LVChoice:
Light Vehicle Market Penetration Model Documentation

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List of Acronyms

AEO	Annual Energy Outlook
ANL	Argonne National Laboratory
CVCS	Consumer Vehicle Choice Submodule of NEMS
DOE	U.S. Department of Energy
EIA	Energy Information Administration, U.S. DOE
FTF	Future Transportation Fuels study
NEMS	National Energy Modeling System
NPC	National Petroleum Council
OTT	Office of Transportation Technologies
OTT-AT	OTT Analytic Team
TAE	TA Engineering, Inc.
VCM	Vehicle Choice Model

1.0 Introduction

The LVChoice light vehicle consumer choice model was developed by TA Engineering, Inc., (TAE) for use in the National Petroleum Council's Future Transportation Fuels Study (FTF). This model estimates future market penetration of advanced or alternative vehicle technologies based on vehicle and fuel attributes, including price. The model calculates market shares separately within five vehicle size classes at annual time steps from 2007 through 2050. The model provides only estimates of market share (percentage of sales) and does not estimate total sales nor track in-use stock. However, the LVChoice outputs are compatible with the Argonne National Laboratory's (ANL's) VISION model which projects the in-use stock of vehicles by applying historical scrappage rates and estimates of future sales.

The LVChoice model is a Microsoft Excel spreadsheet with multiple input, calculation, and output worksheets. The model structure is based on an earlier spreadsheet used by the U.S. Department of Energy's Office of Transportation Technologies (now the Vehicle Technologies Program). However, due to the requirements of the FTF, the LVChoice model differs from this heritage model in methodology, application, and parameter values. As a result, it should be considered a distinctly different model.

The LVChoice model was not developed for distribution beyond the FTF team and a convenient user interface has not yet been developed. However, this report provides instructions for using the model, including development of inputs and interpretation of results.

This document is organized as follows: Section 2.0 provides details on the model purpose and goals and resulting requirements. Section 3.0 discusses the resources used to develop the model. Section 4.0 provides details on the methodology used, including model algorithms. Section 5.0 provides a brief users' guide, including a list of model inputs and outputs and an overview of running the model. Section 6.0 documents the model benchmarking against the Energy Information Administration's (EIA) *Annual Energy Outlook 2010* (AEO 2010).

2.0 Purpose

While developing an approach for the Future Transportation Fuels Study, the NPC obtained a copy of the Vehicle Choice Model (VCM). This model had been used by the U.S. Department of Energy's Office of Transportation Technologies (OTT, now the Vehicle Technologies Program) for analysis of program benefits as discussed further in Section 3.0. The version obtained by the NPC was last used around 2001-2002 and had not been developed for further distribution or use. The VCM methodology and parameters were consistent with what was then incorporated in EIA's National Energy Modeling System (NEMS).

Although the VCM was functional, it did not reflect recent developments within NEMS nor did it include the vehicle size classes or technologies of interest to the NPC. TA Engineering, Inc., was asked to update the model with the following scope of work:

1. Represent the NEMS approach used in AEO 2010:
   a. Change the model structure from multinomial logit to nested multinomial logit.
   b. Apply new logit model coefficients.
   c. Incorporate calibration factors used for AEO 2010.
   d. Apply market share limitations used in AEO 2010.
2. Make alterations for use in the NPC FTF:
   a. Update vehicle size classes.
   b. Update vehicle technologies.
   c. Maintain simplicity relative to NEMS.
   d. Maintain compatibility with VISION.
3. Benchmark to AEO 2010:
   a. Model parameters: develop logit coefficients for FTF size classes based on NEMS coefficients.
   b. Model inputs: combine AEO vehicle attributes to reflect FTF size classes and technologies.
   c. Model results: combine AEO market share results to reflect FTF size classes and technologies and compare to new model results.

The project schedule required delivery of the final work product (a working Excel spreadsheet) within two months of initial contact by NPC. Due to this compressed schedule, improving the user interface was not included within the scope of work.

3.0 Sources

The LVChoice model development was based on a heritage model – the VCM – that previously had been used by the U.S. DOE. The VCM is described briefly in Section 3.1 below. Section 3.2 describes the methodology used to modify the VCM and discusses the resources used. Section 3.3 describes the relationship of LVChoice model to the NEMS consumer vehicle choice submodule (CVCS), noting in particular the differences between the approaches.

