ANL/ESD-14/1

VISION Model Description and User's Guide: Model Used to Estimate the Impacts of Highway Vehicle Technologies and Fuels on Energy Use and Carbon Emissions to 2100

Energy Systems Division

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prepared for
Vehicle Technologies Office, Office of Energy Efficiency and Renewable Energy,
U.S. Department of Energy

January 2014

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ACKNOWLEDGMENTS

The development of the VISION model has been funded by the Vehicle Technologies Office and its predecessor programs and/or offices within the Office of Energy Efficiency and Renewable Energy (EERE), US Department of Energy (DOE). Philip Patterson and Jake Ward have been the primary sponsors of the model and its use and we thank them for their extensive support.

This document represents a revised version of two earlier documents:

- VISION 2.0 user guide written by Jake Ward, DOE and Margaret Singh and Anant Vyas, Argonne National Laboratory (Argonne).

- Model description written by Margaret Singh and Anant Vyas, Argonne and Elyse Steiner, National Renewable Energy Laboratory.

The VISION model has been developed by various analysts over time with primary credit going to John Maples, now of the US Energy Information Administration (EIA) and Anant Vyas, of Argonne. It is sponsored by Phil Patterson (retired) and Jake Ward, DOE EERE.

We would like to thank all of them for their contributions and efforts.

Following Margaret Singh's and Anant Vyas' retirement from Argonne, Yan Zhou has become the manager of the VISION model and can be contacted at yzhou@anl.gov. Now the VISION model is maintained regularly and updated annually by Yan Zhou of Argonne.

The authors are solely responsible for the contents of this report.

ACRONYMS

AEO	Annual Energy Outlook
AER	All-Electric Range
Argonne	Argonne National Laboratory
CD	Charge Depleting (operation of a PHEV)
CNG	Compressed Natural Gas
Comb	Combination (truck)
CS	Charge Sustaining (operation of a PHEV)
DOE	US Department of Energy
DOT	US Department of Transportation
Dsl	Diesel
E85	Ethanol fuel (up to 85% Ethanol)
EERE	US Department of Energy Office of Energy Efficiency and Renewable Energy
EIA	US Department of Energy, Energy Information Administration
EtOH	Ethanol
EV	Electric Vehicle
FCV	Fuel Cell Vehicle
FFV	Flex-Fuel Vehicle
F-T	Fischer-Tropsch (Diesel)
GVW	Gross Vehicle Weight
H_2	Hydrogen
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
LDV	Light-Duty Vehicle
LT	Light Truck (up to 10,000 lbs. gross vehicle weight)
MMTCe	Million Metric Ton Carbon equivalent
MMT CO_2e	Million Metric Ton CO_2 equivalent
MPG	Miles per Gallon
MPGGE	Miles per Gasoline Gallon Equivalent
NHTSA	National Highway Traffic Safety Administration
NEMS	National Energy Modeling System
PHEV A	Plug-In Hybrid Electric Vehicle with CD range less than 20 miles
PHEV B	Plug-In Hybrid Electric Vehicle with CD range greater than 20 miles

SI	Spark-Ignition
SU	Single Unit
VIUS	Vehicle Inventory and Use Surveys
VMT	Vehicle Miles Traveled

1 INTRODUCTION

The VISION model has been developed by the US Department of Energy (DOE) to provide estimates of the potential energy use, oil use, and carbon emission impacts to the year 2100 of advanced light- and heavy-duty highway vehicle technologies and alternative fuels. DOE supports research of advanced transportation technologies (including fuels) and is frequently asked to provide estimates of the potential impacts of successful market penetration of these technologies, sometimes on a relatively-quick turnaround basis.

VISION is a spreadsheet model that was created in Microsoft Excel® that can be used to respond rapidly to quick-turnaround requests, as well as for longer-term analyses. It uses vehicle survival and age-dependent usage characteristics to project total light- and heavy-truck stock, total vehicle miles traveled (VMT), and total energy use by technology and fuel type by year, given market penetration and vehicle energy efficiency assumptions developed exogenously. Total carbon emissions for on-highway vehicles by year are also estimated because life-cycle carbon coefficients for various fuels are included in VISION.

VISION is not a substitute for the transportation component of the US Energy Information Administration's (EIA's) National Energy Modeling System (NEMS). NEMS incorporates a consumer choice model to project market penetration of advanced vehicles and alternative fuels. The projections are made within the context of the entire US economy. However, the NEMS model requires more time to execute and only makes projections to 2040. VISION complements NEMS with its relative ease of use and by extending the time frame of potential analysis beyond 2040.

VISION has been used for a wide variety of purposes. For illustration, we have listed some of its most recent and current uses in Table 1. Figures 1 through 4 illustrate the results of some of those runs. These graphs are not actual model outputs, but they are based on model results. Aside from these, the National Petroleum Council and National Academies used VISION in their recent scenario studies (*1*, *2*).

The original VISION model description (*3*) and user guide (*4*) were written in 2004 and 2006, respectively. Since then, the VISION model has been upgraded with new features and functions. Based on the previous two documents, this report describes the 2013 version including all of the new features that have been added since 2006.

The main body of this report describes VISION's methodology and data sources. The methodology and data sources used in the light- and heavy-vehicle portions of the model are discussed separately. Some suggestions for future improvements to the model are made. Appendix A provides instructions on how to run the VISION model.

TABLE 1 Example Uses of VISION

Requestor	Use	Sample Figures
Vehicle Technologies Office, Office of Energy Efficiency and Renewable Energy (EERE), DOE	Benefits estimates that would accrue from achieving milestones of Vehicle Technologies Program relative to a base case	Figure 1
Office of Hydrogen, Fuel Cells & Infrastructure Technologies, DOE/EERE	Impact of proposed FreedomCAR and Fuel Initiative (potential impact of fuel cell vehicles [FCVs] used in Fuel Cell Report to Congress and draft Multi-Year Research, Development and Demonstration Plan)	Figure 2
	FCV market penetration scenario for draft posture plan	
Office of FreedomCAR and Vehicle Technologies, DOE/EERE	Oil reduction target for hybrid electric vehicles (HEVs) in draft research plan	Figure 3
	Staff paper on potential contribution of gasoline HEVs to oil reduction	
	Respond to congressional questions on light-duty diesels	
Office of Weatherization and Intergovernmental, DOE/EERE	Evaluation of how increased alternative fuel use and light-duty vehicle (LDV) fuel economy could be combined to reach a particular oil-saving goal in 2020	Figure 4
Board of Directors, DOE/EERE	Impact of various forms of rebates and feebates on oil use and associated government expenditures through 2020 (another model was first used to estimate the ultimate new- vehicle miles-per-gallon [MPG] achieved and government expenditures for specific programs)	
Office of Policy and International Affairs, DOE	Demand estimates for DOE's study of premium diesel fuel availability issues	
National Highway Transportation Safety Administration, Department of Transportation/ (DOT/NHTSA)	Answer question on how to reduce LDV fuel use by 5% in 2010 (proposed congressional legislative amendment)	
	Estimate the LDV MPG that would be required to save 1 million barrels per day (mbpd) by 2015	
Congressional Budget Office	Estimate the LDV MPG that would be required to save 1 mbpd by 2015 (different assumptions than for DOT/ NHTSA)	
Private Industry	Estimate impact of various LDV greenhouse gas emission reduction strategies (higher vehicle fuel economy standards and gasoline tax)	

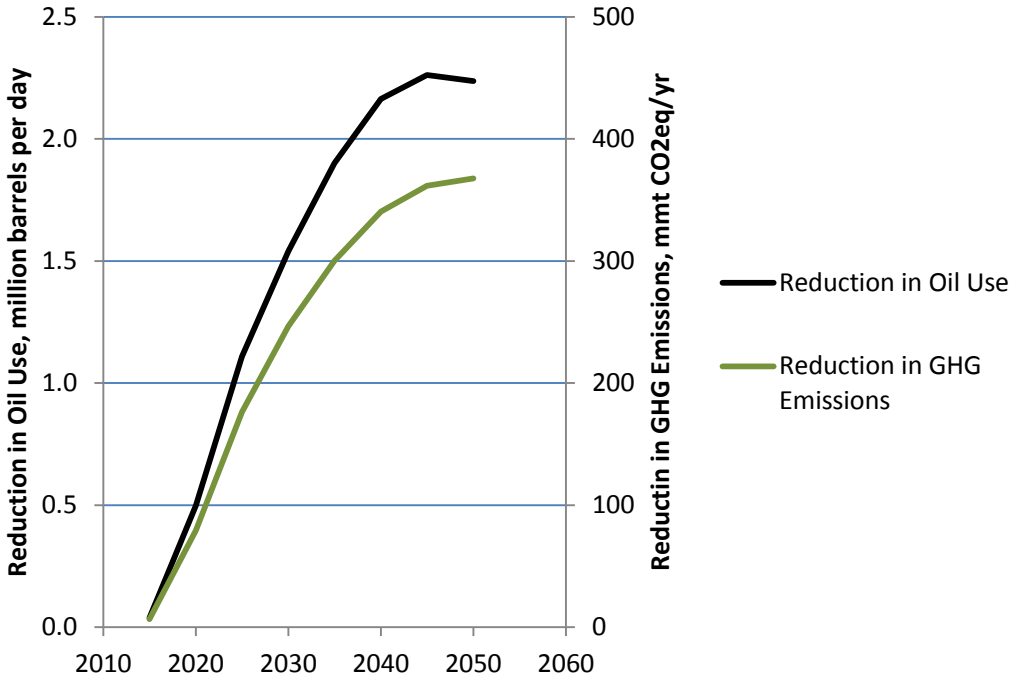

FIGURE 1 Vehicle Technologies Program Benefits Metrics by 2050 (October 2013)

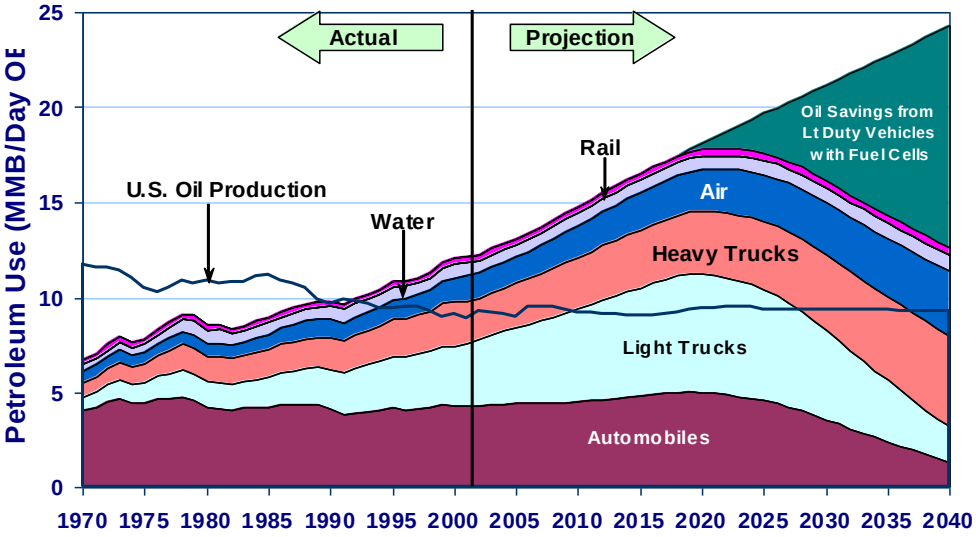

FIGURE 2 Potential Transportation Oil Savings with FCVs (December 2002)

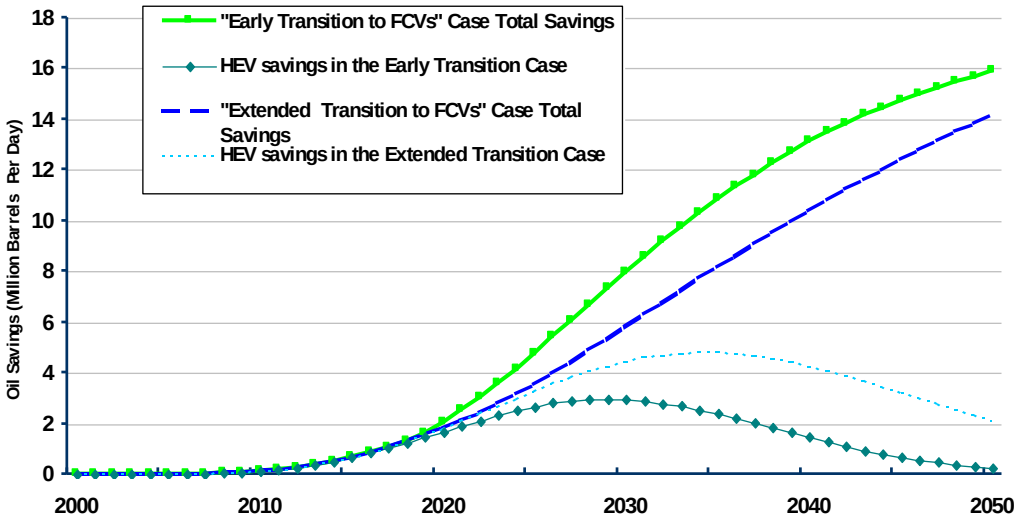

FIGURE 3 HEV Contribution to Total Light Vehicle Oil Savings from Vehicle-Related Technologies Supported by DOE (June 2003)

