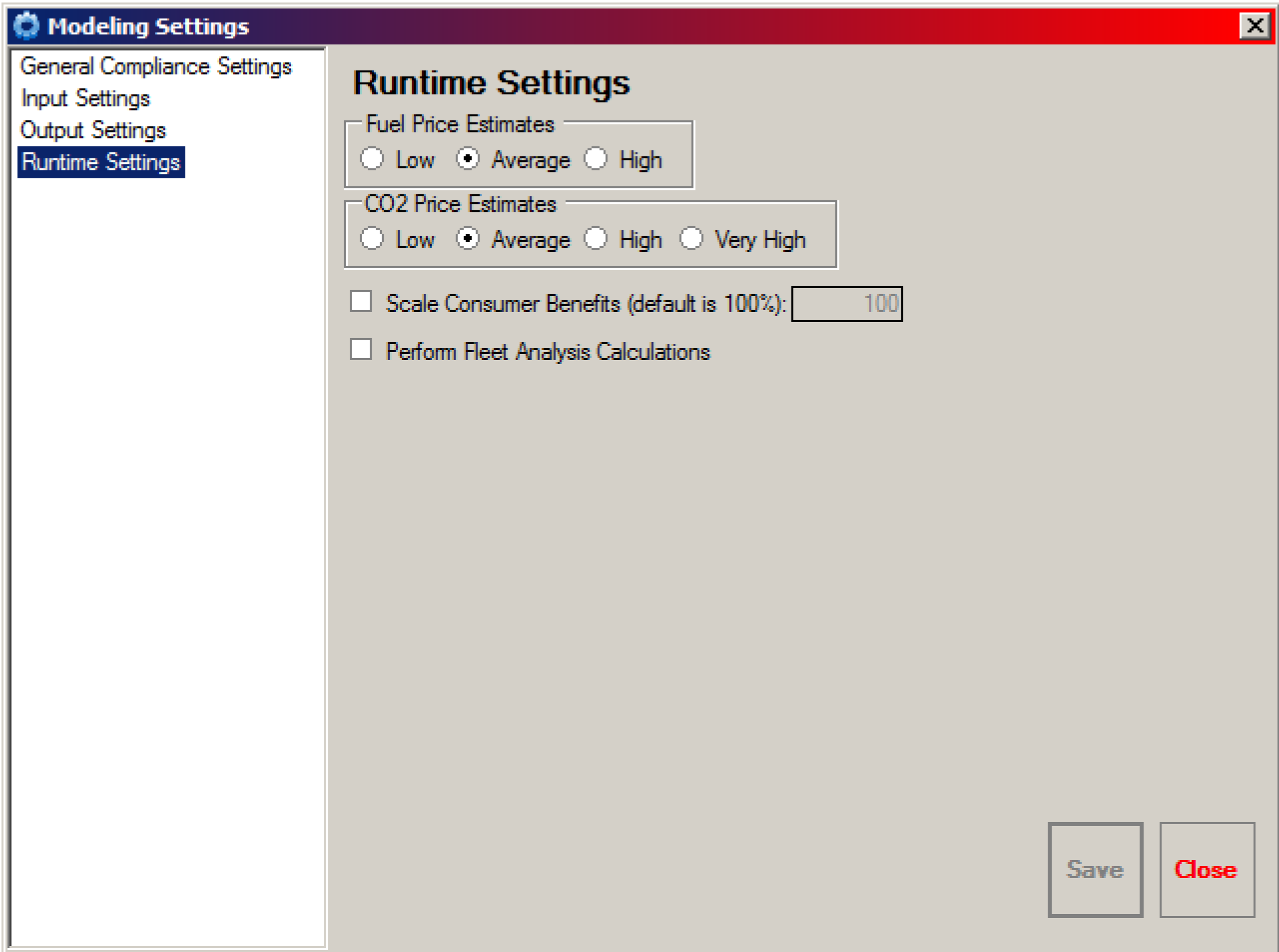

Figure 15. Runtime Settings Panel

D.5 CAFE Model Usage Examples

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

D.5.1 Example 1 – Configuring for Standard Compliance Modeling

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

- Run the CAFE Model by clicking on the **CAFE Model** executable located on the desktop. Read through the **Warnings** dialog box, and then click the **OK** button.
- Select **File** > **New Session** to create a new modeling session. The **Modeling Settings** window appears. Note the errors at the bottom of the window; these indicate that the input files have not been selected.
- On the **General Compliance Settings** panel, select the *Standard Compliance Model* as shown in Figure 16 below.