3.1 Vehicle Choice Model (VCM)

3.1.1 Analytical Context

The VCM was part of a larger modeling system developed for the Office of Transportation Technologies (OTT, now the Vehicle Technologies Program) by the OTT's Laboratory Analytic Team (OTT-AT). The OTT-AT supported Phil Patterson of DOE, and, at the time the VCM was in use, included:

- John Maples of Trancon, Inc., under contract to ORNL (currently employed at EIA) – light and heavy vehicle analyst, original author of the VCM;
- Alicia Birky of NREL (currently employed at TAE) – consumer opinion, policy, and light vehicle analyst;
- Elyse Steiner of NREL (currently employed at EPA) - consumer opinion, policy, and light vehicle analyst; and
- Jim Moore of TA Engineering under contract to ANL (currently TAE Principal) - heavy vehicle technologies analyst.

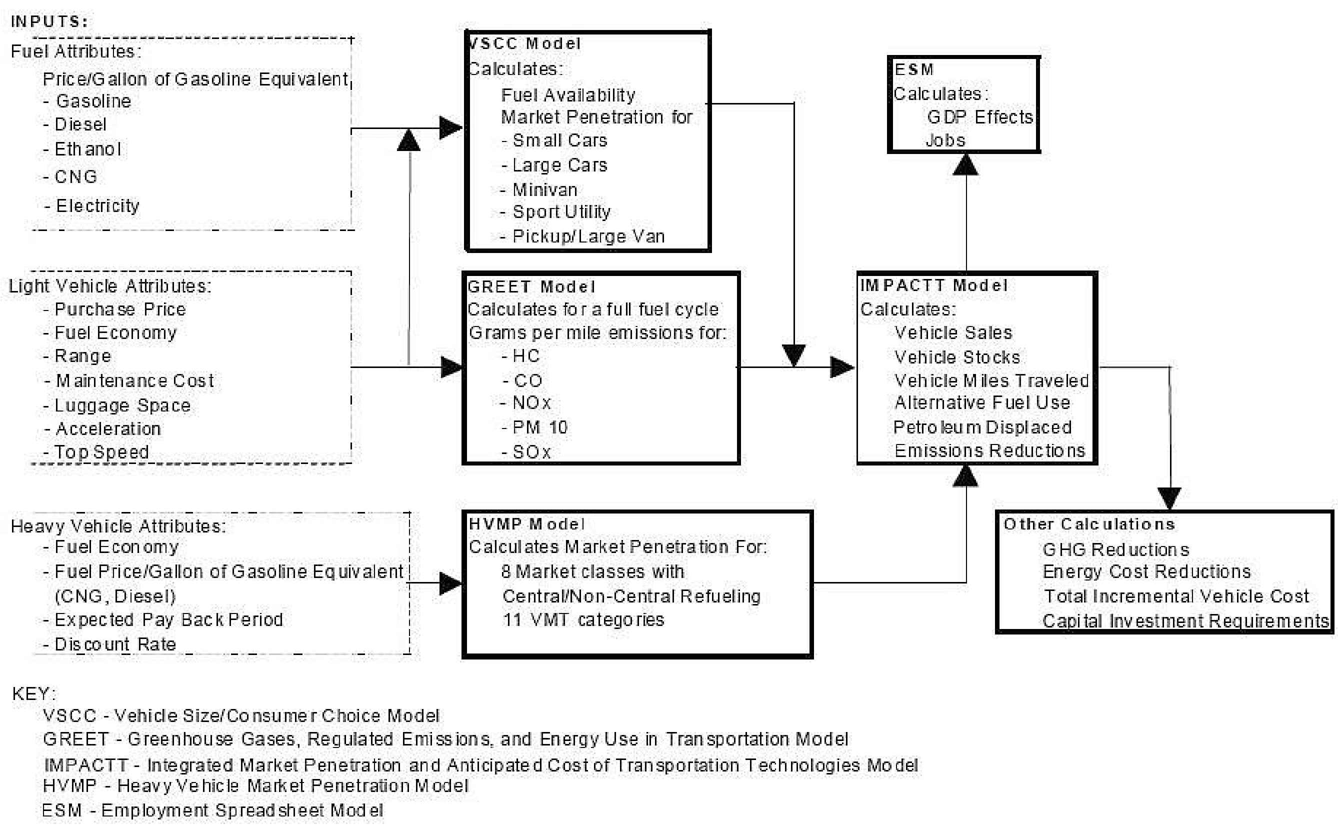
The VCM and the larger modeling system were used by OTT to estimate energy, environmental and economic benefits of OTT program elements using a market based approach. This analysis was performed annually in support of Government Performance and Results Act (GPRA) reporting requirements. Since it was necessary to place this analysis within a widely accepted context, the analysis used the latest AEO reference case as a baseline and approximated NEMS methodologies as much as possible.