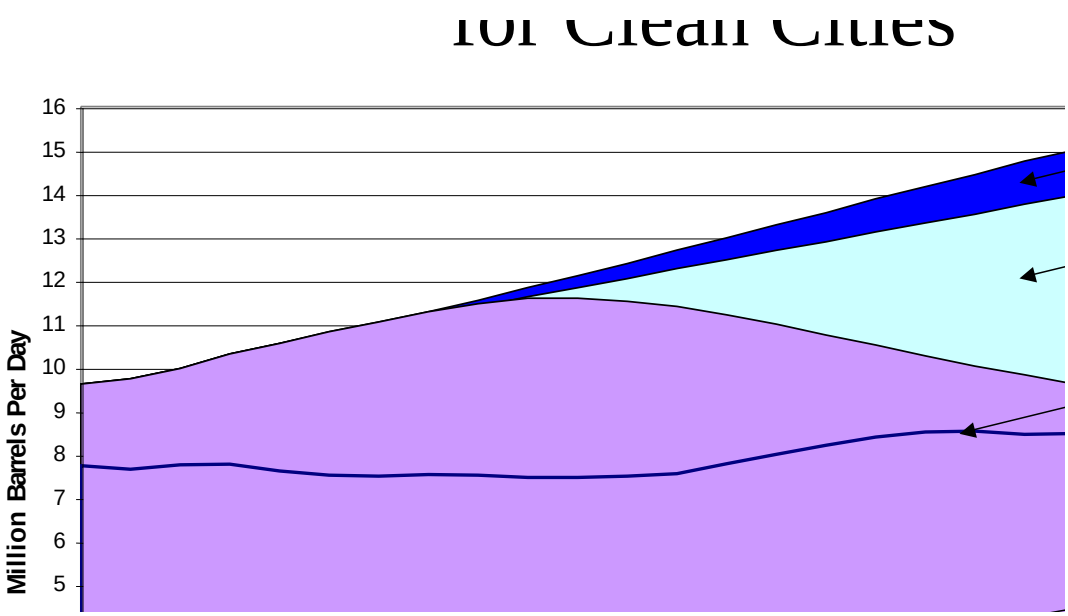

FIGURE 4 Lowering 2020 Oil Use to 2000 Level for Clean Cities (July 2002)

The VISION Model considers a set of input parameters. The default parameter values taken from the Annual Energy Outlook (AEO) Reference Case and its extension are in place. All input values can be changed by the user to customize the simulation. Major input parameters include:

- Car technology market penetration and fuel economy ratio;
- Light-truck technology market penetration and fuel economy ratio;
- Light-truck share of total LDV market;

- Fuel type (including hydrogen and ethanol via multiple production pathways) and price;
- VMT, including growth rate and elasticity to the cost of driving;
- Flex-Fuel Vehicle (FFV) VMT share by E85 and all-electric range for new Plug-In Hybrid Electric Vehicle (PHEV);
- Heavy-truck fuel economy, technology market share, and alternative fuel usage; and
- Light-vehicle cost.

The model generates output values by vehicle type: car, light truck, and heavy truck. The output totals include:

- Energy use by fuel type (oil, compressed natural gas, F-T diesel, bio-diesel, methanol, hydrogen, electricity, and ethanol);
- Full fuel cycle carbon emissions (as million metric tons of carbon equivalent);
- Full fuel cycle GHG emissions (as million metric tons of CO2 equivalent);
- Fuel expenditures;
- Fuel expenditures as a percent of GDP; and
- Light vehicle miles per gasoline gallon equivalent (MPGGE).
- Energy consumed while producing feedstock for end use fuels.
- Energy consumed in producing end use fuels.

VISION software consists of two integrated Excel worksheets:

1. VISION YYYY AEO Base Case.xls

2. File To Be Copied To All Runs of VISION YYYY.xls

The variables YYYY denote which edition of VISION and EIA's Annual Energy Outlook are being used. For example, for VISION 2013, the worksheets are named:

1. VISION 2013 AEO Base Case.xls

2. File To Be Copied To All Runs of VISION 2013.xls

Default values to year 2040 for VISION 2013 are drawn from AEO 2013. Detailed information about the input parameters and output values are explained in Sections 3 and 4.

2 LAUNCHING VISION

The first file (VISION YYYY AEO Base Case) is for user reference only and should not be modified. It contains the inputs and results for the **Base Case** according to projections made by the EIA in the AEO and it extends to the year 2100. This **Base Case** is the scenario against which all hypothetical scenarios are compared.

The second file is the template through which alternative market penetration scenarios can be created. To create a new market penetration scenario, open the file entitled **File to Be Copied to All Runs of VISION YYYY.xls** and immediately save it under a new name. An unmodified version of the original file should always be available since each new scenario created in VISION should originate with this file.

When the file is opened, Excel will automatically open the workbook to the **Model Input** worksheet. The first step in data entry using this worksheet should be the replacement of the contents of cell G1 (**File to Be Copied to All Runs of VISION YYYY**) with the new scenario name. Afterwards, proceed to input parameters for the market penetration scenario being modeled, as described in Section 3.

3 INPUT DATA

VISION contains a **Base Case** projection of US highway transportation vehicle characteristics and energy use to the year 2100. As much as possible, it relies on EIA's AEO projections to its last year (2040 for AEO 2013), but there are some key differences, shown as the following.

1. Class 2b trucks are included with LTs in VISION
2. BEV100 and BEV300 are combined in VISION
3. Class 7&8 Trucks are split into 7&8 SU and 7&8 Combination trucks in VISION
4. LNG, CNG and LPG are combined in VISION
5. New Car and LT prices are weighted by sales shares of size class in VISION

This section of the report explains the derivation of the **Base Case** projections and how that data can be modified in the model to evaluate alternative assumptions about the market penetration of advanced technologies, alternative fuels, and fuel economy.

Market penetration scenarios are defined by the input assumptions in the **Model Input** worksheet. These assumptions guide the calculations in supporting worksheets to generate the results that appear in the **Model Results** worksheet. By choice, the parameters that appear in the **Model Input** worksheet match the values published in and/or underlying the Annual Energy Outlook YYYY Reference Case through the year 2040 (5) or whichever is the last projection year. Post-last AEO year, the inputs are based on a variety of assumptions: e.g., in some cases they are extensions of the AEO values (generally relying on the growth rates in last five years projected in the AEO, 2035–2040 for VISION2013); in other cases, the inputs may be held constant at the AEO's final year values; and in still other cases, the projections may be made to fit a logit curve.

These parameters can be changed to describe hypothetical scenarios by following the directions in this section. In most cases, a user should change values only in cells that are shaded light yellow. Cells that are not shaded are for user information and their contents should not be changed.

The **Model Input** worksheet is organized in two dimensions: by variable type moving down the worksheet and by year moving across the worksheet (where applicable). The sequence of the explanations here mirrors the organization of the **Model Input** worksheet from top to bottom, as follows:

- Automobiles (Cars)
  - Market Penetration
  - New Auto Fuel Economy (as a Ratio to **Base Case** ICE)
- Light Trucks
  - Market Penetration
  - Light Truck Share of Total Light Duty Vehicle Market
  - New Light Truck Fuel Economy (as a Ratio to **Base Case** ICE)
- Technology Fuel Type (selecting fuel type for some technologies)

- Fuel Price
- Other Key Fuel Input Assumptions
  - Ethanol volumetric content in gasoline and bio- and FT-diesel volumetric contents in diesel
  - FFV VMT share by E85 and all electric range for new PHEV
    - Percent of ethanol flex-fuel vehicle VMT on E85
    - Rated electric range for PHEV in miles
  - Ethanol production share by feedstock
  - Hydrogen production share by pathway
  - Utility scenario (electricity generation mix)
- Light-Duty Vehicle Miles Traveled (VMT):
  - VMT growth function and elasticity to the cost of driving
  - VMT growth factors by year (optional, ignores elasticity)
- Heavy trucks
  - New Vehicle Fuel Economy
  - Technology/Fuel Market Share
  - Alternative Fuel Usage
- Car Cost
- Light Truck Cost

The following sections include screenshots as illustrative examples of the **Model Input** worksheet. These screenshots, and the column and row numbers associated with each, are from VISION2013 and could vary slightly in future versions.

3.1 AUTO (CAR) MARKET PENETRATION

The Auto (Car) Market Penetration module allows a user to define the percentage of the total number of new automobiles (cars) sold by technology type. Figure 5 shows these technologies that include:

- Electric vehicles — EV,
- Flex fuel vehicles that can use either E85 or gasoline — E-85/gasoline FFV,
- Diesel,
- Compressed natural gas — CNG,
- Spark ignition hybrid electric vehicle on gasoline — SI HEV on Gasoline,
- Spark ignition hybrid electric vehicle whose internal combustion engine can run on E85/gasoline — flex fuel — or hydrogen — SI HEV on E85/H2,
- Diesel HEV,
- SI PHEV A,
- SI PHEV B,
- Diesel PHEV,
- Fuel Cell, and
- Conventional Vehicles.

Auto (Car) Market Penetration

Enter each technology's share of new vehicles market

MUST specify "1st Year" and "1st Yr Shr" for the technology for which either market share or fuel economy change is desired.

Technology	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year	1st Yr Shr
EV	0.01%	0.01%	0.10%	0.58%	1.19%	1.76%	2.21%	2.54%	2.75%	2.89%	2.96%	0	0.0%
E-85 FFV	0.85%	3.18%	1.67%	1.69%	1.68%	1.71%	1.73%	1.75%	1.76%	1.76%	1.77%	0	0.0%
Diesel	0.26%	2.35%	6.71%	4.81%	4.82%	4.95%	5.03%	5.03%	5.03%	5.03%	5.03%	0	0.0%
CNG	0.39%	0.15%	0.20%	0.21%	0.22%	0.24%	0.26%	0.27%	0.28%	0.29%	0.29%	0	0.0%
SI HEV on Gasoline	0.10%	4.07%	4.88%	5.01%	5.30%	5.55%	5.75%	5.89%	5.98%	6.04%	6.07%	0	0.0%
SI HEV on E85/H2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0	0.0%
Diesel HEV	0.00%	0.00%	0.16%	2.95%	3.52%	3.52%	3.52%	3.52%	3.52%	3.52%	3.52%	0	0.0%
SI PHEV A (1)	0.00%	0.00%	0.71%	1.88%	2.16%	2.40%	2.58%	2.72%	2.81%	2.86%	2.89%	0	0.0%
SI PHEV B (2)	0.00%	0.00%	0.72%	0.83%	1.16%	1.59%	1.93%	2.19%	2.35%	2.45%	2.50%	0	0.0%
Diesel PHEV	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0	0.0%
Fuel Cell	0.00%	0.00%	0.05%	0.04%	0.04%	0.05%	0.06%	0.07%	0.07%	0.07%	0.07%	0	0.0%
Conventional	98.39%	90.24%	84.80%	82.00%	79.89%	78.22%	76.92%	76.03%	75.46%	75.09%	74.89%	0	0.0%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%		

FIGURE 5 Auto (Car) Market Penetration Input

Beginning with its 2012 version, the VISION model can handle two types of PHEV: type A and type B. PHEV type A represents a PHEV with less than or equal to 20 miles of CD range and is assumed to operate in the blended mode. PHEV type B represents a PHEV with greater than 20 miles of CD range and it has an ability to operate all electrically during CD operation.

The compositions of new market sales to AEO's last projection year are, by default, matched to values published in the corresponding Annual Energy Outlook and then trended to 2100. Market share can be user-specified for the first year of change and the year ending in zero of each subsequent decade following these three steps:

1. Change the cell (in column M) in-line with the advanced technology for which the market share is to be changed under the heading **1st Year** from 0 to the year at which the market share begins to deviate from the default value. A year in this column is essential for VISION to identify that a market penetration change is desired.

2. Change the value of the cell directly to the right, under the heading **1st Yr Shr**, to the value of the market share in the year input in step 1.

3. Change the market share in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left of **1st Year**, depending on the year selected for **1st year** in step 1.

VISION automatically linearly interpolates for those years between user specifications.

Note that Conventional Vehicles are automatically calculated to comprise the proportion of the market that is not made up of one of the preceding advanced technologies. For direction on inputting more complex market share patterns, see Advanced Input (Section 3.16).

3.2 NEW AUTO FUEL ECONOMY (AS A RATIO TO BASE CASE ICE)

The new auto (car) fuel economy module allows a user to define the fuel economy of each advanced vehicle technology. These values indicate the ratio of fuel economy per gasoline gallon equivalent to the **Base ICE** fuel economy from the AEO, which appears in row 31 (see Figure 6). Note that the **Conventional** Vehicle in row 46 is, by default, set equivalent to the **Base Case** via a 1:1 ratio. Any improvement in the conventional ICE vehicle over what AEO projects (and later extended to 2100) needs to be input in the **Conventional** row.

New Auto Fuel Economy Ratio to Base ICE (using gasoline equivalent gallons)
Enter a ratio to Base ICE mpg (listed in the top row).
*For Reference Case Fuel Efficiency, enter **"1"** under **"Use Ref. Case MPG"***
*If a fuel economy change is desired, specify the **first year fuel economy (i.e. mpg)** in column N.*
*Enter **"0"** under **"Use Ref. Case MPG"** to change Fuel Efficiency Ratio*

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	Use Ref Case MPG	MPG in 1st Year
Base ICE	28.19	34.60	42.45	52.40	52.23	52.33	52.43	52.53	52.63	52.73	52.83		
EV (1)	2.77	4.67	3.92	3.52	3.59	3.59	3.58	3.58	3.58	3.57	3.57	1	0.00
E-85 FFV (2)	0.99	1.00	1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1	0.00
Diesel (3)	1.15	1.26	1.15	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1	0.00
CNG	1.05	0.98	1.00	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1	0.00
SI HEV on Gasoline	1.54	1.46	1.41	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1	0.00
SI HEV on E85/H2	1.57	1.46	1.41	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1	0.00
Diesel HEV	1.79	1.69	1.48	1.40	1.40	1.40	1.40	1.39	1.39	1.39	1.39	1	0.00
SI PHEV A-on Gasoline/ E85/ H2 (4)	1.50	1.41	1.37	1.35	1.35	1.35	1.39	1.35	1.35	1.35	1.35	1	0.00
SI PHEV A-on Electricity (4)	3.47	2.89	2.63	3.32	3.34	3.33	3.32	3.32	3.31	3.31	3.30	1	0.00
SI PHEV B-on Gasoline/ E85/ H2 (4)	1.54	1.46	1.41	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1	0.00
SI PHEV B-on Electricity (4)	3.47	2.89	2.42	2.57	2.57	2.57	2.57	2.56	2.56	2.56	2.55	1	0.00
Diesel PHEV- on Diesel (4)	1.79	1.69	1.48	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1	0.00
Diesel PHEV-on Electricity (4)	3.58	3.38	2.95	2.74	2.74	2.74	2.74	2.73	2.72	2.72	2.72	1	0.00
Fuel Cell	2.17	1.36	1.26	1.04	1.05	1.05	1.05	1.06	1.06	1.07	1.07	1	0.00
Conventional	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1	0.00

(1) EV MPG values represent miles per 125000 Btu at the plug.
(2) VISION assumes that fuel ethanol is denatured with 5% gasoline.
(3) Multiply diesel MPG by 0.9012 to compute gasoline gallon equivalent MPG.
(4) Should reflect fuel economy while using this fuel. Please see cells O15-Y16 in worksheet "Light Vehicle MPG (geg)" for combined liquid fuel and electric MPG.