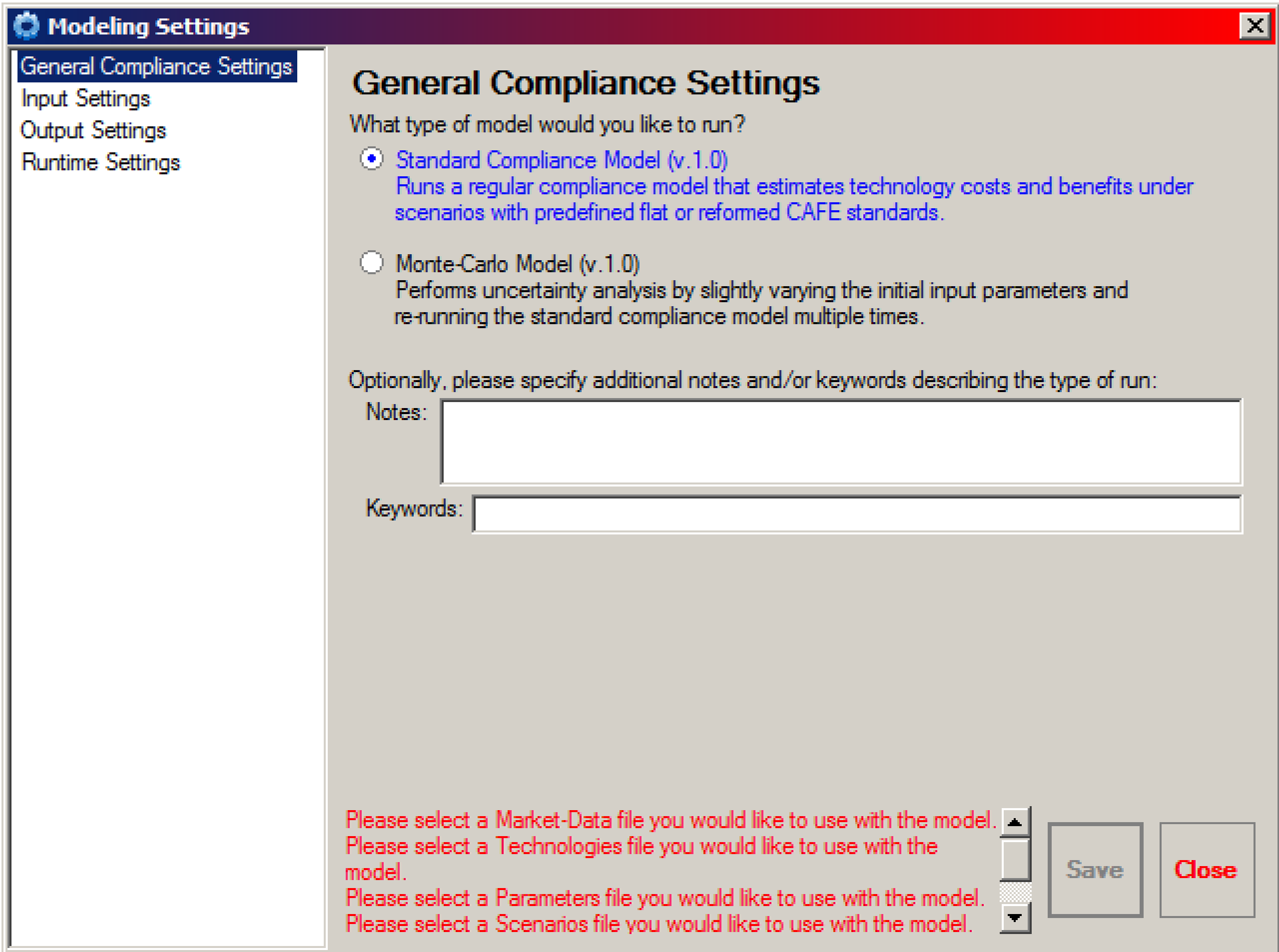

Figure 16. Select Standard Compliance Model

- Click on the **Input Settings** panel to select the input files to use for modeling (Figure 17). Note that once all the input files have been selected appropriately, the error messages disappear.

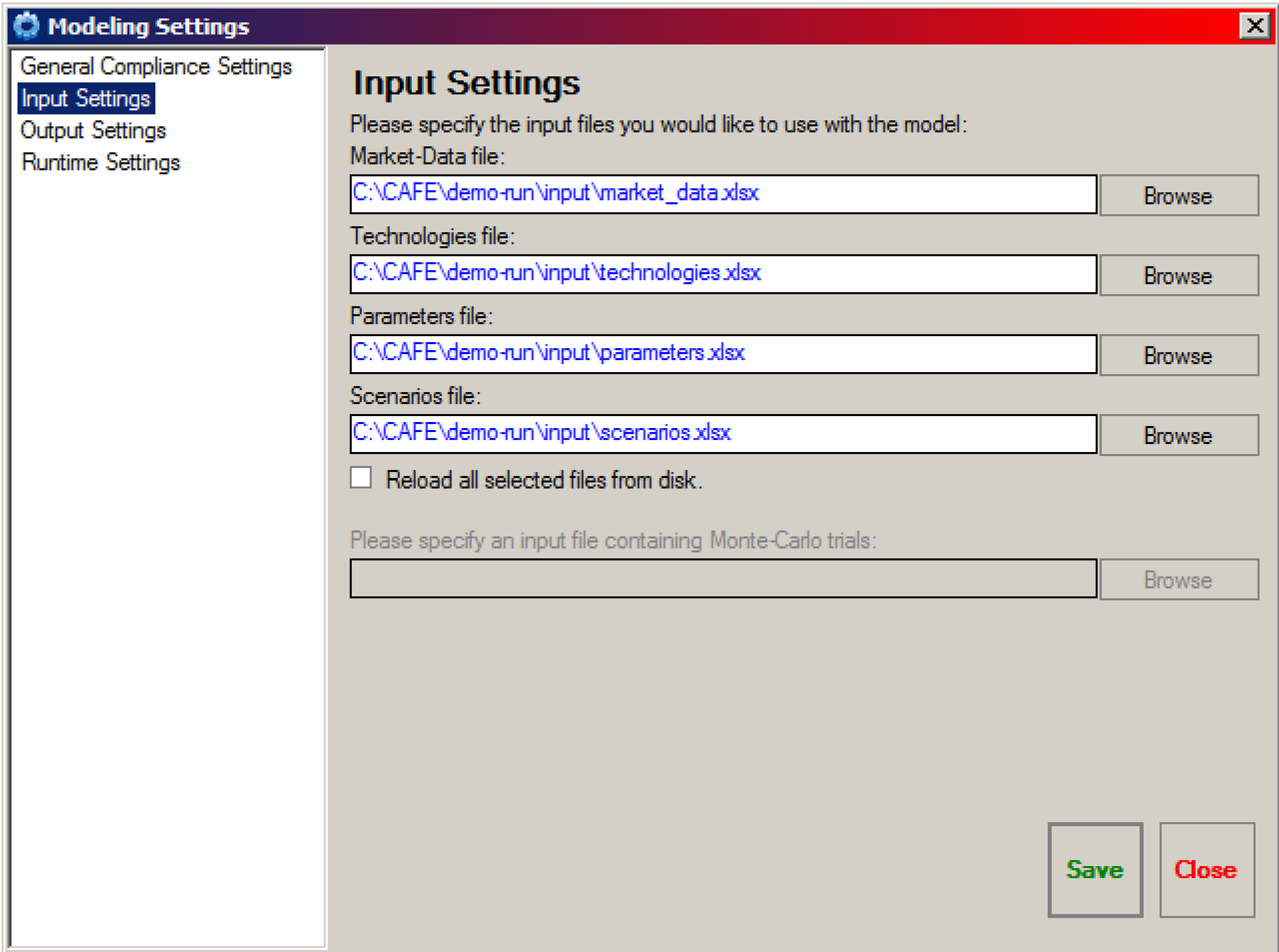

Figure 17. Select Input Files

- On the **Output Settings** panel, select the location for output files (Figure 18).