Figure 3-1 illustrates the three step OTT program benefits analysis methodology. In the first step, a set of models was used to calculate market penetration of advanced or alternative-fuel vehicles that incorporate technologies supported by DOE funding and that meet OTT technology performance goals. Two tools were used for this: 1) the VCM (shown as the VSCC in Figure 3-1) for light vehicles and 2) the HVMP for heavy vehicles. These models estimate market shares as percentages of total vehicle sales but do not project total sales.

In the second analysis step, results from the VCM and HVMP were used as inputs to the IMPACTT model which used sales projections and historical scrappage rates to project the future stock of advanced vehicles, the fuel economy of the in-use fleet, and total consumption of traditional and alternative transportation fuels.[1] The IMPACTT model also was linked to the GREET model to estimate impacts on the emission of criteria pollutants. Benefits were quantified for reductions in energy use, petroleum consumption, and pollutant emissions.

In the final step of the analysis, an input/output model called the Employment Spreadsheet Model (ESM) was used to estimate the impact of the advanced technologies on GDP and employment. Additional calculations were made outside of these linked models to estimate greenhouse gases reductions, incremental vehicle costs, and capital investment requirements.

Figure 3-1: OTT Program Benefits Analysis Methodology, circa 2002



The VCM was frequently updated to reflect changes in program focus and evolution of the NEMS methodology. However, it was not developed for distribution or use beyond the OTT-AT due to resource constraints. Sometime after 2002, OTT discontinued use and maintenance of the model.

[1] The IMPACTT model later evolved into the VISION model which currently is maintained by Argonne National Laboratory. For further information or to download the VISION model, see http://www.transportation.anl.gov/modeling_simulation/VISION/.

3.1.2 VCM Structure

The VCM divides the light vehicle market is into five size classes:

1. Small Cars,
2. Large Cars,
3. Minivans,
4. SUVs, and
5. Pickup Trucks and Large Vans.

Within each size class, there is one conventional gasoline-powered vehicle and ten advanced technology or alternative-fuel vehicles. The version used as the basis for the LVChoice model included the following vehicles:

- Diesel
- Advanced Diesel
- Flex-fuel Alcohol
- Dedicated Alcohol
- Fuel Cell Hydrogen
- Spark ignited direct injection (SIDI)
- CNG Dedicated
- CNG Bi-fuel
- Electric
- Hybrid-electric (other fuel user-specified) with fuel economy equal to two times the conventional vehicle's (HEV 2X)
- Hybrid-electric (other fuel user-specified) with fuel economy equal to three times the conventional vehicle's (HEV 3X)

These technologies correspond to what was available in IMPACTT (now VISION) when the VCM was last modified. The advanced vehicles (AVs) compete with the conventional vehicle only within each size class. The model does not estimate market shares of each size class within the light vehicle market and the user must specify these as an input. Therefore, the model cannot predict shifts in preferences for size classes due to new attributes.

Model calculations are performed for each year from 2000 to 2030.

3.1.3 Model Methodology

The VCM uses a logit choice model to estimate the percentage market share of each technology within each size class based on vehicle and fuel attributes. The version used as the basis for the LVChoice model incorporated the following attributes:

- Vehicle purchase price
- Dedicated AFV range on a tank of fuel
- Annual maintenance cost
- Acceleration time from 0-60 mph

- Top speed
- Luggage space
- Fuel cost to drive ($/mile – includes both fuel economy and fuel price)
- Home refueling capability
- Multiple fuel capability
- Gasoline capability
- Range on gasoline

The logit model essentially calculates the consumer utility for each vehicle type. This utility is then scaled by the total utility of all the technologies to estimate the likelihood the consumer will purchase each technology. The probabilities thus sum to 100% for each size class and represent the "take rate" or market share for each technology within the size class. The coefficients on the utility function (logit equation) that apply to each attribute vary among size classes and represent the average consumer within that submarket. For example, the coefficients may reflect that the average small car consumer is more sensitive to vehicle purchase price and cost to drive compared to the average SUV consumer.

Depending on input assumptions regarding vehicle attributes, market shares calculated by choice models for the first few years following introduction of a new technology may exceed what is typically observed in the market. This can be due to several factors, including consumer risk aversion for new technologies (which is not captured in the logit model) and/or limited market availability. Historically, technology introductions have often followed a sigmoid (s-shaped) curve, beginning at 0 and gradually approaching a saturation value less than or equal to 100%. Therefore, the market shares calculated by the VCM are shaped using a sigmoid curve. "Deferred" shares are reallocated among the other technologies.

The final calculated market share of AVs within a size class is multiplied by the user specified size class share to calculate a technology's share of the total light vehicle market. The VCM then calculates the projected fuel economy of the sales fleet of cars and light trucks for each technology. This result is used as an input to the IMPACTT (VISION) model.