FIGURE 6 New Auto Fuel Economy Ratios to Base ICE Fuel Economy

The technologies for which user-input is possible mostly mirror those in the market penetration module explained above, with the following exceptions. Both SI and diesel PHEV technologies are split across two lines: a first for energy economy on liquid fuel (gasoline, E85, or hydrogen for a spark-ignition technology and diesel for a compression ignition technology) and a second for energy economy on electricity within the vehicle's all-electric range.

The fuel economies of advanced technology vehicles to AEO's last projection year are, by default, matched to values predicted by the Annual Energy Outlook and trended to the year 2100. Thus, a user can opt to use the AEO reference case fuel economies by making no changes in rows 32–46. Changing these default economies requires two preliminary steps in the **Auto (Car) Market Penetration** module because the **Auto (Car) Market Penetration** module and **New Auto Fuel Economy** module are interrelated, even if a user does not wish to change the default technology market penetration values. If changes are already made to the market penetration values in rows 9–20 for all technologies whose fuel economy ratios are to be changed, skip steps 1 and 2.

1) Change the cell in-line in rows 9–20 with the advanced technology for which the fuel economy is to be changed under the heading **1st Year** from 0 to the year at which the fuel economy begins to deviate from the default value.

2) Change the value of the cell directly to the right, under the heading **1st Yr Shr**, to the value of the market share in the year input in step 1 (this year should appear in the column with the heading **1st Year** in rows 9–20).

After completing the preliminary steps in the **Auto (Car) Market Penetration** module, the fuel economies can be changed in three steps:

3) Change the cells in-line with the advanced technology (in rows 32–46) for which the fuel economy ratio is to be changed under the heading Use Ref Case MPG from 1 to 0.

4) Change the value of the cell directly to the right, under the heading **MPG in 1st Year**, to the desired fuel economy in the year input in rows 9–20 while changing the market penetration. Note that the desired MPGGE should be entered here instead of the fuel economy ratio because the corresponding base fuel economy may not be known for the year of interest.

5) Change the fuel economy ratio in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left of the column marked **Use Ref Case MPG**, depending on the year selected for **1st year** in step 1 or in the **Auto (Car) Market Penetration** module.

When changed, the fuel economy is user specified for the first year of change and fuel economy ratios are user specified for the year ending in zero of each subsequent decade. VISION automatically linearly interpolates for those years between user specifications. For direction on inputting more complex fuel economy ratio patterns, see Advanced Input (Section 3.16).

3.3 LIGHT TRUCK MARKET PENETRATION

The Light Truck Market Penetration module allows a user to define the percentage of the total number of new light trucks sold by technology type. This module is analogous to the Auto (Car) Market Penetration module described in Section 3.1. In the **Model Input** worksheet, rows 56–67, which comprise the light truck market penetration module, are exact copies of rows 6–20, which comprise the Auto (Car) Market Penetration module. The three-step process for modifying the Auto (Car) Market Penetration module is also applicable for modifying this Light Truck module. See Section 3.1 for details.

3.4 LIGHT TRUCK SHARE OF TOTAL LIGHT DUTY VEHICLE MARKET

The Light Truck Share of Total Light Duty Vehicle Market module allows a user to define the percentage of all new light duty vehicles sold that are light trucks. Changing the light duty vehicle market share requires four steps:

1) Alert VISION to changes in the module by changing the **NO** in cell A77 to **YES**.

2) Change the value of the cell under the heading **1st Year** to the first year in which the total light truck market share deviates from the default value.

3) Change the value of the cell directly to the right, under the heading **1st Yr Shr**, to the value of the market share in the year input in step 2.

4) Change the total light truck market share in all subsequent years ending in zero to the values associated with your user-defined scenario.

3.5 NEW LIGHT TRUCK FUEL ECONOMY (AS A RATIO TO BASE CASE ICE)

The New Light Truck Fuel Economy allows a user to specify the fuel economy of each advanced vehicle technology that is different from the **Base Case** value. This module is analogous to the New Auto Fuel Economy module described in Section 3.2. In the **Model Input** worksheet, rows 85–100, which comprise the New Light Truck Fuel Economy module, are exact copies of rows 31–46, which comprise the New Auto Fuel Economy module. The five-step process for modifying the New Auto Fuel Economy module is also applicable for modifying this Light Truck module. See Section 3.2 for details.

3.6 TECHNOLOGY FUEL TYPE

The Technology Fuel Type module allows a user to specify the fuel used in some HEVs, PHEVs, and fuel cell vehicles. A user can modify the fuel assigned to these technologies in column B of rows 108–114 by inputting a number representing another fuel type using the appropriate legend in column F. Note that only ethanol flex fuel (E85/gasoline) and hydrogen are valid for SI HEV E85/H2. Three fuels: gasoline, ethanol flex fuel (E85/gasoline), and hydrogen are valid for PHEVs. Gasoline, diesel, natural gas, ethanol (E100), hydrogen, and methanol are valid for fuel cell vehicles and one must be selected. The legends in column F clearly indicate fuels that are valid for modeling each vehicle technology for which multiple options are available.

3.7 FUEL PRICE

The Fuel Price module (see Figure 7) allows a user to define the price of various fuels, including: gasoline (blended with up to 15% ethanol), diesel, natural gas, ethanol (E85), hydrogen, F-T (Fischer-Tropsch) diesel, bio-diesel, methanol, and electricity. Note that fuel prices should be interpreted and input in constant 2005 dollars per gasoline gallon equivalent. Also note that prices for F-T-diesel and bio-diesel should reflect the price of the pure fuel. Fuel blends can be specified in the module immediately following the Fuel Price module.

FUEL PRICE OPTION

VISION uses fuel price projections by the Dept of Energy allowing user specification only for the shaded area in the table below. The DOE projections include federal and state taxes, where applicable. If you are simulating a fuel price scenario, type "1" in the box below and specify your prices. ***Fuel Prices are in 2005 dollars; dollars per gasoline gallon equivalent.***

CHANGE FUEL PRICES? 0 1=Yes

Fuel Prices	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year	1st Yr Price
Gasoline	1.70	2.56	3.07	3.39	3.99	4.59	4.97	5.22	5.38	5.49	5.55	0	0.00
Diesel	1.52	2.47	2.93	3.40	3.97	4.51	4.86	5.08	5.22	5.32	5.37	0	0.00
Natural Gas	1.16	1.82	1.86	2.08	2.34	2.60	2.79	2.92	3.03	3.11	3.18	0	0.00
Ethanol (E85)	2.23	2.82	3.27	2.97	3.37	3.65	3.85	4.03	4.15	4.23	4.31	0	0.00
Hydrogen	14.53	12.35	10.90	7.99	7.67	7.75	7.83	7.91	7.99	8.07	8.15	0	0.00
F-T Diesel	2.18	3.00	4.23	4.92	5.65	6.30	6.76	7.05	7.32	7.52	7.70	0	0.00
Bio-Diesel	2.24	3.53	4.99	5.79	6.66	7.42	7.97	8.31	8.63	8.86	9.07	0	0.00
Methanol	1.94	3.19	3.26	3.65	4.09	4.53	4.81	4.99	5.11	5.19	5.23	0	0.00
Electricity	2.93	3.74	3.26	3.48	3.87	4.31	4.63	4.82	5.00	5.13	5.26	0	0.00

FIGURE 7 Fuel Price Input

Fuel prices are, by default, matched to values published in the Annual Energy Outlook up to its last projection year (2040 for AEO 2013) and extrapolated after that. The price of each fuel can be changed in four steps:

1) Alert VISION to changes in the module by changing the **0** in the cell next to **Change Fuel Prices?** to **1**.

2) Change the cell in-line with the fuel for which the price is to be changed under the heading **1st Year** from **0** to the **year** at which the price begins to deviate from the default value.

3) Change the value of the cell directly to the right, under the heading **1st Yr Price**, to the price in the year input in step 2.

4) Change the fuel price in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns on the left, depending on the year selected for **1st year** in step 2.

Fuel prices can be user-specified for the first year and the year ending in zero of each subsequent decade. VISION automatically linearly interpolates for years between user specifications. For direction on inputting more complex fuel price patterns, see Advanced Input (Section 3.16).

3.8 OTHER KEY FUEL INPUT ASSUMPTIONS

3.8.1 Share, by Volume, in Blended Fuels

VISION offers three options to incorporate fuel blends: ethanol in conventional gasoline, F-T diesel in conventional diesel, and bio-diesel in conventional diesel. Fuel blend percentages by volume are, by default, computed to match the alternative fuel values in the Annual Energy Outlook to its last projection year and held constant after that. VISION allows a user to specify

the percentage of an alternative fuel that is blended with the conventional fuel by following three steps:

1) Change the cell in-line with the fuel for which the blend percentage by volume is to be changed under the heading **1st Year** from **0** to the **year** at which the blend begins to deviate from the default value.

2) Change the value of the cell directly to the right, under the heading **1st Yr Shr**, to the **percentage** of the fuel that is to be effective beginning the year input in step 1.

3) Change the **blend percentage** in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left, depending on the year selected for **1st year** in step 1.

Fuel blend percentages can be user-specified for the first year and the year ending in zero of each subsequent decade. VISION automatically linearly interpolates for years between user specifications. For direction on inputting more complex fuel blend patterns, see Advanced Input (Section 3.16).

3.8.2 FFV VMT Share by Fuel and All-electric Range for New PHEV

The module for specifying flex fuel vehicle VMT share by E85 and all-electric range for new PHEVs provides a mechanism for defining the details for vehicles with multiple power sources. This module (see Figure 8) consists of specifications for flex-fuel vehicles VMT share and specifications for PHEV electric range. Note that for PHEVs, VISION automatically calculates the percentage of vehicle miles traveled on electricity based on the all-electric range and one charge per day by using a mathematical formula [specified in SAE's J2841 procedure, (*6*)]. A PHEV's all-electric range may be changed to simulate more than one charge per day. Please note that the rows 158–163 containing percent PHEV VMT on electricity are not shaded and thus, should not be changed. The percent VMT values in these rows are shown to let the user know the shares of VMT on electricity associated with the specified all-electric range values. For changing the formula for computing percent VMT on electricity or to override percent VMT on electricity, please see the Advanced Input (Section 3.16).

In the first section, specifications for flex-fuel vehicles, a user can define the percentage of total vehicle miles traveled using E85 ethanol — instead of gasoline — in each of three flex fuel vehicles. These vehicles are: ethanol ICE (auto ETOH and LT ETOH), SI HEV (auto SI HEV E85 and LT SI HEV E85), and both SI PHEVs (auto SI PHEV A, LT SI PHEV A, auto SI PHEV B, and LT SI PHEV B). These specifications can be made in three steps:

1) Change the cell in-line with the flex-fuel vehicle for which the percentage of travel made using E85 is to be changed under the heading **1st Year** from **0** to the **year** at which the VMT share begins to deviate from the default value.

2) Change the value of the cell directly to the right of **1st Year**, under the heading **1st Yr Value**, to the percentage of travel made using E85 in the year input in step 1.

3) Change the percentage of travel made using E85 in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left of **1st Year**, depending on the year selected for **1st year** in step 1.

FFV VMT Share by Fuel and All-electric Range for New PHEV

Enter percent of miles by FFV that will be on E85 fuel (rest of the miles are assumed to be on ethanol & gasoline blend)

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year	1st Yr Value
E85 VMT Share for E85 FFV (1)	0.2%	0.7%	5.8%	11.6%	12.4%	11.2%	11.2%	11.2%	11.2%	11.2%	11.2%	0	0.0%
E85 VMT Share for SI HEV on E85 (1)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
E85 VMT Share for SI PHEV (2) (excluding Electric Mode VMT)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
Rated Electric Range for PHEV in Miles (3)													
Auto SI PHEV A (Default is PHEV10)	0	10	10	10	10	10	10	10	10	10	10	0	0
Auto SI PHEV B (Default is PHEV40)	0	40	40	40	40	40	40	40	40	40	40	0	0
Auto D PHEV	0	0	12	18	17	17	18	19	20	20	20	0	0
Lt Truck SI PHEV A	0	0	10	10	10	10	10	10	10	10	10	0	0
Lt Truck SI PHEV B	0	40	40	40	40	40	40	40	40	40	40	0	0
Lt Truck D PHEV	0	0	10	10	10	11	12	12	13	13	14	0	0

Electricity VMT Share of PHEV VMT (for user information only; can be changed by changing range in rows 149-154)

Degradation factor for computing on-road Electric Range of PHEV B=	0.8												1st Yr VMT Share
Auto SI PHEV A	0.0%	22.8%	22.8%	22.8%	22.8%	22.8%	22.8%	22.8%	22.8%	22.8%	22.8%		0.0%
Auto SI PHEV B	0.0%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%		0.0%
Auto D PHEV	0.0%	0.0%	26.5%	36.0%	35.6%	34.9%	36.5%	38.0%	39.5%	39.7%	39.7%		0.0%
Lt Truck SI PHEV A	0.0%	0.0%	22.8%	22.8%	22.8%	22.8%	22.8%	22.8%	22.8%	22.8%	22.8%		0.0%
Lt Truck SI PHEV B	0.0%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%	54.4%		0.0%
Lt Truck D PHEV	0.0%	0.0%	22.8%	22.8%	22.8%	24.7%	25.6%	26.5%	27.5%	28.4%	29.2%		0.0%

(1) VISION assumes that ethanol is denatured with 5% gasoline.