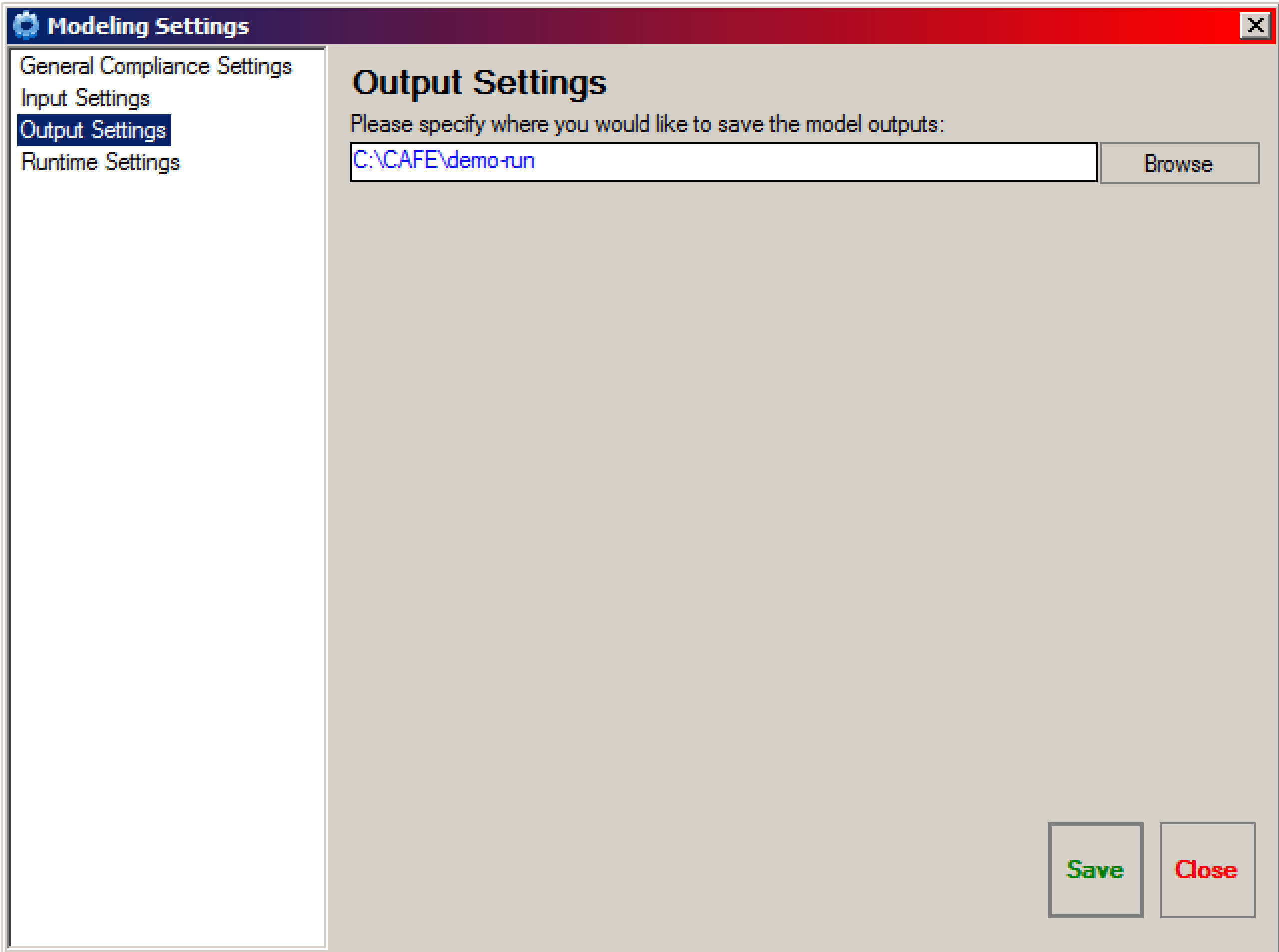

Figure 18. Select Output Location

- The **Runtime Settings** panel is not used for this exercise.
- Click the **Save** button to save the modeling settings and load the input files (Figure 19).

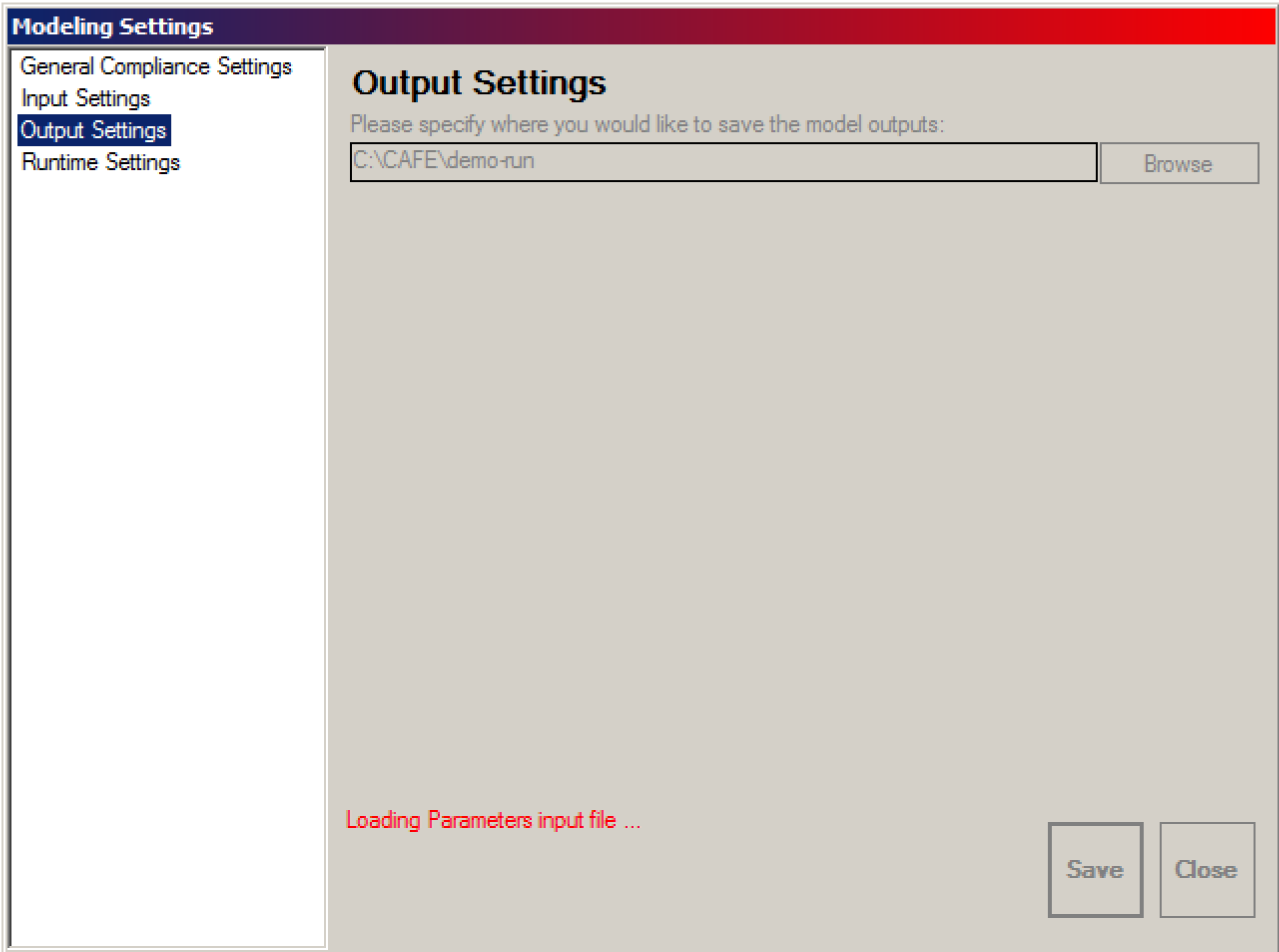

Figure 19. Save Modeling Settings

- 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 20).