3.2 Model Update Reference Material

3.2.1 Nested Multinomial Logit

The VCM and the NEMS CVCS from the 1990s used a multinomial logit (MNL) model to estimate technology market shares. MNL models apply to problems of discrete choice where the outcome is one of a fixed number of possibilities. In the case of the consumer vehicle choice model, the discrete choices are the vehicle technology alternatives. The MNL model estimates the probability $P_{i,t}$ that the modeled consumer will choose a given technology i in year t based on the vehicle attributes according to the equation:

$$P_{i,t} = \frac{e^{\sum_j \beta_j \cdot x_{i,j,t}}}{\sum_i^N e^{\sum_j \beta_j \cdot x_{i,j,t}}}$$

Where:

$x_{i,j,t}$ = value of attribute j for advanced vehicle i in year t
β_j = logit coefficient for attribute j
N = total number of vehicle technology options

The core equation of the model represents the utility the consumer derives from the attributes of the vehicle and the equation coefficients (β_j) represent the consumer's relative weighting of each attribute. In other words, the consumer utility derived from selecting technology i in year t is:

$$U_{i,t} = \sum_j \beta_j \cdot x_{i,j,t}$$

It should be noted that consumers differ in their valuation of vehicle attributes. The use of market data (revealed preferences) or survey data (stated preferences) to determine the value of the logit coefficients results in values that represent an average consumer. In this case, the MNL estimates are the probability that the average consumer will choose a given technology or that any consumer will choose that technology on average. The estimates then represent the market share for that technology.

The underlying assumptions of the MNL model require that the choice outcome is independent of "irrelevant alternatives." In other words, the introduction of another alternative that is identical to one *not* chosen does not change the preference for the one chosen. Consider an example where two modeled vehicle technologies result in choice probabilities of 60% for A and 40% for B. Now consider introduction of a third technology C that is substitute for B and provides the same utility. While alternative C is as undesirable as B for those who preferred alternative A in the original choice problem, the MNL model now estimates choice probabilities of 42% for A, 28% for B, and 28% for C. The introduction of C – an irrelevant alternative to B – has altered the market share for A. This example could be illustrated by the choice between a conventional gasoline vehicle (A), a plug-in hybrid electric vehicle (PHEV) (B), and a second PHEV (C) with higher all electric range. Option C costs more than B, but the additional all-electric range exactly offsets that cost in terms consumer utility. While the choice between B and C may be policy relevant and therefore important to distinguish in the model, the fact that this choice exists should not change the market share of the conventional vehicle.

In order to account for this issue, the NEMS CVCS was updated from a MNL methodology to a nested MNL model around 2000 (Greene and Chin, 2000). To understand the updated methodology used in NEMS, TAE relied on two principal sources: Greene and Chin (2000) and EIA (2010a). While the basic methodology remains the same, the nested MNL partitions the choice problem to capture correlations among alternatives and thereby avoid the difficulties presented by the dependence of alternatives. The nested structure does not necessarily follow the order of actual consumer decision-making, but rather groups related alternatives within a nest.

The NEMS CVCS incorporates three levels of nesting. The lowest level nest estimates the consumer's choice of fuel for vehicles capable of using more than one fuel, conditional on selection of a bi- or flex-fuel vehicle. This calculation determines fuel-related attributes such as fuel availability, cost of driving, and range on a tank of fuel. These fuel-related characteristics are then used within the next level of calculations. The second level nest estimates the consumer choice probabilities among vehicles within a group of technologies with similar characteristics, conditional on the choice of that technology group. This results in market shares within each technology group. The third and final nest estimates the probability of choice among the technology groups. Then, for technology A included in technology group 1, the final market share of A is the probability of selecting group 1 times the probability of selecting A over the other alternatives in group 1: P(1)*P(A).

For AEO2010, NEMS used the following five technology groups with the technologies listed below:[2]

Group 1: Conventional-fuel capable vehicles:
- gasoline,
- turbo direct injection (TDI) diesel,
- gasoline/ethanol flex-fuel (E85),
- CNG bi-fuel, and
- LPG bi-fuel.

Group 2: Hybrids:
- plug-in hybrid, 10 mile all-electric range (PHEV10),
- plug-in hybrid, 40 mile all-electric range (PHEV40),
- diesel/electric hybrid, and
- gasoline/electric hybrid.

Group 3: Dedicated alternative fuel vehicles:
- dedicated ethanol,
- dedicated CNG, and
- dedicated LPG.

Group 4: Fuel cell vehicles:

[2] The vehicles listed represent the technologies included in the model. Some technologies may have been characterized with attributes that intentionally precluded entrance in the market. This allows the modeler to easily remove technologies no longer of market or policy interest and to maintain "slots" within the model code for future use.