(2) Electric share will be calculated internally based on electric range. The share specified here is of non-electric VMT.

(3) PHEV VMT % on electricity is computed by using the Fleet Utility Factor equation from SAE J2841. A user may accept it, change electric range, or change on-road degradation factor for PHEV B electric range..

FIGURE 8 Fuel Input Assumptions

In the second section, specifications for PHEV electric range, a user can define the all-electric (or CD) range of PHEVs in three steps:

1) Change the cell in-line with the PHEV for which the all-electric range is to be changed under the heading **1st Year** from **0** to the **year** at which the range begins to deviate from the default value.

2) Change the value of the cell directly to the right, under the heading **1st Yr Value**, to the all-electric range in the year input in step 1.

3) Change the all-electric range in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left, depending on the year selected for **1st year** in step 1.

As mentioned above, VISION uses the user-defined all-electric range to calculate the percentage of vehicle miles traveled using electricity based on a mathematical formula in SAEJ2481 (6). The formula assumes one full charge of PHEV battery pack per day. If the PHEV battery packs are likely to be charged more than once per day, the all-electric (CD) range should be increased accordingly.

Because the all-electric range of a PHEV is specified as the EPA-test value, its on-road range would be shorter. Within VISION, PHEV A is assumed to operate in blended mode and its electricity and gasoline consumptions are computed internally based on simulation results from the Autonomie model *(29)*. PHEV B is assumed to operate in the CD mode until its battery pack reaches a predetermined state of charge. VISION uses a default range degradation factor shown in cell B157, also from Autonomie simulations. This value is shaded yellow and can be changed by the user.

Note that in each of these cases (except the range degradation factor), input values can be user-specified for the first year and the year ending in zero of each subsequent decade. VISION automatically linearly interpolates for years between user specifications. For direction on inputting more complex patterns, see Advanced Input (Section 3.16).

3.8.3 Ethanol Production Share by Feedstock, Hydrogen Production share by Pathway and Utility (Electricity Generation) Mix

The Production Share by Feedstocks module provides a mechanism for defining the details for the production of the two alternative fuels: ethanol and hydrogen (See Figure 9). This module consists of three sections: specifications for ethanol production share by feedstock, specifications for hydrogen production share by pathway, and selection of utility electricity generation scenario.

In the first section, specifications for ethanol production share by feedstock, a user can define the percentage of ethanol produced using five feedstocks in three steps:

1) Change the cell in-line with the feedstock (corn stover, switchgrass, woody biomass, forest residue, and sugarcane) for which the feedstock is to be changed under the heading **1st Year** from **0** to the **year** at which the feedstock share of ethanol production begins to deviate from the default value.

2) Change the value of the cell directly to the right, under the heading **1st Yr Shr**, to the **percentage** of ethanol produced using the specified feedstock in the **year** input in step 1.

3) Change the percentage of ethanol produced using the specified feedstock in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left, depending on the year selected for **1st year** in step 1.

Note that the percentage of ethanol produced using corn is automatically calculated to be equal to the remainder. Also, feedstock shares for imported ethanol are included.

Ethanol Production Share by Feedstock

Enter percent of ethanol produced from the following feedstock

Ethanol feedstock	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year	1st Yr Shr
Corn (1)	100.0%	100.0%	92.0%	94.2%	89.9%	87.9%	86.2%	84.7%	84.2%	84.0%	84.0%		
Corn stover	0.0%	0.0%	0.2%	0.1%	0.4%	0.6%	0.8%	0.9%	1.0%	1.0%	1.0%	0	0.0%
Switchgrass	0.0%	0.0%	0.2%	0.2%	0.9%	1.5%	2.0%	2.4%	2.8%	3.0%	3.0%	0	0.0%
Woody biomass	0.0%	0.0%	1.1%	1.3%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	0	0.0%
Forest residue	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0	0.0%
Imported Sugarcane	0.0%	0.0%	6.5%	4.1%	7.8%	9.0%	10.0%	11.0%	11.0%	11.0%	11.0%	0	0.0%

(1) Computed as 100 minus the sum of other feedstock.

Hydrogen Production Share by Production Pathway

Enter percent of hydrogen produced from the following feedstock

Hydrogen feedstock	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year	1st Yr Shr
NG- Station (1)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%		
Electrolysis - Station	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
NG - Central	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
Coal With CCS - Central (2)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
Coal Without CCS - Central	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
Biomass With CCS - Central (2)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
Biomass Without CCS - Central	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
High Temp. Electro. - Central	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
TC Conversion of Water - Central (3)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
Solar - Central	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
Wind - Central	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%

(1) Computed as 100 minus the sum of other feedstock. (2) With CO2 capture and sequestration (CCS). (3) Thermochemical Conversion of water to H2

Utility Scenario ==> 1 Select from one of the followi 1 - Reference Case (AEO)
2 - Renewable Scenario
3 - Natural Gas Scenario
4 - Nuclear Scenario

FIGURE 9 Energy Pathways for Ethanol and Hydrogen and Electricity Scenario

In the second section, specifications for hydrogen production share by production pathway, a user can define the percentage of hydrogen produced using ten pathways. For hydrogen production by using coal and biomass, a pathway involving carbon capture and sequestration (CCS) is included for each. Note that the percentage of hydrogen produced via **natural gas – station** is automatically calculated as one minus the sum of all other pathways. The hydrogen production shares can be defined in three steps:

1) Change the cell in-line with the pathway (electrolysis – station, natural gas – central, coal with CCS – central, coal without CCS – central, biomass with CCS – central, biomass – without CCS central, high temperature electrolysis – central, TC [thermochemical] conversion of water – central, solar – central, wind – central) for which the share of hydrogen production is to be changed under the heading **1st Year** from **0** to the **year** at which the production share begins to deviate from the default value.

2) Change the value of the cell directly to the right, under the heading **1st Yr Shr**, to the **percentage** of hydrogen produced using the specified pathway in the year input in step 1.

3) Change the percentage of hydrogen produced using the specified pathway in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left, depending on the year selected for **1st year** in step 1.

Finally, in the third section, a user can specify one of four scenarios that describe the future mix of electric power sources for the US electricity grid. The Reference Case represents AEO Reference Case projections extended to the year 2100, the Renewable Scenario assumes significant increases in renewable energy to power the electric grid, the Natural Gas Scenario

assumes significant increases in electricity generation by using natural gas, and the Nuclear Scenario assumes significant increases in electricity generation through nuclear energy. The **Util Mix** sheet contains these four scenarios. To specify one of these scenarios, a user should input the number of the desired scenario from the legend in column G (as shown in Figure 9).

3.9 LDV VMT GROWTH RATE AND ELASTICITY TO THE COST OF DRIVING

The light-duty VMT module allows a user to estimate VMT based on one of three prediction algorithms: a mathematical VMT growth function, exogenously calculated growth factors, or VMT per vehicle estimates from AEO and their extension to the year 2100. The **Model Input** worksheet allows a user to specify which algorithm to use in the cell next to **Select LDV VMT growth method**. A **1** in this cell alerts VISION to use the mathematical growth function; a **2** tells VISION to use exogenously calculated growth factors; a **3** triggers a combination of these two, in which the formula is used until a **1st year**, specified by the user, after which exogenously calculated growth factors are used; and a **4** tells VISION to use annual VMT per car and VMT per LT estimates from AEO and their extensions. The default algorithm is specified as 1. This method also applies a VMT elasticity parameter (with a default value of -0.1).

The model is set to work with this option specified as **1**. Other options are provided for users to analyze the impacts of alternative VMT scenarios involving different rates of change.

Specification of **1** signals use of the mathematical algorithm,

VMT growth = $\exp(rt + at^2)$, where
r = rate of growth,
t = year at start, and
a = the discount rate.

The growth parameters can be entered in column C, in rows following **VMT Growth Function**. Of these three parameters, a user can change the rate of growth "r" directly and the discount rate "a" indirectly. The discount rate "a" is not user specified, but computed as r/(years to zero VMT growth × 0.8). The default value for "years to zero VMT growth" is 200, which can be changed by the user.

O**ption 1** also considers elasticity to cost of driving — that is, the percent change in VMT resulting from a 100 percent change in fuel cost per mile from the **Base Case** value — in cell E209. The default value of the elasticity is -0.1 (i.e., minus 10%), which can be changed by the user.

Specification of **2** signals use of exogenously calculated growth factors.

VISION will use exogenously computed values for VMT growth factors (where a growth factor is the proportion of VMT in a given year compared to that of the year prior). A user can control automobile (car) VMT over time in 2 steps:

1) Inputting a value for the **1st Year** that manually entered VMT growth factors should be considered in the simulation and the VMT growth factor for that year in the cell next to it with the heading **VMT Factor** (note: the year should be 2000 if a VMT growth factor is input for all years in the simulation), and

2) Manually entering an exogenously calculated value for each year in the simulation covering all years, beginning with the column C (as shown in Figure 10).

Light truck VMT growth can be controlled using the above process in the appropriate cells just beneath the cells used for automobile (car) manual entry.

Specification of **3** indicates a mixture of the preceding methods.

The same procedure described for **2**, **signaling use of manually entered values,** is applicable here. The only difference between a mixture of VMT growth calculation methods and purely manual entry is the **1st Year** values for cars and for light trucks, which determines the transition point from method **1** to method **2**.

Specification of **4** signals the use of annual VMT per car and VMT per LT estimates based on AEO data and the extension to the last year of VISION simulations.

EIA does not publish the annual VMT/car and VMT/LT estimates. For VISION, these are derived from the AEO projections of car and LT energy use, vehicle stock, and stock fuel economy. They are then extended to the year 2100. Note that the annual VMT/car and VMT/LT estimates are consistent with the default annual growth factors in the **Model Input** worksheet.

LDV VMT Growth Rate

*Four options: 1=use exponential function Exp(r*t+a*t^2) for all years; 2=user specified fixed rates by year (see rows 202-224);*
3=combination of two, option 1 applied until the "1st Year" (in M215 and M224) and option 2 after that; or 4=use AEO extended (see worksheet "Auto-LT data").

Selected LDV VMT growth method	**1**
VMT Growth Function ~ e^(rt+at^2)	
r = rate of growth	0.0081
t = time at start	2000
a = discount rate	-0.000051
years to zero growth	200

VMT Elasticity to Cost of Driving (cents/mile) -0.1 *Use only when VMT Growth Method= **1***

VMT Growth Factors for Cars

InputVMT growth factors for cars when the selected VMT Growth Method is 2 or 3.
MUST specify the first year and first year VMT factor.

Car VMT Factor for the Decade Year	2000	2001 - 2010	2011 - 2020	2021 - 2030	2031 - 2040	2041- 2050	2051- 2060	2061- 2070	2071- 2080	2081- 2090	2091- 2100	1st Year	1st Yr VMT Factor
1			0.9839	1.0232	1.0184	1.0110	1.0081	1.0072	1.0062	1.0055	1.0051	2009	0.9030
2			1.0128	1.0251	1.0171	1.0107	1.0080	1.0072	1.0062	1.0055	1.0052		
3			1.0044	1.0256	1.0187	1.0106	1.0079	1.0071	1.0062	1.0055	1.0052		
4			1.0061	1.0258	1.0171	1.0103	1.0079	1.0071	1.0061	1.0056	1.0052		
5			1.0109	1.0253	1.0157	1.0100	1.0079	1.0070	1.0061	1.0056	1.0052	CARS	
6			1.0155	1.0247	1.0145	1.0093	1.0074	1.0066	1.0058	1.0053	1.0051		
7			1.0172	1.0248	1.0139	1.0089	1.0074	1.0066	1.0058	1.0054	1.0051		
8			1.0184	1.0233	1.0130	1.0087	1.0073	1.0066	1.0057	1.0054	1.0051		
9		0.9030	1.0203	1.0215	1.0123	1.0086	1.0073	1.0066	1.0057	1.0054	1.0051		
0		1.0091	1.0223	1.0202	1.0119	1.0085	1.0073	1.0065	1.0058	1.0055	1.0051		

VMT Growth Factors for Light Trucks

InputVMT growth factors for light trucks when the selected VMT Growth Method is 2 or 3.
MUST specify the first year and first year VMT factor.

LDT VMT Factor for the Decade Year	2000	2001 - 2010	2011 - 2020	2021 - 2030	2031 - 2040	2041- 2050	2051- 2060	2061- 2070	2071- 2080	2081- 2090	2091- 2100	1st Year	1st Yr VMT Factor
1			0.9878	1.0019	1.0033	1.0041	1.0055	1.0057	1.0054	1.0047	1.0043	2009	1.1039
2			1.0156	1.0036	1.0024	1.0043	1.0056	1.0058	1.0054	1.0047	1.0043		
3			1.0081	1.0032	1.0076	1.0047	1.0057	1.0059	1.0054	1.0047	1.0043		
4			1.0058	1.0035	1.0070	1.0051	1.0059	1.0060	1.0054	1.0047	1.0043		
5			1.0058	1.0037	1.0063	1.0053	1.0060	1.0061	1.0054	1.0048	1.0044	LIGHT TRUCKS	
6			1.0071	1.0041	1.0061	1.0052	1.0056	1.0056	1.0050	1.0044	1.0042		
7			1.0061	1.0057	1.0055	1.0053	1.0058	1.0056	1.0050	1.0045	1.0042		
8			1.0041	1.0053	1.0051	1.0054	1.0060	1.0056	1.0050	1.0045	1.0042		
9		1.1039	1.0040	1.0049	1.0043	1.0056	1.0060	1.0056	1.0050	1.0046	1.0043		
0		1.0238	1.0021	1.0046	1.0040	1.0058	1.0061	1.0057	1.0050	1.0046	1.0043		

FIGURE 10 LDV Vehicle Miles Traveled Change Specification

3.10 NEW HEAVY TRUCK MPG RATIO TO REFERENCE VEHICLE

The New Heavy Truck MPG Ratio to Reference Vehicle module allows a user to define the fuel economy of heavy truck technologies. The values in this module indicate the ratio of volumetric fuel economy to a reference vehicle, as shown in Figure 11.