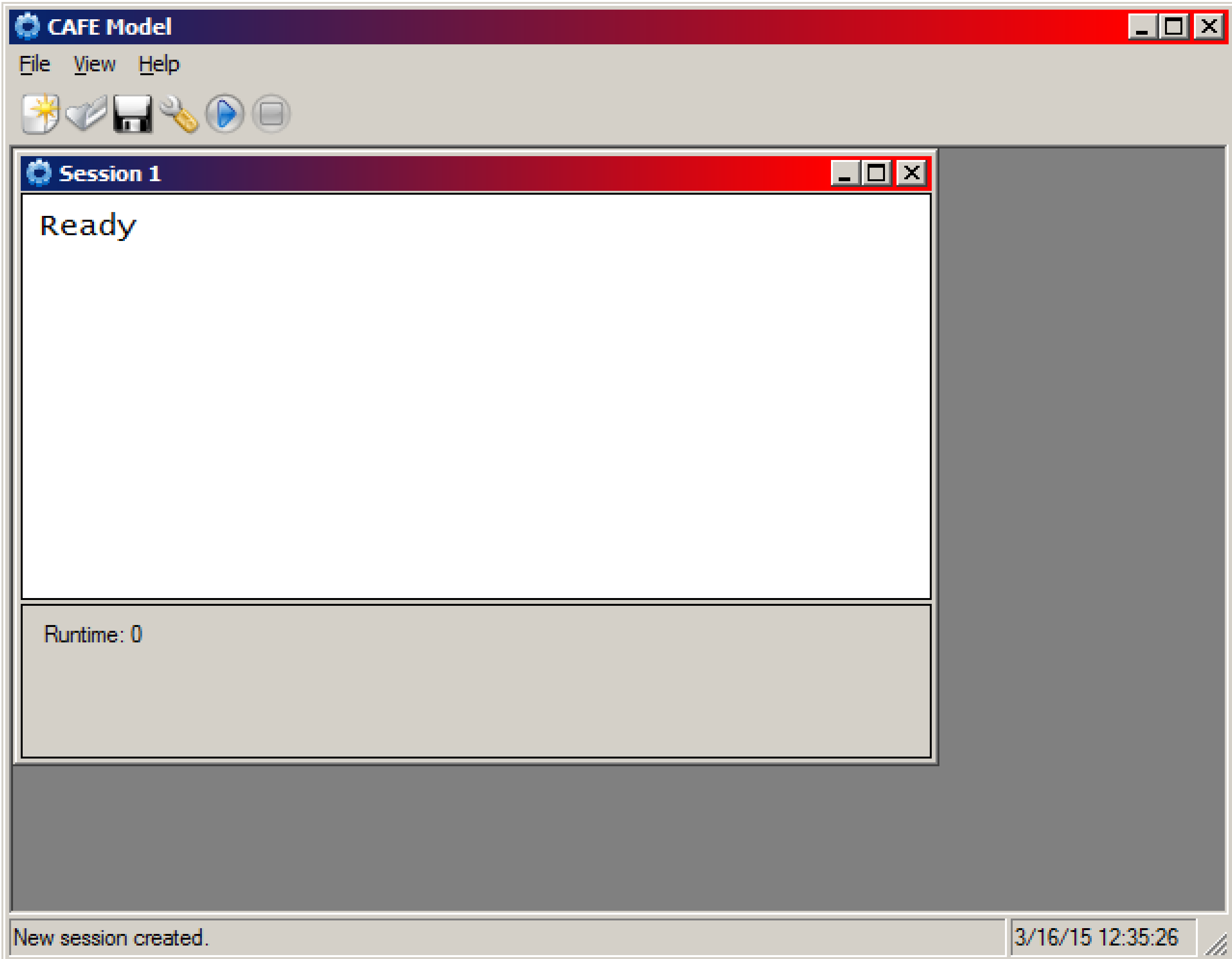

Figure 20. New Compliance Model Session Created

- 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 21).

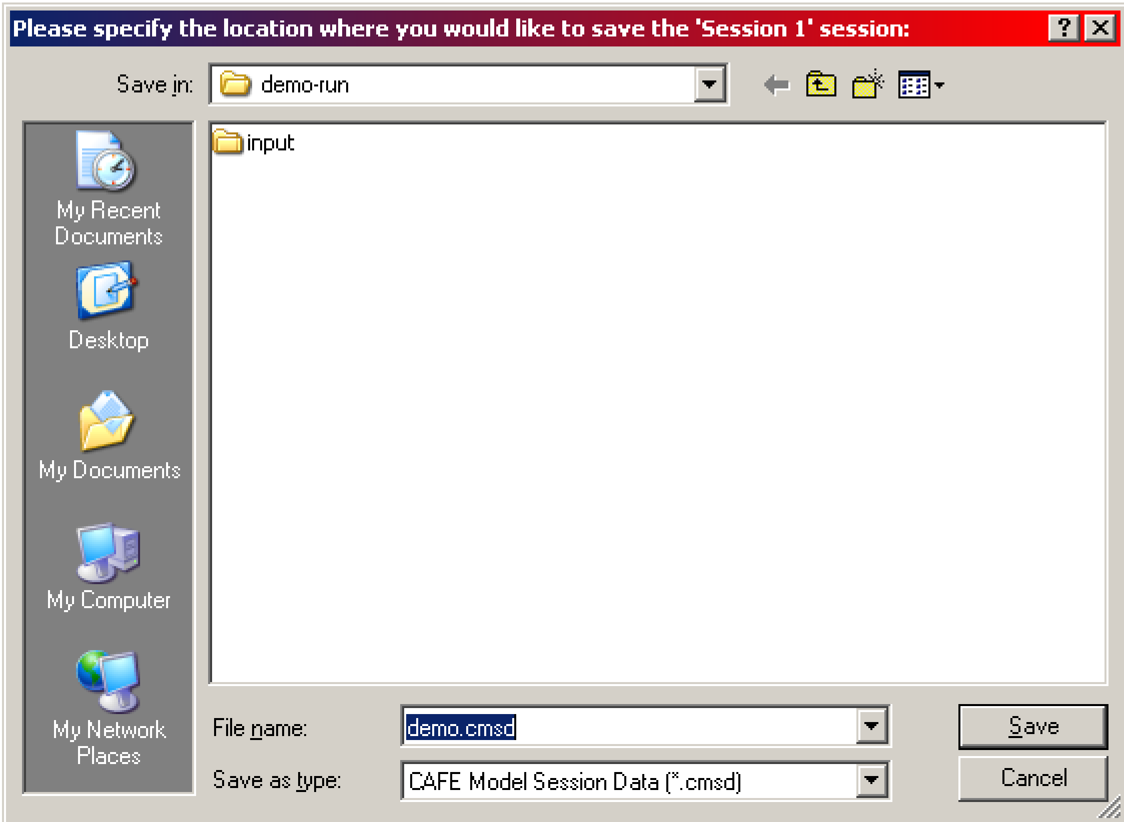

Figure 21. Save New Session

- After the session has been saved, notice the title of the session has changed to "demo" (Figure 22).