- methanol fuel cell,
- hydrogen fuel cell, and
- gasoline fuel cell.

Group 5: Electric vehicles:

- dedicated all-electric.

3.2.2 NEMS Computational Resolution

The NEMS CVCS performs choice calculations independently for the following twelve vehicle classes:

1. Miniature cars,
2. Subcompact cars,
3. Compact cars,
4. Midsize cars,
5. Large cars,
6. 2-Seater cars,
7. Compact pickup trucks,
8. Standard pickup trucks,
9. Compact vans,
10. Standard vans,
11. Compact SUVs, and
12. Standard SUVs.

In addition, the NEMS model is run on a regional basis, using different attributes for fuel availability and price within each of 9 census divisions. Therefore, the CVCS must be run for each vehicle class above within each census division. This data is aggregated using regional sales volumes by size class to report national sales shares.

3.2.3 NEMS Logit Equation Coefficients

The development of the coefficients for the NEMS CVCS nested MNL model is documented in Greene and Chin (2000). Evaluation of this methodology was beyond the scope of this task. Therefore, TAE relied on the AEO 2010 NEMS transportation sector module input file, trnldv.xml, to determine the attributes and coefficients to be used in the LVChoice model (EIA, 2010b). TAE referred to the model documentation (EIA, 2010a) to interpret the units and application of these coefficients as shown in Table 3-1. A detailed discussion of the application of the coefficients is included in Section 4.0.

Table 3-1: NEMS CVCS Vehicle Attributes and Coefficients for AEO 2010

Attribute	Units	Coefficient Value for Cars: Mini	Sub-compact	Compact	Midsize	Large	2-Seater
Vehicle Price	1990$	-0.00131	-0.00131	-0.00131	-0.00082	-0.00082	-0.00131
Fuel Cost	1990 cents/mile	-0.62159	-0.62159	-0.62159	-0.38981	-0.38981	-0.62159
Range	Miles	-155.398	-155.398	-155.398	-97.4525	-97.4525	-155.398
Battery Replacement Cost	1990$	-0.00082	-0.00082	-0.00082	-0.00052	-0.00052	-0.00082
Acceleration, 0-60 mph	Seconds	-0.28482	-0.28482	-0.28482	-0.24085	-0.24085	-0.28482
Home Refueling for EVs	index to conventional, 0-1.0	0.66045	0.66045	0.66045	0.39085	0.39085	0.66045
Maintenance Cost	1990$/yr	-0.00397	-0.00397	-0.00397	-0.00249	-0.00249	-0.00397
Luggage Space	index to conventional, 0-1.0	2.355299	2.355299	2.355299	1.72322	1.72322	2.355299
Fuel Availability 1	index to gasoline, 0-1.0	-9.81375	-9.81375	-9.81375	-6.15436	-6.15436	-9.81375
Fuel Availability 2	index to gasoline, 0-1.0	-20.149	-20.149	-20.149	-20.149	-20.149	-20.149
Make/Model Availability	dummy, 0 or 1	0.3	0.3	0.3	0.3	0.3	0.3
Technology Set Gen. Cost	NA	-0.00065	-0.00065	-0.00065	-0.00041	-0.00041	-0.00065
Multi-Fuel Gen. Cost	NA	-2.73637	-3.28364	-3.18038	-2.69506	-2.51952	-2.75702
Attribute	**Units**	**Coefficient Value for Trucks: Compact Pickup**	**Standard Pickup**	**Compact Van**	**Standard Van**	**Compact SUV**	**Standard SUV**
Vehicle Price	1990$	-0.00134	-0.00134	-0.00109	-0.00109	-0.00079	-0.00079
Fuel Cost	1990 cents/mile	-0.63878	-0.63878	-0.5156	-0.5156	-0.37566	-0.37566
Range	Miles	-159.694	-159.694	-128.9	-128.9	-93.9161	-93.9161
Battery Replacement Cost	1990$	-0.00085	-0.00085	-0.00068	-0.00068	-0.0005	-0.0005
Acceleration, 0-60 mph	Seconds	-0.32869	-0.32869	-0.24032	-0.24032	-0.20003	-0.20003
Home Refueling for EVs	index to conventional, 0-1.0	0.76493	0.76493	0.55802	0.55802	0.44728	0.44728
Maintenance Cost	1990$/yr	-0.00408	-0.00408	-0.0033	-0.0033	-0.0024	-0.0024
Luggage Space	index to conventional, 0-1.0	2.823821	2.823821	2.279298	2.279298	1.660687	1.660687
Fuel Availability 1	index to gasoline, 0-1.0	-10.0851	-10.0851	-8.14035	-8.14035	-5.93103	-5.93103
Fuel Availability 2	index to gasoline, 0-1.0	-20.149	-20.149	-20.149	-20.149	-20.149	-20.149
Make/Model Availability	dummy, 0 or 1	0.3	0.3	0.3	0.3	0.3	0.3
Technology Set Gen. Cost	NA	-0.00067	-0.00067	-0.00043	-0.00043	-0.0004	-0.0004
Multi-Fuel Gen. Cost	NA	-2.5505	-1.84834	-2.35431	-1.82769	-2.08583	-1.72443