The module first lists the default MPG values. The vehicles for which default values are provided are: Class 3–6 Gasoline, Class 3–6 Diesel, Class 3–6 Natural Gas, Class 3–6 Diesel HEV, Class 7&8 Single Unit Conventional (gasoline and diesel), Class 7&8 Single Unit Natural Gas, Class 7&8 Single Unit Diesel HEV, Class 7&8 Combination LNG, and Class 7&8 Combination Diesel. These values, not shaded in yellow, are for reference only and should not be changed by the user.

A user can customize heavy truck fuel economy by altering the fuel economy ratios in the rows following **Reference Gasoline and Diesel Fuel Economy**. Three groups of heavy trucks are simulated in VISION: (1) Class 3–6 trucks, (2) Class 7&8 Single Unit (SU) trucks, and (3) Class 7&8 combination trucks. The fuel economy ratios are specified relative to the fuel economy of a reference vehicle in each group. Gasoline trucks represent the reference vehicle for class 3–6 trucks, Conventional SU trucks (with harmonic means of gasoline and diesel fuel economy)

HEAVY VEHICLES

1. Fuel Economy of New Trucks

1.1 Reference Gasoline, Diesel, NG, and HEV Fuel Economies (MPG), Should not be Changed by the Users

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Class 3-6 Gasoline	8.80	10.13	11.30	12.97	13.27	13.37	13.47	13.57	13.67	13.77	13.87
Class 3-6 Diesel	10.23	13.50	16.12	16.38	16.38	16.38	16.38	16.38	16.38	16.38	16.38
Class 3-6: Natural Gas (MPGGE)	6.90	9.76	11.33	12.57	12.66	12.76	12.86	12.95	13.05	13.14	13.24
Class 3-6 Diesel HEV	12.59	16.61	19.83	20.14	20.14	20.15	20.15	20.15	20.15	20.15	20.15
Class 7&8 Single Unit Conventional	6.13	6.12	7.29	7.53	7.70	7.62	7.60	7.58	7.60	7.60	7.62
Class 7&8: SU Natural Gas (MPGGE)	5.54	5.45	6.54	7.26	7.42	7.60	7.74	7.88	8.00	8.15	8.28
Class 7&8 Single Unit (SU) Diesel HEV	7.54	7.53	8.97	9.27	9.47	9.38	9.35	9.33	9.35	9.35	9.38
Class 7&8 Combination LNG (MPGGE)	5.04	4.91	5.89	6.53	6.67	6.84	6.97	7.09	7.20	7.33	7.45
Class 7&8 Combination	6.11	5.68	7.18	7.39	7.24	7.25	7.32	7.39	7.43	7.48	7.52

Note: Gasoline and diesel truck MPG are per gallon of respective fuel. MPG of Clss 7&8 single unit trucks represent VMT weighted harmonic means. NG truck MPG are per gasoline gallon equivalent.

	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year of Change	MPG in 1st Year
1.2 New Class 3-6 Truck MPG Ratio to Reference Gasoline												
Class 3-6: Gasoline	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0	0.00
Class 3-6: Diesel	1.33	1.43	1.26	1.23	1.23	1.22	1.21	1.20	1.19	1.18	0	0.00
Class 3-6: Natural Gas (MPGGE)	0.96	1.00	0.97	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0	0.00
Class 3-6: Diesel HEV	1.64	1.75	1.55	1.52	1.51	1.50	1.48	1.47	1.46	1.45	0	0.00
1.3 New Class 7 & 8 Single Unit Truck MPG Ratio to Reference SU Converntional												
Class 7&8: Single Unit Conventional	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0	0.00
Class 7&8: SU Natural Gas (MPGGE)	0.89	0.90	0.96	0.96	1.00	1.02	1.04	1.05	1.07	1.09	0	0.00
Class 7&8: SU Diesel HEV	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	0	0.00
1.4 New Class 7&8 Comb. Truck MPG Ratio to Reference												
Class 7&8 Combination LNG (MPGGE)	0.86	0.82	0.88	0.92	0.94	0.95	0.96	0.97	0.98	0.99	0	0.00
Class 7 & 8: Combination	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0	0.00

Note: Gasoline and diesel truck MPG are per gallon of respective fuel while MPG for natural gas and LPG trucks are in gasoline gallon equivalent (MPGGE). MPG of Clss 7&8 single unit conventional trucks represent VMT weighted harmonic means.

2. New Truck Market Share

2.1 Class 3-6 Truck Market Shares

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year	1st Yr Shr
Class 3-6: Conventional Gasoline	40.9%	35.4%	26.2%	25.0%	24.5%	24.0%	23.8%	23.6%	23.5%	23.4%	23.3%		
Class 3-6: Conventional Diesel	58.8%	63.7%	72.1%	72.4%	72.5%	72.7%	72.8%	72.9%	72.9%	73.0%	73.1%	0	0.0%
Class 3-6: Natural Gas	0.3%	1.0%	1.7%	2.6%	3.0%	3.3%	3.4%	3.5%	3.5%	3.6%	3.6%	0	0.0%
Class 3-6: HEV Diesel		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%

Note: Market Share of Class 3-6 Conventional Gasoline Truck is Calculated Automatically

2.2 Class 7&8 Truck Market Shares

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year	1st Yr Shr
Class 7&8: Conv Single Unit (SU)	28.3%	26.5%	28.0%	28.9%	29.4%	30.0%	26.8%	23.7%	23.2%	22.6%	22.6%	0	0.0%
Class 7&8: SU Natural Gas	0.3%	0.3%	0.4%	1.1%	1.6%	2.0%	2.2%	2.3%	2.3%	2.4%	2.4%	0	0.0%
Class 7&8: Single Unit HEV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%
Class 7&8 Combination LNG	0.0%	0.0%	0.5%	6.3%	21.3%	24.0%	25.0%	26.0%	26.8%	27.2%	27.5%	0	0.0%
Class 7&8: Conventional Combination	71.4%	73.2%	71.2%	63.7%	47.7%	44.0%	46.0%	48.0%	47.7%	47.8%	47.5%		

Note: Market Share of Class 7&8 Conventional Combination Truck is Calculated Automatically

FIGURE 11 New Heavy Truck MPG and Market Share

represent the reference vehicle for class 7&8 SU trucks, and combination trucks (diesel powered) represent the reference vehicle for combination trucks. Although the default ratio values for the reference vehicle in each group is one, it can be changed to simulate new scenario values indicating improvement/degradation in the reference vehicle fuel economy. The ratios are relative to the reference vehicle fuel economy values in the rows above them, which remain unchanged. Changing the fuel economy that is used in the scenario requires three steps:

1) Change the cell in-line with the truck and engine type for which the fuel economy ratio is to be changed under the heading **1st Year of Change** from **0** to the **year** at which the fuel economy begins to deviate from the default value.

2) Change the value of the cell directly to the right, under the heading **MPG in 1st Year**, to fuel economy for the year input in step 1 above. Please note that the actual MPG should be entered here instead of the fuel economy ratio because the corresponding base fuel economy may not be known for the year of interest.

3) Change the fuel economy ratios in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left, depending on the year selected for **1st year of Change** in step 1.

Note that this process is analogous to adjusting the New Auto Fuel Economy module, described and pictured in Section 3.2, except that the fuel economies are not always in gasoline gallon equivalents.

When changed, the fuel economy is user-specified for the first year and fuel economy ratios are user-specified for the years ending in zero of each subsequent decade. VISION automatically linearly interpolates for those years between the user specifications. For direction on inputting more complex fuel economy ratio patterns, see Advanced Input (Section 3.16).

3.11 NEW HEAVY TRUCK MARKET SHARE

The New Heavy Truck Market Share module is divided into two parts — class 3–6 and class 7&8 subdivided as SU and combination — that allow a user to define the percentage of the total number of new trucks sold by engine type. This division is also shown in Figure 11.

Technologies for Class 3–6 trucks include Conventional Gasoline, Conventional Diesel, Natural Gas, and HEV Diesel. Technologies for Class 7&8 trucks include SU Conventional, SU Natural Gas, SU HEV, Combination LNG, and conventional Combination.

The composition of new market shares are, by default, matched to values published in the Annual Energy Outlook through its last projection year. Class 7&8 trucks are subdivided as a single unit and combination by using data from the Vehicle Inventory and Use Survey (*7-11*) (because it provides additional detail) and Transportation Energy Data Book (*12*). Note that Class 3–6 Conventional Gasoline trucks and Class 7&8 Conventional Combination trucks are automatically calculated to comprise the proportion of the market that is not made up by other technologies; therefore, user input should include only those other technologies (in the rows that are shaded yellow). The market share values for each technology can be changed in three steps:

1) Change the cell in-line with the advanced technology for which the market share is to be changed under the heading **1st Year** from **0** to the **year** at which the market share begins to deviate from the default value.

2) Change the value of the cell directly to the right, under the heading **1st Yr Shr**, to the value of the market share in the year input in step 1 above.

3) Change the market share in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left of column with the heading **1st Year**, depending on the year selected for 1st year in step 1.

Market share can be user-specified for the first year and the year ending in zero of each subsequent decade. VISION automatically linearly interpolates for those years between user

specifications. For direction on inputting more complex market share patterns, see Advanced Input (Section 3.16).

3.12 DIESEL SHARE OF CLASS 7&8 SINGLE-UNIT TRUCK VMT

Because class 7&8 gasoline and diesel single-unit trucks are simulated together, this Heavy Truck module enables a user to specify the VMT percentage of class 7&8 single-unit trucks running on diesel. The default values are derived from the past Vehicle Inventory and Use Surveys and the resulting trend is extrapolated. To change these percentages from the default values:

1) Change the cell under the heading **1st Year of Change** from **0** to the **year** at which the percentage of diesel truck VMT deviates from the default value.

2) Change the value of the cell under the heading **Share in 1st Year** to the VMT by diesel trucks, as a percentage of the total.

3) Change the percentage of diesel truck VMT in all subsequent years ending in zero to the values associated with your user-defined scenario. These years appear in some columns to the left of **1st Year of Change**, depending on the year selected for **1st Year of Change** in step 1.

3.13 SHARE OF ALTERNATIVE FUELS

VISION offers two options to incorporate diesel fuel blends for heavy trucks: bio-diesel and Fischer-Tropsch diesel. Shares of these two fuels in blended diesel fuel are, by default, matched to values in the Annual Energy Outlook. The default values are the same as those developed for light vehicles. Because many class 3–8 diesel trucks are fueled at truck owners' facilities, their average diesel fuel blend shares can be different than those for the light duty vehicles. VISION allows users to specify their own compositions of diesel blends for all class 3–8 trucks, as shown in Figure 12. The user should change the blend shares here only if they are different from those for the light-duty vehicles. When specified, the alternative fuel shares for heavy trucks should account for fuel obtained at facilities where light-duty vehicles also refuel. A user can specify the percentage of an alternative fuel that is blended with the conventional diesel fuel for use by class 3–8 trucks by following three steps:

1) Change the cell in-line with the fuel for which the blend is to be changed under the heading **1st Year** from **0** to the **year** at which the blend begins to deviate from the default value.

2) Change the value of the cell directly to the right, under the heading **1st Yr Shr**, to the percentage of the fuel by volume that is added to conventional diesel fuel in the year input in step 1.

3) Change the shares in all subsequent years ending in zero to the values associated with your user-defined scenario.

4. Share of Alternative Fuels

4.1 F-T and Bio-Diesel Share of Diesel Fuel Use by Heavy Vehicles (specify only if different than LDV diesel share in Rows 128-129)

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year	1st Yr Shr
Bio-Diesel in Diesel	0.01%	0.65%	4.02%	4.25%	4.07%	4.26%	4.26%	4.26%	4.26%	4.26%	4.26%	0	0.0%
F-T Diesel in Diesel	0.00%	0.14%	6.31%	19.13%	26.27%	27.50%	27.50%	27.50%	27.50%	27.50%	27.50%	0	0.0%

4.2 Share, by energy, diesel fuel used in CNG/LNG-fueled Medium- and Heavy-Duty Vehicles, Base Case. Should not be Changed by the User

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Diesel in Natural Gas, Class 3-6	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Diesel in Natural Gas, Class 7&8 SU	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Diesel in LNG, Class 7&8 Combination	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

4.3 Share, by energy, diesel fuel used in CNG/LNG-fueled Medium- and Heavy-Duty Vehicles, Scenario Case

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	1st Year	1st Yr Shr
Diesel in Natural Gas, Class 3-6	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0	0.0%
Diesel in Natural Gas, Class 7&8 SU	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0	0.0%
Diesel in LNG, Class 7&8 Combination	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0	0.0%

The above shares are based on higher heating values of natural gas (1,027 Btu/scf) and diesel (138,700 Btu/gal).

FIGURE 12 Share of Alternative Fuels

Fuel blends can be user-specified for the first year and the year ending in zero of each subsequent decade. VISION automatically linearly interpolates for years between user specifications. For direction on inputting more complex alternative fuel blending patterns, see Advanced Input (Section 3.16).