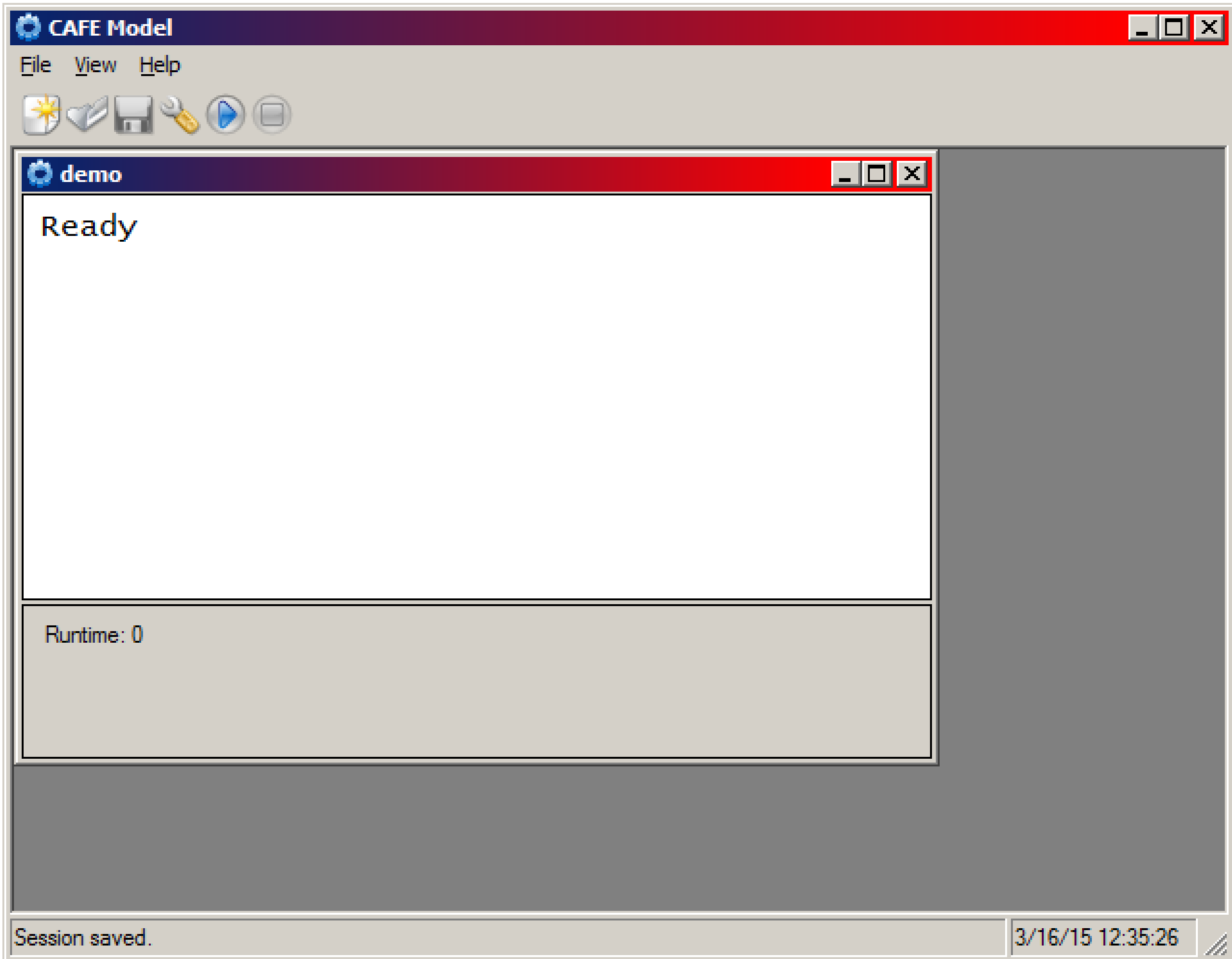

Figure 22. "demo" Session Saved

- 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 23).

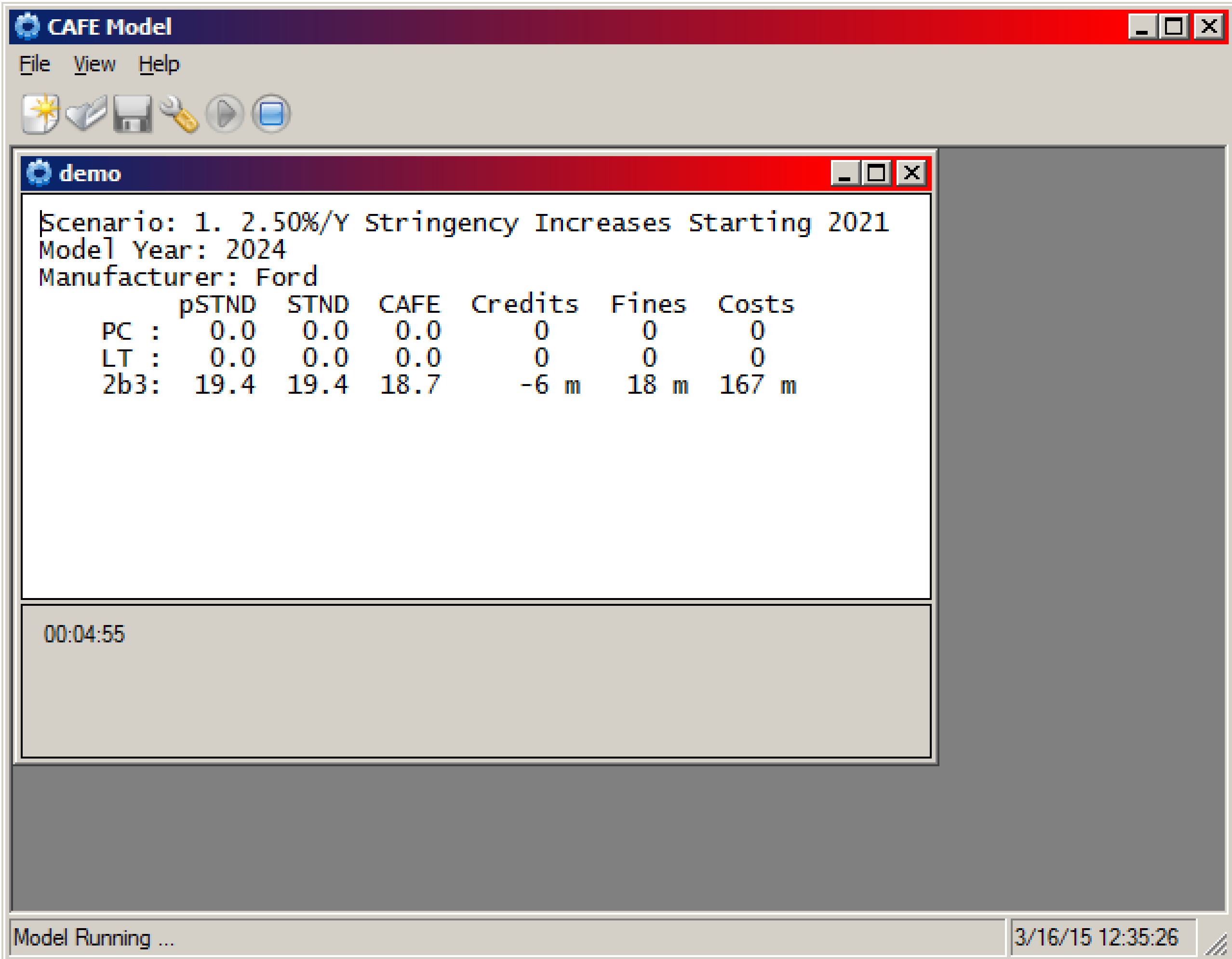

Figure 23. Modeling Progress from the Compliance Model

- After modeling has completed, the "Modeling Completed!" message appears at the bottom of the main **CAFE Model** window (Figure 24).