3.2.4 AEO 2010 Calibration Coefficients

As discussed in Section 3.2.1, the MNL model is based on consumer utility theory, where the utility $U_{i,t}$ a consumer derives from vehicle technology i in year t depends on the vehicle and fuel attributes $x_{i,j,t}$:

$$U_{i,t} = \sum_j \beta_j \cdot x_{i,j,t}$$

However, it is difficult to completely specify the list of attributes that determine consumer utility and many factors not directly related to vehicle or fuel attributes are relevant, including consumer risk aversion, government policies, identity or image conveyed by the vehicle, etc. The effect of these omitted variables can be captured in an error term, $\varepsilon_{i,t}$:[3]

$$U_{i,t} = \sum_j \beta_j \cdot x_{i,j,t} + \varepsilon_{i,t}$$

The subscript t on the error term reflects the fact that elements captured in the error term may change from year to year. The NEMS model uses "calibration coefficients" that change over the course of the analysis to account for omitted variables represented in the error term $\varepsilon_{i,t}$. Values for the calibration coefficients are calculated to adjust the estimated market shares for historic years to approximate actual data. These values are then projected to future years based on expected changes in policy and other factors. TAE referred to the NEMS transportation module FORTRAN code documented in file "tran.f" to determine the values of the calibration coefficients that were applied in the AEO 2010 reference case (EIA, 2010b). These values are documented in the Appendix.

3.2.5 Market Share Limitations

As discussed in Section 3.1.3, the VCM applies a sigmoid shaping curve to the market penetration calculations. This function limits the market share of new technologies in the first few years following introduction and mimics what historically has been observed. This historic pattern results from several factors, including initial conditions of limited consumer awareness, consumer risk aversion, limited market availability, higher cost, and lower performance in some attributes compared to the conventional option. Each of these factors changes over time, improving marketability. All of these factors must be considered when constructing choice model inputs or the model will produce erroneous results. Unfortunately, many of these factors are difficult to model and are usually omitted, producing unrealistically optimistic results during the introductory years. In addition, there is some rationale for limiting calculated market share in the *long* term as well: expert opinions on maximum market viability of various technologies often disagree with model projections. This discrepancy may be due in part to the

[3] This error term is distinguished from the regression model error term which, under the assumptions of ordinary least squares (OLS), is randomly distributed. In contrast, $\varepsilon_{i,t}$ is both biased (representing consistent over- or under-estimates of market share) and correlated with time (i.e., has a trend).

use of utility equation coefficients that represent average consumers, while some consumers would never consider purchasing a given technology. Other limiting factors include long-term fuel availability and refueling infrastructure.

TAE reviewed the NEMS transportation module documentation for the CVCS and found no reference to any limitations applied to market share calculations. It should be kept in mind that NEMS incorporates multiple submodules that represent both manufacturer and consumer decision-making and consider economic, regulatory, and other policy factors. The transportation module includes cost and performance models for vehicle components that improve fuel economy or are required in advanced technology vehicles. These models incorporate positive feedback loops that allow cost reductions and performance improvements with cumulative production (learning curves). As a result of these models, the decision-making of the Manufacturer Technology Choice Submodule (MTCS), and the careful construction of model inputs, the CVCS is unlikely to produce unrealistic early-year projections.

However, review of the NEMS transportation module code revealed that plug-in hybrid vehicle market shares were in fact limited for AEO 2010 within the second-level MNL nest to 50% of their calculated market potential. This limit reflects expert opinion on the availability of in-home recharging infrastructure.[4] The "deferred" market demand for PHEVs was reallocated to gasoline electric and diesel electric hybrid vehicles.

Since the LVChoice model was developed for stand-alone use, user specified vehicle attributes could easily result in unrealistic market shares during introductory years. Therefore, the model incorporates a flexible method that allows the user to specify maximum market potential and sigmoid curve shape parameters to be applied to each alternative technology. These curves primarily influence the introductory period for new technologies and not their long term market potential, *unless* the user intentionally chooses to limit that market potential to a value less than 100% of either calculated market share or total market share. LVChoice also applies the NEMS PHEV market limitations within the second MNL nest, but allows the user to specify the value for this limitation.