3.14 SHARE OF DIESEL FUEL USED IN NATURAL GAS VEHICLES

Although all natural gas trucks in the AEO 2013 were spark ignited, VISION anticipates that a user may simulate a scenario in which some future natural gas heavy trucks use compression ignition technology with diesel fuel providing pilot ignition. To accommodate this, VISION allows users to specify unique shares, by energy, of diesel fuel used in CNG/LNG-fueled medium- and heavy-duty trucks for compression ignition to initiate combustion of the natural gas. The steps to specify the percentages for Class3–6, Class 7&8SU and Class 7&8 Combination trucks in row 309–311, shown in Figure 12, are similar to what were described in Section 3.13.

3.15 LIGHT VEHICLE COST RATIO

VISION enables a user to make future projections regarding the incremental vehicle costs of each advanced light vehicle technology included in a scenario: EV, E-85 FFV, Diesel, CNG, SI HEV on Gasoline, SI HEV on E85/H2, Diesel HEV, SI PHEV, Diesel PHEV, and Fuel Cell Vehicles. These options are shown in Figure 13. The prices of these vehicles are indexed to a base price — input in column B for cars and light trucks — for an ICE vehicle of each type in the year 2000, where the index is the ratio of the advanced vehicle technology price to the Base ICE price (e.g., by default, an electric car costs almost 250% of a midsize conventional ICE in the year 2000). The average car and light truck base price are assumed to be $23,086/vehicle and $23,864/vehicle in year 2000, respectively. A user should first verify that the base price is

Light Vehicle Cost Ratio

User may change the Base Price and/or cost ratios.

Car Base ICE Price in 2005 dollars: 23,086 (Average Year 2000 price)

Technology	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
EV	2.44	1.46	1.27	1.14	1.09	1.06	1.04	1.04	1.04	1.04	1.04
E-85	0.99	0.89	0.92	0.98	0.98	0.96	0.94	0.92	0.92	0.92	0.92
Diesel	1.13	1.02	1.02	1.01	1.01	0.98	0.98	0.98	0.98	0.98	0.98
CNG	1.34	1.14	1.17	1.24	1.24	1.20	1.17	1.14	1.14	1.14	1.14
SI HEV on Gas	1.19	1.05	1.02	1.05	1.05	1.03	1.02	1.02	1.02	1.02	1.02
SI HEV on E85/H2	1.41	1.29	1.27	1.31	1.30	1.28	1.24	1.20	1.20	1.20	1.20
Diesel HEV	1.34	1.03	1.01	1.11	1.11	1.10	1.10	1.10	1.10	1.10	1.10
SI PHEV A	2.44	1.27	1.07	1.10	1.09	1.06	1.04	1.04	1.04	1.04	1.04
SI PHEV B	2.44	1.44	1.31	1.26	1.22	1.18	1.14	1.10	1.10	1.10	1.10
Diesel PHEV	2.73	1.03	1.13	1.13	1.12	1.10	1.10	1.10	1.10	1.10	1.10
Fuel Cell	3.90	2.87	2.49	2.02	1.75	1.60	1.50	1.45	1.40	1.40	1.40

Lt Trk Base ICE Price in 2005 dollars: 23,864 (Average Year 2000 price)

Technology	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
EV	2.49	1.77	1.45	1.26	1.21	1.18	1.16	1.14	1.14	1.14	1.14
E-85	1.20	1.09	1.12	1.17	1.17	1.14	1.12	1.10	1.10	1.10	1.10
Diesel	1.12	1.12	1.10	1.13	1.13	1.12	1.10	1.09	1.09	1.09	1.09
CNG	1.44	1.41	1.44	1.48	1.48	1.44	1.41	1.38	1.36	1.36	1.36
SI HEV on Gas	1.27	1.27	1.22	1.26	1.26	1.22	1.20	1.18	1.18	1.18	1.18
SI HEV on E85/H2	1.28	1.27	1.23	1.27	1.26	1.23	1.21	1.19	1.19	1.19	1.19
Diesel HEV	1.30	1.25	1.44	1.44	1.43	1.38	1.36	1.34	1.34	1.34	1.34
SI PHEV A	1.73	1.16	1.15	1.30	1.29	1.26	1.24	1.20	1.20	1.20	1.20
SI PHEV B	1.73	1.32	1.38	1.45	1.42	1.40	1.38	1.36	1.36	1.36	1.36
Diesel PHEV	2.68	1.20	1.18	1.33	1.31	1.29	1.26	1.24	1.24	1.24	1.24
Fuel Cell	3.70	3.36	2.63	2.30	1.97	1.70	1.55	1.45	1.40	1.40	1.40

FIGURE 13 Light Vehicle Cost Ratio

appropriate for the scenario or change it, if necessary. Subsequently, the user can adjust the price of advanced technology vehicles by manually entering new price ratios in the car price ratio grid and the light truck price ratio grid.

As with other variables, light vehicle prices can be user-specified for the first year ending in zero of each decade. VISION automatically linearly interpolates for years between user specifications. For direction on inputting more complex price patterns, see Advanced Input (Section 3.16).

3.16 ADVANCED INPUT

This section details the location into which a user can manually input (i.e., hard-wire) parameters to describe more complex patterns over time than the decadal linear interpolation that VISION uses by default. Aside from this, the electricity share of total VMT can be modified by the user, overriding the default shares computed through the SAE J2481 equation (*6*). Advanced data entry is possible for all variables discussed in section 3 except for two: Technology Fuel Type and LDV VMT Growth Rate and Elasticity to the Cost of Driving. For the first one, complex entry is unnecessary; for the second, the VMT equation or annual entry is also facilitated by the existing **Model Input** worksheet.

3.16.1 Utility Mix

Mix of electric power sources.....B24:V42 in **Utility Mix** worksheet. There are two ways for a user to specify the future mix of electric power sources in three alternative scenarios: renewable, natural gas, or nuclear. The first way is to specify the fuel share in 2050 and 2100; the shares in the rest of the years are computed automatically. The other way is to manually input the shares in B24:V42 in the selected scenario. Shares of different fuel sources in each scenario need to sum up to 100%.

3.16.2 Other Advanced Inputs

Rated Electric Range for PHEV in Miles .....B158:N163 in **Model Inputs**. These values should be changed per the directions in the following paragraph if you wish to manually input a different percentage of the total VMT on electricity than the VISION-calculated value based on the given PHEV electric (or CD) range.

Override specifications for PHEV electric (or CD) range, you can specify the percentage of total vehicle miles traveled on electricity, shown in Figure 8. These specifications are calculated automatically based on the all-electric ranges input in B149:N154. To override the calculated value, simply input the percentage of the total VMT for the PHEV technology in a given year. (Note that the rows in which percentages of total miles using electricity appear are not shaded. Unless the user has a basis for changing the values, only the equation parameters should be changed with your own justification. The equation in these rows is based on an analysis by SAE International.)

Auto (Car) Market Penetration ..... AR40:AR140 in multiple tabs: **auto XX** where XX indicates the fuel/technology type of car for which a modification is to be made (EV, EtOH, Dsl, CNG, SI HEV Gas, SI HEV E85, D HEV, SI PHEV A, SI PHEV B, D PHEV, FCV). Market penetration of conventional cars in worksheet **auto ICE** is computed automatically as the remainder.

New Auto Fuel Economy (in miles per gasoline gallon equivalent).....AT40:AT140 in multiple tabs: **auto XX** where XX indicates the fuel/technology type of car for which a modification is to be made (ICE, EV, EtOH, Dsl, CNG, SI HEV Gas, SI HEV E85, D HEV, SI PHEV A, SI PHEV B, D PHEV, FCV). PHEV fuel economies on electricity are in column BE in worksheets **auto SI PHEV A**, **auto SI PHEV B**, and **auto D PHEV**.

Light Truck Market Penetration..... AR40:AR140 in multiple tabs: **LT XX** where XX indicates the fuel/technology type of car for which a modification is to be made (EV, EtOH, Dsl, CNG, SI HEV Gas, SI HEV E85, D HEV, SI PHEV A, SI PHEV B, D PHEV, FCV). Market penetration of conventional light trucks in the worksheet **LT ICE** is computed automatically as the remainder.

Light Truck Share of Total Light-Duty Vehicle Market ..... ……..J40:J140
in **Auto-LT data**. If these values are changed, the option to change **Light Truck Share of Total LDV Market** in the worksheet **Model Input** should be set to "**No**".

New Light Truck Fuel Economy (in MPGGE).....AT40:AT140
in multiple tabs: **LT XX** where XX indicates the fuel/technology type of car for which a modification is to be made (ICE, EV, EtOH, Dsl, CNG, SI HEV Gas, SI HEV E85, D HEV, SI PHEV A, SI PHEV B, D PHEV, FCV). PHEV fuel economies on electricity are in column BE in worksheets **LT SI PHEV A**, **LT SI PHEV B**, and **LT D PHEV**.

Fuel Price L40:T140
in **Fuel $ Data**. The values inserted in these cells are used by each technology sheet. The **Model Input** worksheet take price values from each technology sheet.

Ethanol Share, by volume, in Blended Gasoline M55:M155
in **Carbon Coefficients**.

F-T Diesel Share, by volume, in Blended Diesel.....F55:F155
in **Carbon Coefficients**.

Bio-diesel Share, by volume, in Blended Diesel H55:H155
in **Carbon Coefficients**.

E85 VMT Share of Flexible Fuel Vehicles (FFV)..... R55:R155
in **Carbon Coefficients**.

E85 VMT Share of Flexible Fuel SI HEV.....W55:W155
in **Carbon Coefficients**.

E85 VMT Share of Flexible Fuel SI PHEV..... AB55:AB155
in **Carbon Coefficients**.

% VMT on Electricity for New PHEV BB40:BB140
in multiple tabs: **auto XX** and **LT XX** where XX indicates the PHEV type for which a modification is to be made (SI PHEV A, SI PHEV B, D PHEV).

Ethanol and Hydrogen Production Share by Feedstock/Pathway.....AO55:AY155
in **Carbon Coefficients** for hydrogen and BG55:BL155 in **Carbon Coefficients** for ethanol.

New Truck MPG (miles per gallon of gasoline or diesel and miles per gasoline equivalent gallon for natural gas trucks) AT50:AT150
in multiple tabs: **Class XX**, where XX indicates the fuel/technology types of truck (Class 3-6G, Class 3-6D, Class 3-6 HEV, Class 7&8SU, Class 7&8SU HEV, and Class 7&8C_Dsl) and in AV50:AV150 for three natural gas trucks (Class 3-6 NG, Class 7&8SU NG, and Class 7&8C_NG).

New Truck Market Share AQ50:AQ150
in multiple tabs: **Class XX**, where XX indicates the fuel/technology types of truck (Class 3-6D, Class 3-6 HEV, Class 7&8SU, Class 7&8SU HEV) and in AS50:AS150 for three natural gas trucks (Class 3-6 NG, Class 7&8SU NG, and Class 7&8C_NG). Note that Class 3-6G and 7&8C_Dsl are calculated automatically as the market share not comprised by other medium and heavy duty trucks, respectively.

Diesel Share of 7&8 Single Unit Truck VMT AZ50:AZ150
in **Class 7&8 SU.**

Diesel Share of F-T Diesel or Bio Diesel (in terms of volume) S50:T150
in **HVY TRK ENERGY**.

Carbon coefficient for each advanced technology ..... C4:C35 and B38:J43
in **Carbon Coefficients**. Note that these values are, by default, derived from Argonne National Laboratory's GREET model, version 2012. These coefficients can be seen in the **Carbon Coefficients** worksheet by selecting **Unfreeze Panes** from Microsoft Excel's Window Menu.

4 METHODOLOGY: LIGHT-DUTY VEHICLES

Light-duty vehicles' (lightweight cars and trucks) energy and oil use and carbon emissions are determined by the total number of vehicles in operation, the total number of miles they travel, their energy efficiency, and the fuels they use. The derivation of these estimates is explained in the following sections.

4.1 VEHICLE SALES

Historical sales of cars and light trucks (to 2009 for VISION 2013) are derived from the Transportation Energy Data Book and Ward's Motor Vehicle Facts and Figures (*12, 13*). *LDV sales by vehicle type to 2040 (last projection year)* are taken from the AEO 2013. EIA provides separate sales projections of cars and light trucks, which it calls light-duty vehicles, and of commercial light trucks, which are Class 2b light trucks (8,500–10,000 lb GVW). In VISION, the Class 2b light trucks are added to light trucks.

Total LDV sales post-2040 are projected based on a function of driving age population, gas price, GDP change in percentage and total LDV sales in the last AEO projection year (2040 in VISION2013) using the following formula. The light-truck share of total LDV sales from AEO is trended to the year 2100. These light-truck shares are applied to the total LDV sales to estimate car and light truck sales.

*Total LDV Sales in Year i (post-AEO projection) = (3181.7+53.52*Driving age population in Year i-997.41*Current Gas Price in Year i+772.28*GDP Change in Year i)*(Total LDV Sales in 2040 /(3181.7+53.52* Driving age population in 2040-997.41* Current Gas Price in 2040+772.28 GDP Change in 2040))*

The total population projection for the years 2040–2060 is estimated following the growth rate that was estimated by the US Census Bureau (*14*). Growth rates after 2060 are kept constant at 0.5%/yr. AEO gives projections of population age 16 and older. Population age 85 and older before 2050 is taken from the US Census Bureau. Based upon these, VISION has estimated the driving age population (age 16–84). The driving age (age 16–84) population for 2040–2060 is extended based on the growth rate during 2035–2040.

In the AEO 2013, EIA projects that the light-truck share of LDV sales will decrease from 49.2% in 2009 to 39.5% in 2040. VISION 2013 assumes the trend will continue, but at a much slower pace, decreasing to 37.5% in the year 2100 with regard to estimates of the total auto and light-truck sales. Total auto and light-truck sales are then allocated to each technology based on their projected market penetration.

Although EIA projects have limited market penetration of *some alternative fuel and advanced technology vehicles*, such as electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), compressed natural gas (CNG), and fuel cell vehicles (FCV), AEO 2013 projects that ethanol FFV sales will continue to grow and account for 6.5% of car sales and 18.6% of LT sales by

2040. AEO 2013 also projects that electric vehicles will start to take off after 2020 and fuel cell vehicles will be introduced to the market in 2015. VISION **Base Case** keeps AEO's market penetration projections to 2040 (for AEO 2013) and extends them to the year 2100. Users can change these technology market penetration shares in a scenario to evaluate the effects of new technologies relative to the **Base Case**.