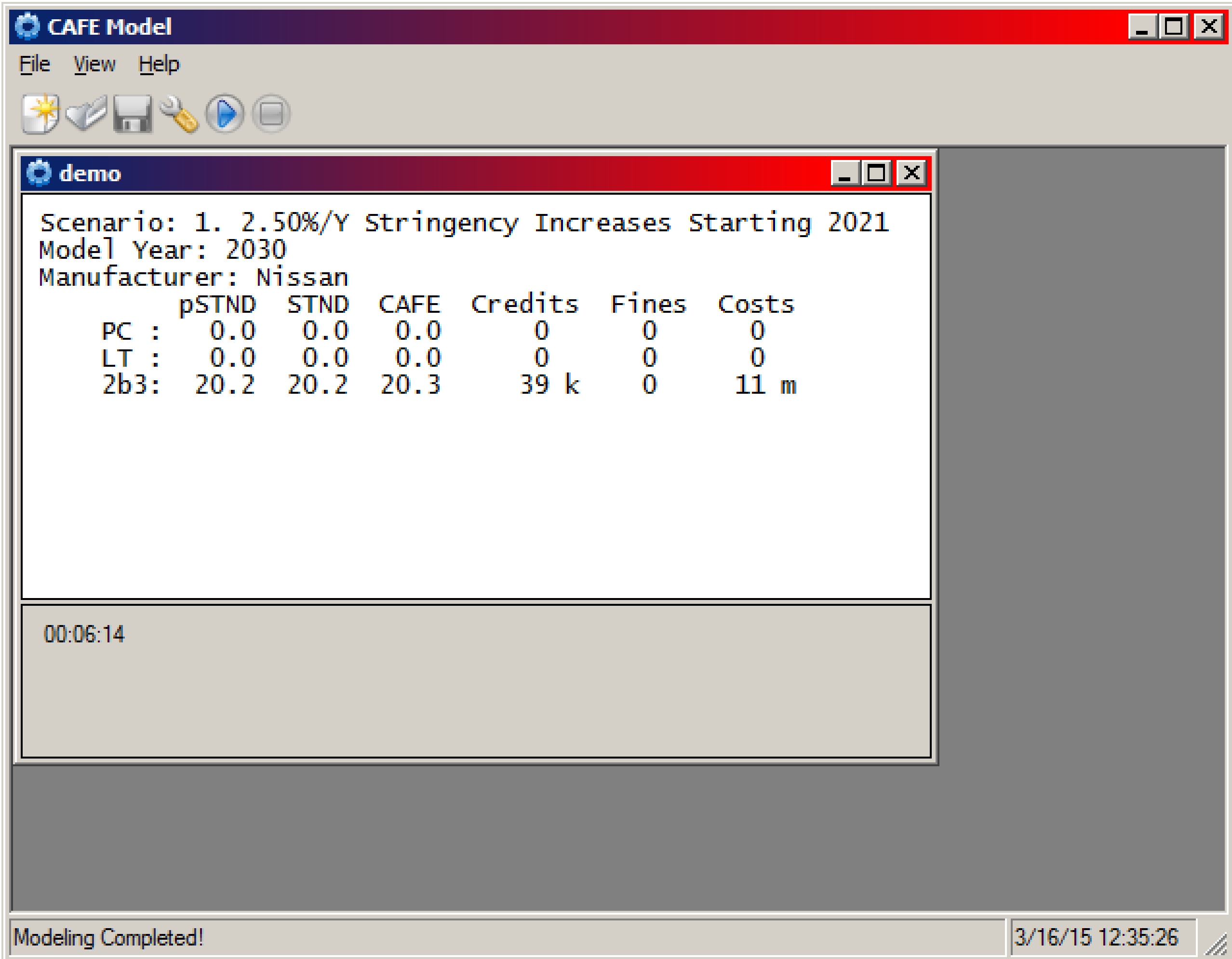

Figure 24. Compliance Model Completed

- 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.

D.5.2 Example 2 – Configuring for Monte-Carlo Modeling

This example demonstrates how to take an existing session created in Example 1 – Configuring for Standard Compliance Modeling, and modify it to run the *Monte-Carlo 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 25).