3.3 Relationship of LVChoice to VCM and NEMS

The LVChoice model is similar in structure and basic approach to the original VCM but the methodology has been updated to approximate that used in the CVCS submodule of NEMS for AEO2010. However, compared to the NEMS CVCS approach, the LVChoice model is greatly simplified. This section provides details on the differences between the LVChoice model, the original VCM, and the CVCS as used in NEMS for AEO 2010.

3.3.1 Size Classes

As discussed in Sections 3.1.2 and 3.2.2, the VCM spreadsheet includes five vehicle size classes while the NEMS CVCS used for AEO 2010 includes twelve vehicle size classes. Since the NPC

[4] Personal communication with John Maples of EIA.

desired to maintain as much simplicity in the LVChoice model as possible, five size classes were retained. However, the size classes used were altered to accommodate the needs of the FTF.

In order to update the model to the NEMS methodology and benchmark it to the AEO 2010, it was necessary to aggregate the nested MNL coefficients from the twelve NEMS vehicle size classes to the five used in the LVChoice. It also was necessary to similarly aggregate the AEO vehicle attributes (price, fuel economy, luggage space, etc.). Therefore, it was desirable to define size classes for which the vehicles were both similar in attributes and similar in terms of the preferences of the consumers that would purchase them. For example, while small and large SUVs may appear to be points on a spectrum of size and fuel economy, the preferences and priorities of their users are likely to be quite different. Small SUVs are built on car platforms while large SUVs are built on light truck platforms and are capable of some hauling and towing. As a result, purchasers of small SUVs are likely to put a higher valuation on fuel economy and lower valuation on horsepower compared to purchasers of large SUVs. After some consideration, the size classes shown in Table 3-2 were adopted for the LVChoice model. This table also shows the mapping of these classes to those used in NEMS for AEO 2010.

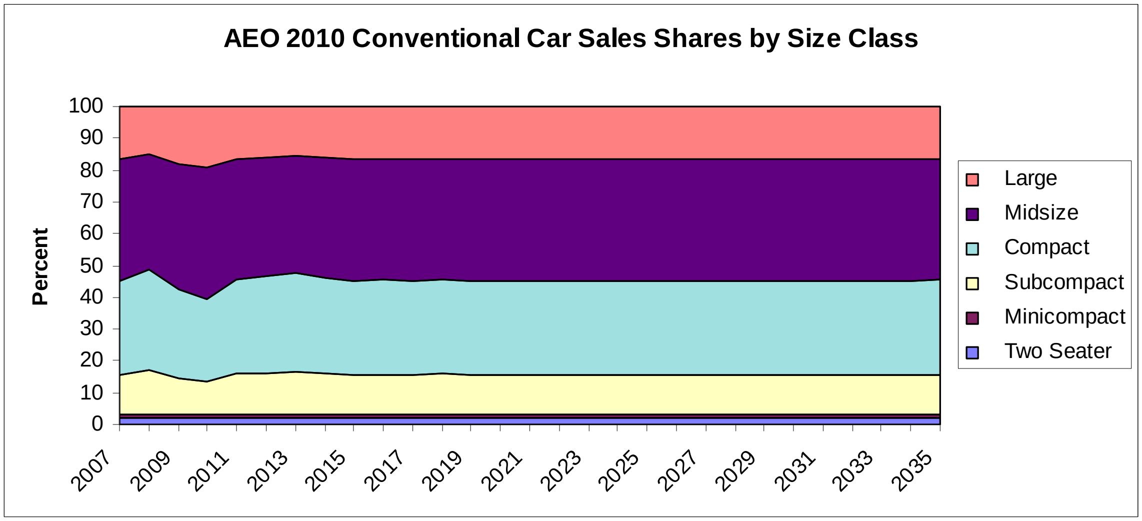
Table 3-2: Comparison of Vehicle Size Classes