4.2 VEHICLE STOCK

For VISION 2013, *Historical car and light truck stocks before 2010* are taken from the Transportation Energy Data Book and Federal Highway Administration's Highway Statistics (*15-28*). *Annual car and light truck stock from 2010 to 2040* is taken from AEO 2013. Total LV stock is extended to the year 2100 based on the growth rate during the last five years of the AEO projection period (2035–2040 in VISION2013). Car stock is also extended based on the growth rate during the last five years of AEO projections, but not to exceed the growth rate of total LV stock in that year. Then LT stock is calculated as the difference between total LV stock and car stock. Except for conventional vehicles, stock of each vehicle technology is projected using the total sales in the last twenty years as a guide. The rate of growth is lowered every five years until 2100. Then conventional vehicle stock will be automatically calculated to comprise the proportion of the total stock that is not made up by other technologies.

4.3 TOTAL ANNUAL VMT AND ANNUAL VMT/VEHICLE

VISION uses EIA's estimates of *total VMT estimates* to 2040. EIA's total light duty VMT projections are first subdivided as car VMT and light truck VMT by using energy consumption by cars and light trucks, energy per gallon of gasoline from the conversion factor table within AEO, and on-road fuel economies of cars and light trucks. These VMT values, together with stock, provide annual VMT/vehicle estimates through 2040 (e.g., 12,893 mi/yr for cars and 12,467 mi/yr for light trucks in 2040). Historical values are obtained from the Federal Highway Administration's (FHWA's) Highway Statistics.

Post-2040, VISION assumes a gradual increase in *annual* VMT/vehicle by cars and light trucks not to exceed 15,000 mi/yr by the year 2100 for each vehicle type. The total VMT for any projection year represents the product of vehicle stock and annual VMT/vehicle. The default or any specific annual growth rates can be used as model inputs. You can specify the annual VMT growth rate in **Model Input** following the steps described in Section 3.9.

VISION allows a user to select one of the four alternative methods of projecting future annual VMT/vehicle growth, as compared with that used in the **Base Case**, described in Section 3.9. The first method computes total VMT by using an exponential function and applies a user-specified elasticity to fuel cost per mile relative to the **Base Case**. The exponential function is calibrated such that it produces the desired annual VMT/vehicle when divided by vehicle stock. In method 2, the user may replace the default growth rates of the **Base Case**. The main advantage of using the exponential function method to estimate VMT growth is that it allows the user to incorporate the effect on a scenario's total VMT and total fuel use of VMT elasticity to

the cost of driving (i.e., driving more when fuel costs/mile decrease because of improved vehicle fuel economy and vice versa). Fuel cost per mile is automatically derived from fuel prices, given the fuel economy assumptions of the scenario. The historical value of such VMT elasticity is approximately -0.1 (i.e., a 1% increase in VMT results from a 10% reduction in fuel cost/mile). VISION uses -0.1 as a default value, but you may use other values.

Finally, you may also change the rate of growth parameter of the exponential function within method 1, as well as the number of years-to-zero growth. VISION includes default values for these variables.

4.4 FUELS

VISION develops consumption estimates for nine fuel types: (1) gasoline, (2) diesel, (3) ethanol, (4) FT diesel, (5) Bio-diesel, (6) natural gas, (7) electricity, (8) hydrogen, and (9) methanol. However, it combines the two petroleum based fuels, gasoline and diesel, while summarizing consumption. Ethanol can be used either as E85 (85% ethanol) or as a low level blend (up to 15%) with gasoline. Conventional cars (auto ICE) and light trucks (LT ICE) as well as gasoline powered cars and light truck HEVs (auto SI HEV Gas and LT SI HEV Gas) consume gasoline blended with ethanol. Aside from these technologies, SI PHEV A and SI PHEV B may be selected to run on gasoline blended with up to 15% ethanol. Both ethanol cars and light trucks (**auto ETOH** and **LT ETOH**) are simulated as flexible fuel vehicles for which you can either accept the default values of the VMT percent for E85 or enter your own exogenously computed values. Diesel cars and light trucks as well as diesel HEVs and PHEVs consume diesel fuel blended with bio- and FT-diesel. VISION can simulate cars and light trucks that are powered by compressed natural gas (CNG). The shares of ethanol in gasoline and bio- and FT-diesel in diesel are computed to match the AEO through the last year of projections. The shares are kept constant after that. VISION also allows a user to simulate car and light truck SI HEV operating on either flex fuel E85/gasoline or hydrogen (H2).

Fuel cell vehicles can use one of the six fuels: (1) gasoline (not blended with ethanol), (2) diesel (not blended), (3) natural gas, (4) ethanol (E100), (5) hydrogen, or (6) methanol.

PHEVs are assumed to use one of the three fuels: (1) gasoline blended with ethanol, (2) flex fuel E85/gasoline, or (3) hydrogen (H2) to power their ICE.

4.5 FUEL ECONOMY

In the VISION 2013 **Base Case**, the *2040 certification test fuel economy* values are 52.23 MPG for new gasoline cars and 39.77 MPG for new gasoline light trucks. Fuel economy values for all other technologies are also taken from AEO. Some technologies, BEV100 and BEV3000, LPG and NG, are combined and their sales are weighted and harmonic fuel economy values are taken. You can modify the fuel economy of different vehicle types to evaluate the effects of new fuel economy values relative to **Base Case** fuel economy values (please see sections 3.2 and 3.5). *On-road vehicle fuel economy* is lowered by applying degradation factors. For (conventional) ICE,

EtOH, Diesel, and CNG technologies as well as charge sustaining operation of all PHEVs, VISION 2013 uses on-road fuel economy degradation factors of 0.817 for cars and 0.8 for LTs. These factors were provided by EIA which are assumed not to change over time. A degradation factor of 0.85 is used for both car and LT HEVs and FCV. Within each technology worksheet, the VMT weighted on-road fuel economy represents the harmonic mean of all vintages.

EIA's AEO provides fuel economy projections for new PHEV 10s, PHEV 40s, and HEVs. However, for PHEV 10 and 40, the AEO combines city and highway (unadjusted) fuel economy values in both charge depleting (CD) and charge sustaining (CS) modes into one fuel economy value (as MPGGE). Assumptions about ratios of fuel economy in CS and CD mode and ratios of PHEV CS mode fuel economy to HEV fuel economy are based on previously reported simulations of these vehicles performed by using Argonne's Autonomie model (*29*). Detailed methodologies for estimating on-road fuel economies of PHEVs based on aggregated AEO projections are discussed in (*30*).

For electric operation, the on-road degradation factor is estimated to be 0.7 for electric vehicles, based on earlier Argonne analyses (*30, 31*). There are both non-electric and electric operations in PHEV A and PHEV B. Similar to conventional vehicles, degradation factors of 0.817 and 0.8 are used for non-electric operation for PHEV cars and PHEV LT in VISION 2013, respectively. There is no adjustment to electric operation of PHEV A so the factor is considered as 1, while the factor is 0.8 for PHEV B. A detailed explanation can be found in (*30*).

VISION calculates *average on-road fleet fuel economy* for each year. It uses age-dependent usage functions, vehicle survival rates by age, and on-road vehicle fuel economy by year to generate these estimates. The fuel economy value represents the VMT weighted harmonic mean for all vintages. The initial estimates that VISION generates for the historical years are matched to the FHWA estimate for each year by applying a correction factor.

4.6 TOTAL FUEL USE

Total fuel use for any year for each technology is computed as total VMT divided by fleet fuel economy. Again, the initial estimate for the historical years that VISION generates is matched to the FHWA estimate (of gallons of fuel used) for that year by applying a correction factor. For the future years, VISION generated estimates are matched with AEO projected values by applying correction factors. Similarly, VISION estimates for the period beyond the AEO projection horizon are matched with previously generated extensions. Total fuel use for each fuel type in gallons is converted to Quads, assuming the higher heating value of gasoline (125,000 Btu/gal), diesel (138,700 Btu/gal), FT diesel (130,030), bio-diesel (127,960) and Ethanol (84,600 Btu/gal). All other fuel quantities are estimated as gasoline gallon equivalent.

4.7 TOTAL CARBON-EQUIVALENT EMISSIONS

Total carbon-equivalent emissions are estimated by using a carbon coefficient per unit of fuel consumed. The carbon coefficient represents full fuel cycle emissions associated with fuel use (i.e., it includes carbon emissions from petroleum extraction through emissions at the refinery to delivery to and use of the fuels in the vehicles). Thus, the carbon-equivalent emissions estimates cover more phases of the fuel cycle than are captured in the vehicle energy use estimates developed with VISION. The source of these carbon coefficients is Argonne's GREET model (*32*). The coefficients account for the global warming potential of carbon dioxide, methane, and nitrous oxide. Within VISION, gasoline represents low level ethanol blends with ethanol denatured by 5% gasoline. The carbon coefficients of various fuels may vary over time, depending on input assumptions regarding the percentage of ethanol blends in gasoline, shares of various feedstock used in ethanol production, Fischer-Tropsch diesel and bio-diesels blended with petroleum diesel, shares of pathways used to produce hydrogen, and a mix of fuels used in electricity generation. Four future utility fuel mixes are provided. Also, the carbon emissions generated by hybrids and fuel cell vehicles vary, depending on the selection of fuel.

Full fuel cycle carbon-equivalent emissions rates for all fuels are generated by using the latest version of GREET. Because GREET uses a lower heating value of each fuel (except electricity), the emissions rates are lowered by applying the heating value ratio (lower heating value divided by higher heating value) for each fuel. Full fuel cycle carbon-equivalent emissions rates are obtained for the following fuels for each feedstock and/or pathway.

1. Gasoline (feedstock: crude oil)
2. Diesel (feedstock: crude oil)
3. Ethanol (feedstock: corn, corn stover, switchgrass, woody biomass, forest residue, and sugarcane)
4. Compressed Natural Gas (feedstock: North American natural gas)
5. FT-diesel (feedstock: North American natural gas)
6. Bio-diesel (feedstock: soybean)
7. Electricity (generation pathways: four scenarios representing varying mixes of coal, natural gas, nuclear, and/or renewable energy)
8. Hydrogen (pathways: natural gas – at station and central production –, coal – with and without CCS –, biomass – with and without CCS –, electrolysis – regular and high temperature water –, thermo-chemical conversion of water)
9. Methanol (feedstock: North American natural gas)

VISION computes Btu-weighted carbon-equivalent shares by converting volumetric shares to Btu shares for ethanol blended gasoline and FT- and bio-diesel blended diesel. Where multiple feedstock or pathway options are available, VISION computes share-weighted carbon-equivalent emissions.

4.8 TOTAL FUEL EXPENDITURES

VISION includes fuel price/gallon estimates for gasoline (including taxes). AEO 2013 is the source of the estimates to 2040. Post-2040, it is assumed that the real price of gasoline will rise to $5.55/gal by 2100 (in constant 2005 dollars). Given these price assumptions and total fuel use estimates, VISION calculates annual total fuel expenditures.

4.9 UPSTREAM ENERGY CONSUMPTION

Upstream energy consumption in fuel production and feedstock production are estimated by using an energy consumption rate per unit of end use fuel and the amount of that fuel used in VISION. Energy consumption rates for fuel production and feedstock production are generated by using the latest version of GREET. The upstream energy consumption values, for feedstock production and fuel production, represent the sum of all types of fuels used for producing the amount of end use fuel consumed. These values are summarized by end use fuel.

4.10 HYDROGEN PRODUCTION ENERGY USE BY PATHWAY

VISION estimates energy consumed to produce the hydrogen used in LDVs through different pathways (11 pathways as mentioned in Section 4.7). In VISION **Base Case**, hydrogen is assumed to be produced only by natural gas at the station. Energy use (Quads) and carbon emissions (Million Metric Ton Carbon equivalent — Mln MT C eqv) by pathways are summarized in **Hydrogen Results** for car and LT separately.

4.11 CORRECTION FACTORS

Correction factors are applied to vehicle stock, VMT, fleet fuel economy and fuel use of each LDV technology to make the VISION estimates match with AEO projections in every year. Correction factors are calculated by dividing the AEO projections by initial VISION estimates for total LDV vehicle stock, VMT, fleet fuel economy and fuel use. Correction factors are stored in each technology worksheet and are not supposed to be changed by the users. Correction factors are internally computed at the time of updating the model and are applied throughout the projection period (2010–2100 for VISION 2013).

5 METHODOLOGY: HEAVY TRUCKS

Heavy trucks in VISION 2013 include trucks of Gross Vehicle Weight (GVW) Class 3–8. Trucks in Class 3–6 are referred to as medium or medium-duty trucks and trucks in Class 7–8 are referred to as heavy or heavy-duty trucks. Heavy truck (medium and heavy trucks) energy and oil use and carbon emissions are determined by the total number of trucks in operation, the total number of miles they travel, their energy efficiency, and the fuels they use. The derivation of these estimates is explained below.

5.1 HEAVY TRUCK SALES, STOCK, AND TOTAL VMT

Truck sales, stock, and VMT are disaggregated into three groups of trucks: (1) Class 3 through 6 trucks, (2) Class 7&8 single unit trucks, and (3) Class 7&8 combination trucks. Historical data were obtained from the Transportation Energy Data Book, Ward's Motor Vehicle Facts & Figures, and FHWA's Highway Statistics (*13, 15–28*). FHWA's Highway Statistics provide historical vehicle stock and VMT data, but combines all heavy single unit trucks in one category. AEO projections of sales, stock, and VMT do not separate Class 7&8 SU trucks and Class 7&8 Combination trucks. Therefore, these data are not available for direct use in VISION. Estimation factors were developed on the basis of an analysis of the 1982 through 1992 Truck Inventory and Use Surveys and 1997 and 2002 Vehicle Inventory and Use Surveys (7–11).