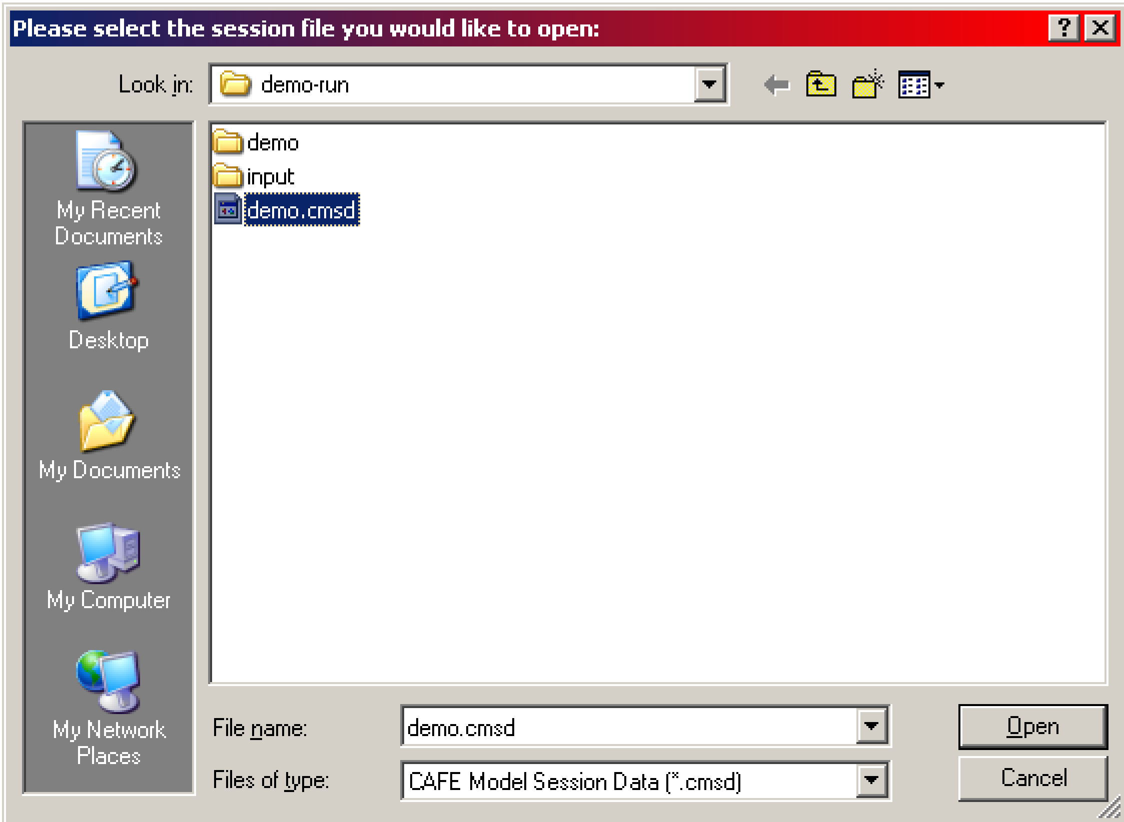

Figure 25. Open "demo" Session

- Once the session has been loaded, select **View** > **Modeling Settings** to bring up the **Modeling Settings** window. There select the *Monte-Carlo Model* as in Figure 26.

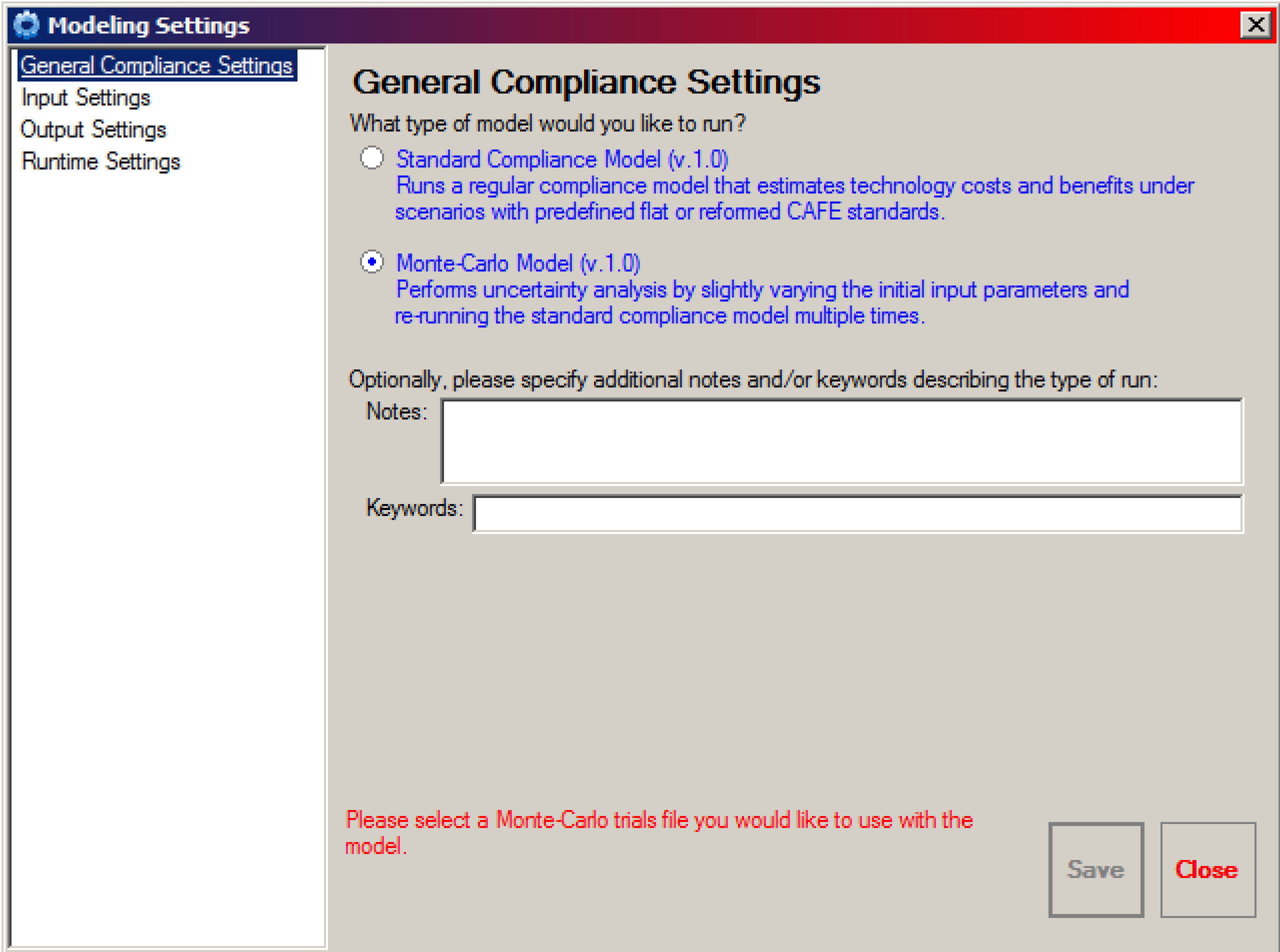

Figure 26. Select Monte-Carlo Model

- Under the **Input Settings** panel, select a Monte-Carlo trials file (Figure 27).

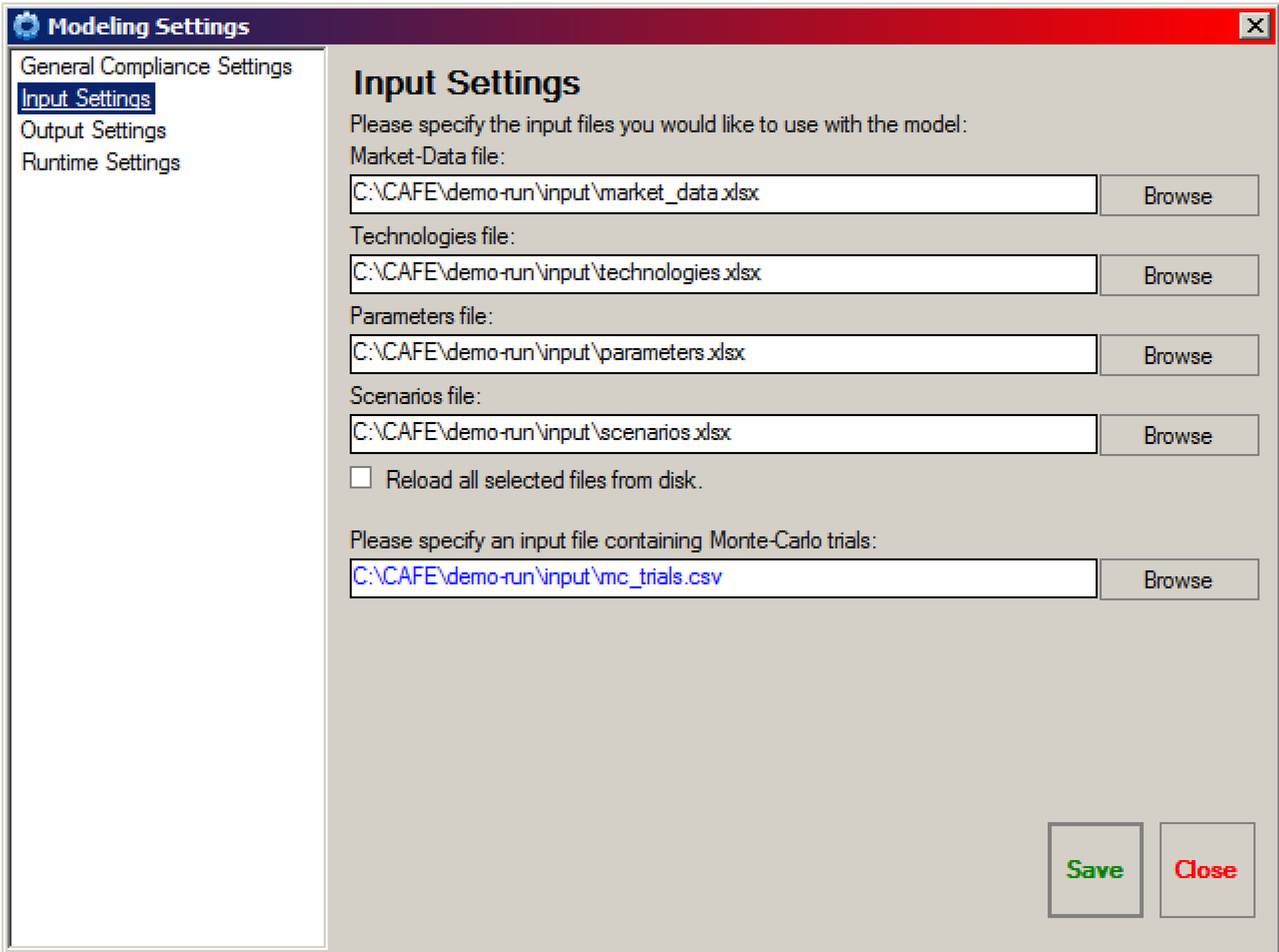

Figure 27. Select Monte-Carlo Trials File

- The **Output Settings** and **Runtime Settings** panels are not used for this exercise.
- Click the **Save** button to save the updated modeling settings; then click **Close**, once saving completes.
- 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 Monte-Carlo session was saved as “demo-mc.cmsd”.
- Select **File** > **Start Modeling** to start the Monte-Carlo modeling process. As the model runs, the progress of the *Monte-Carlo Model* is displayed in the session window (Figure 28).

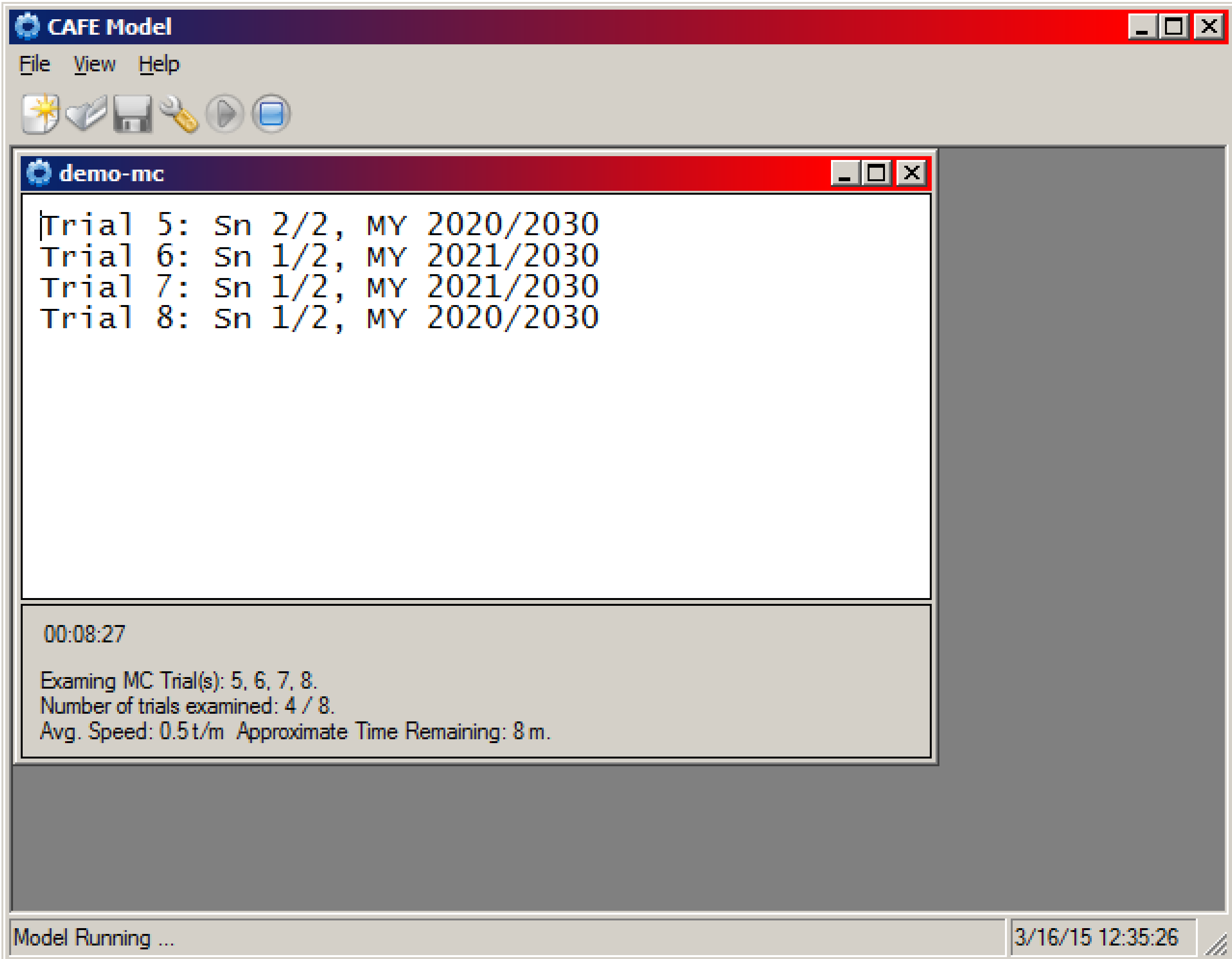

Figure 28. Modeling Progress from the Monte-Carlo Model

- After Monte-Carlo 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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