Before the 2008 version of VISION, the post-2035 estimates of heavy truck sales, stock, and VMT were taken from the **Base Case** of a joint DOE/Natural Resources Canada study of North American transportation energy futures (hereafter referred to as the Phase 2 2050 Study) (*33*). In the Phase 2 2050 Study **Base Case**, trends projected by EIA to 2035 for heavy truck use were generally assumed to continue post-2035 and were tied to GDP growth.

Beginning in 2008, the analysis horizon has been extended to 2100. The projected GDP, sales, stock, and total VMT of medium and heavy trucks used in VISION 2013 differ somewhat from those of the Phase 2 2050 study.

5.1.1 Heavy Truck Sales

Total sales of Class 3–6 trucks, 3–6 gasoline trucks, 3–6 diesel trucks and 3–6 NG/LPG trucks for the period 2010–2040 are taken from the current AEO. Total sales of 3–6, 3–6 diesel and 3–6 NG/LPG trucks are extended to 2100 based on the growth rate of the last five years of the AEO projection period with the growth rate lowered every five years. From these extended sales, 3–6 gasoline truck sales are calculated as the proportion of the total sales that is not made up by 3–6 diesel, 3–6 NG/LPG, and 3–6 HEV trucks. EIA projects limited market penetration of alternative fuel (natural gas, LPG) medium trucks in AEO 2013. The share for class 3–6 gaseous fuel vehicles is 3.0% in 2040. VISION 2013 **Base Case** assumes no market penetration for diesel powered hybrid trucks by the year 2100, but you could define HEV sales share in your own scenarios.

Historical total 7&8 truck sales are allocated to 7&8 SU trucks and 7&8 Combination trucks based on the sales share identified form Vehicle Inventory and Use Surveys (VIUS). VIUS 2002 indicates the 7&8 SU truck sales share of total 7&8 trucks is about 25.4%. The share increases initially and then declines while the number of trucks represented keeps on increasing. Historical figures for 7&8 NG/LPG truck sales are taken from Alternative Fuel Vehicle Data at EIA. Before 2008, 7&8 NG/LPG truck sales are assumed to be all SU trucks. Starting from 2008, VISION allocates total 7&8 NG/LPG truck sales to 7&8 SU and 7&8 Combination. In 2009, 7&8 SU NG/LPG trucks account for 0.21% of total 7&8 truck sales and the share is assumed to increase to 1.6% and 1.8% by 2040 and 2100, respectively. During the AEO projection period, 7&8 Combination NG/LPG sales are calculated by subtracting the 7&8 SU NG/LPG truck sales from total 7&8 NG/LPG sales. After AEO projection, 7&8 Combination NG/LPG sales share of total 7&8 truck sales is assumed to increase from 21.4% in 2040 to 23.5% in 2100. Then, 7&8 Combination diesel truck sales are calculated by subtracting the 7&8 Combination NG/LPG truck sales from the total 7&8 Combination truck sales. The annual 7&8 SU G&D truck sales are calculated to comprise the proportion of the total 7&8 SU truck sales that are not made up by 7&8 NG, 7&8 SU HEV, and 7&8 Combination diesel trucks.

5.1.2 Heavy Truck Stocks

VISION contains separate stock estimation methodologies for class 3-6 and class 7&8 trucks in which historical and projected sales are combined with historical vehicle survival rates to estimate truck stock by year. (This calculation is made separately for the three groups of trucks.) Subsequently, the truck stock by age of vehicle in any year is combined with the corresponding amount of annual travel to develop the initial total VMT estimates for that year.

Total stocks of Class 3-6 gasoline truck, 3-6 diesel truck and 3-6 NG/LPG truck for the period 2010–2040 are taken from current AEO. VISION extends the total stocks of 3-6 gasoline, 3-6 diesel and 3-6 NG/LPG trucks to 2100 based on the growth rate of last five years of the AEO projection period with the growth rate lowered progressively every five years.

Total stocks of 7&8 gasoline truck, 7&8 diesel truck, and 7&8 NG/LPG trucks for the period 2010–2040 are taken from AEO. All Class 7&8 gasoline trucks are assumed to be 7&8 SU gasoline trucks. 7&8 NG/LPG Combination truck stock is estimated separately. Then 7&8 NG/LPG SU truck stock is calculated by subtracting 7&8 NG/LPG Combination truck stock from total 7&8 NG/LPG truck stock. The 7&8 combination truck stock share is estimated and extended based on the historical trend identified from Highway Statistics. The 7&8 diesel Combination truck stock is calculated by subtracting 7&8 NG/LPG Combination truck stock from the total 7&8 Combination truck stock. After the AEO projection period, the 7&8 Combination truck stock share is extended to be 62% of the total 7&8 truck stock in 2050 and 74% in the year 2100 in VISION 2013.

5.1.3 Heavy Truck VMT

Of the three variables (sales, stock, and VMT), the final VMT estimates directly impact energy use and thus, are the most important in VISION. Highway Statistics give historical VMT driven by SU and Combination trucks. VMT of 3–6 gasoline, 3–6 diesel, 7&8 SU gasoline, 7&8 SU diesel, and 7&8 Combination trucks are estimated based on the historical trend identified from VIUS.

The total VMT driven by 3–6 trucks, 3–6 gasoline trucks, 3–6 diesel trucks and 3–6 NG/LPG trucks for the period 2010–2040 are taken from the current AEO. The total VMT of 3–6 trucks are extended to 2100 based on the growth rate of the last five years of the AEO projection period with the growth rate lowered every five years. During AEO projections, the ratio of VMT per 3–6 diesel truck to VMT per 3–6 gasoline truck is automatically calculated. After the AEO projection period, this ratio is assumed to stay at the level of 1.335–1.338. Next, total VMT driven by 3–6 gasoline and 3–6 diesel trucks beyond the AEO projection period are estimated separately based on this ratio. VMT driven by 3–6 NG/LPG truck is calculated to comprise the remaining VMT that is not made up by other Class 3–6 technologies.

The VMT driven by 7&8 trucks are estimated in a similar manner as to 3–6 trucks. The total VMT driven by 7&8 trucks, 7&8 gasoline trucks, 7&8 diesel trucks, and 7&8 NG/LPG trucks for the period 2010–2040 are taken from the current AEO. Total VMT of all 7&8 trucks and 7&8 diesel trucks are extended to 2100 based on the growth rate of the last five years of the AEO projection period with the growth rate lowered every five years. To further allocate the VMT, the ratio of VMT per 7&8 Combination diesel truck to VMT per 7&8 SU diesel truck and ratio of VMT per 7&8 Combination NG/LPG truck to VMT per 7&8 SU NG/LPG truck are first estimated. VISION 2013 assumes the ratio for diesel truck to be 6.15 in 2010 and gradually decrease to 5.06 by the end of the AEO projection period (2040 for VISION 2013). After the AEO projection period, the VMT per 7&8 SU diesel truck is assumed to slowly increase following an exponential trend. The ratio of VMT per 7&8 Combination NG/LPG truck to VMT per 7&8 SU NG/LPG truck is assumed to be higher than for diesel trucks because the 7&8 Combination NG/LPG fleet contains more new vehicles in earlier years. The ratio initially starts at about 6 and then slowly decreases to 3 by 2100. A 7&8 SU NG/LPG truck is assumed to be driven as much as a 7&8 SU diesel truck and the same assumption applies to their combination counterparts. The total VMT for each technology/class combination is estimated by multiplying the corresponding VMT/ truck by total stock. All class 7&8 gasoline trucks are assumed to be SU trucks and thus, the VMT of 7&8 SU gasoline trucks equals the VMT of 7&8 gasoline trucks.

5.2 FUELS

Three fuels: gasoline, diesel, and natural gas/liquid petroleum gas are used by medium and heavy trucks. Although AEO projects LPG use, LPG volume is assumed to be insignificant and treated as natural gas. Gasoline is assumed to be blended with ethanol and diesel with bio- and F-T diesels. The VISION **Base Case** assumes that both light- and heavy-duty vehicles use the same blends of gasoline and diesel fuel. However, you are given the option to change the blend

of diesel fuel used by heavy trucks to simulate a scenario in which centrally fueled heavy trucks may use different diesel blends. However, care should be taken to account for heavy trucks that are not centrally fueled (as these shares apply to all diesel powered heavy trucks).

5.3 FUEL ECONOMY

Historical fuel economy values are taken from the FHWA's Highway Statistics and Vehicle Inventory and Use Surveys. Because separate fuel economy values by fuel are not available in Highway Statistics, data from the Vehicle Inventory and Use Surveys are used to develop disaggregated estimates. Fuel economy projections to 2040 of new and stock medium (class 3–6) and heavy trucks (class 7&8 single units and combination) are derived from AEO. For heavy trucks (class 7 and 8), fuel economy for single unit (SU) and combination trucks are estimated separately by fuel type. All gasoline heavy trucks are assumed to be single units, so the 7&8 SU gasoline trucks' MPG is equal to 7&8 gasoline heavy trucks' MPG in AEO. The 7&8 SU diesel trucks' MPG is assumed to be a ratio of 7&8 gasoline heavy trucks' MPG. Based on the 7&8 SU diesel trucks' MPG, VMT weighted harmonic MPG for 7&8 combination diesel trucks is estimated such that the combined MPG match AEO projected value. NG and LPG trucks for a given truck group (class 3–6 or class 7&8 SU/Comb) are combined and MPG are VMT weighted. Class 7&8 combination NG/LPG trucks' MPG is assumed to be a fraction of 7&8 SU NG/LPG trucks' MPG and is represented as miles per gasoline gallon equivalent (MPGGE).

5.4 TOTAL FUEL USE BY FUEL TYPE

Beginning with 2011, VISION can simulate natural gas powered medium trucks (class 3–6) and SU heavy trucks (class 7&8) as well as liquid natural gas powered class 7&8 Combination trucks. VISION can also account for diesel fuel used in CNG/LNG-fueled medium- and heavy-duty Vehicles for pilot ignition. The **Base Case**, however, assumes that all gaseous fuel trucks do not require any pilot ignition. The share, by energy, of diesel used in pilot ignition is set as 0% in the **Base Case**. You can change these values to simulate alternative scenarios.

Similar to LDV (see Session 4.6), total fuel use by gasoline, diesel, and natural gas medium trucks for any year is computed as total VMT divided by fleet fuel economy. The initial estimate for the historical years that VISION generates is matched to the FHWA estimate (of gallons of fuel used) for that year by applying a correction factor. For the future years, VISION generated estimates are matched with AEO projected values by applying correction factors. Similarly, VISION estimates for the period beyond the AEO projection horizon are matched with previously generated extensions. Total fuel use for each fuel type in gallons is converted to Quads, assuming the higher heating value of gasoline (125,000 Btu/gal), diesel (138,700 Btu/gal), FT diesel (130,030), bio-diesel (127,960) and Ethanol (84,600 Btu/gal). All other fuel quantities are estimated as gasoline gallon equivalent.

Historical fuel use of heavy duty trucks is estimated based on the trend identified from the Transportation Energy Data Book (*12*). For future years, AEO provides projection fuel use for gasoline, diesel, NG, LPG heavy duty trucks. Since VISION assumes all gasoline Heavy trucks

are single units, the gasoline use by 7&8 SU trucks equals the gasoline usage of 7&8 gasoline heavy trucks in AEO. The 7&8 trucks total diesel use is allocated to 7&8 SU-D trucks and 7&8 Comb-D trucks based on their VMT and MPG. The same method is applied to 7&8 SU-NG/LPG trucks and 7&8 Comb-NG/LPG trucks. Heavy duty trucks are already mainly diesel powered. In terms of fuel use in Btu, AEO projects diesel share as 97% in 2010 declining to 82.3% in 2040, gasoline share as 2.6% in 2010 declining to 1.6% in 2040, and gaseous fuel share as 0.4% in 2010 increasing to 16.1% in 2010. In post-AEO projection years, fuel use is computed as total VMT divided by fleet fuel economy.

5.5 TOTAL CARBON-EQUIVALENT EMISSIONS

Total carbon emissions are estimated by using a carbon coefficient per unit of gasoline, diesel, compressed natural gas, and liquefied natural gas consumed. Gasoline is assumed to be blended with ethanol, and diesel is assumed to be blended with bio-and FT-diesel. The **Base Case** blend percentages, by volume, are developed to match the AEO projections. As discussed in Section 4.7, the carbon coefficient for each fuel represents full fuel cycle emissions per quadrillion Btu. The coefficients are estimated by using the latest version of the GREET model (*11*). The coefficients of various fuels may vary over time, depending on input assumptions regarding the percentage of ethanol blended in gasoline as well as bio- and Fischer-Tropsch diesel blended with diesel fuel.

5.6 TOTAL FUEL EXPENDITURES

VISION includes fuel price/gallon estimates for gasoline and diesel fuel (including taxes). AEO 2013 is the source of the estimates to 2040. Post-2040, it is assumed that the real price of all the fuels, except for hydrogen, will rise. For example, the real price of gasoline will rise to $5.55/gallon by 2100 and that diesel will be $5.37/gallon on a gasoline equivalent gallon basis. Prices are in 2005 dollar values. Given these price assumptions and total fuel use estimates, VISION calculates annual total fuel expenditures for heavy trucks.

5.7 CORRECTION FACTORS

Correction factors are applied to vehicle stock, VMT, fleet fuel economy, and fuel use of each technology to make the VISION estimates match with AEO projections and their extension to 2100 in every year. Correction factors are calculated by dividing the AEO projections by VISION estimates for total vehicle stock, VMT, fleet fuel economy, and fuel use. Correction factors are calculated separately for 3–6 Gasoline truck, 3–6 diesel truck, 3–6 NG truck, 7&8 SU truck, and 7&8 Combination truck. Correction factors are stored in each technology worksheet and are not to be changed.

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