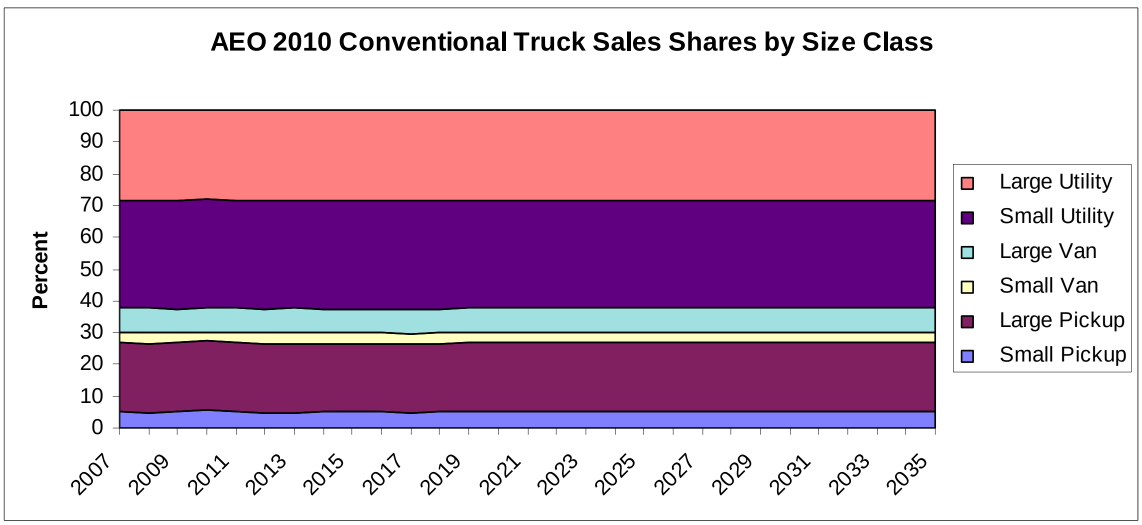
NEMS (AEO 2010)	LVChoice
Miniature Cars	Small Cars
Subcompact Cars	
Compact Cars	
Two-seater Cars	
Midsize Cars	Large Cars
Large Cars	
Compact Pickup Trucks	Pickup Trucks
Standard Pickup Trucks	
Compact Vans	Small SUVs
Compact SUVs	
Standard Vans	Large SUVs
Standard SUVs	

Figure 3-2 shows the sales shares of the NEMS size classes for conventional cars and conventional light trucks. The vehicles included in the LVChoice ‘Small Car’ class account for about 45% of car sales in the AEO 2010 reference case projection. The LVChoice ‘Large Car’ class accounts for the remaining 55% of car sales. Compact cars account for about 65% of the LVChoice Small Car class while midsize cars account for about 69% of the LVChoice ‘Large Car’ class.

Of the AEO 2010 reference case light truck sales, about 27% are included in the LVChoice ‘Pickup Truck’ class, 37% are included in the ‘Small SUV’ class, and 36% are included in the ‘Large SUV’ class. More than 80% of the LVChoice ‘Pickup Truck’ sales are standard pickup trucks. More than 90% of the 'Small SUV' class sales are small SUVs with minivans accounting for the remaining 10%. Finally, about 79% of the 'Large SUV' class is large SUVs with the remainder comprised of standard vans.

Figure 3-2: AEO 2010 Size Class Market Shares, Conventional Vehicles





3.3.2 Vehicle Technologies

A total of sixteen vehicle technologies are included in the NEMS CVCS used for AEO 2010, including two conventional vehicles (gasoline and diesel). Not all of these technologies were of interest for the FTF. Similar to the original VCM, the LVChoice model includes one conventional vehicle (gasoline) and "slots" for ten alternative vehicle technology types. However, only eight are actually populated and these are not identical to those used in the VCM. Vehicle technologies included in LVChoice were specified by the NPC.

One of the requirements of this task was to maintain the compatibility of the LVChoice model outputs with the VISION model inputs. Unfortunately, this requirement was not entirely compatible with the requirement to update the model to the NEMS AEO 2010 methodology since VISION does not include all the vehicle technologies modeled for AEO 2010 nor does it include all technologies of interest for the FTF. A comparison of the vehicle technologies included in these models is shown in Table 3-3 within the nested MNL technology groups from NEMS. Additional modeling work is required to update the VISION model to be compatible with LVChoice but was beyond the scope of the task documented in this report.

Table 3-3: Comparison of Vehicle Technologies Included in Models

Vehicle Technology	CVCS AEO 2010	LVChoice[1]	VISION
Conventional-Fuel Capable Vehicles			
Gasoline	✓	✓	✓
Turbo Direct Injection (TDI) Diesel	✓	✓	✓
Gasoline/Ethanol Flex-Fuel (E85)	✓	✓	✓
CNG Bi-Fuel	✓		
LPG Bi-Fuel	✓		
Hybrids			
Plug-In Hybrid, 10 Mile All-Electric Range (PHEV10)	✓	✓	✓[2]
Plug-In Hybrid, 40 Mile All-Electric Range (PHEV40)	✓	✓	
Diesel/Electric Hybrid	✓		✓
Gasoline/Electric Hybrid	✓	✓	✓[3]
Dedicated Alternative Fuel Vehicles			
Dedicated Ethanol	✓		
Dedicated CNG	✓	✓	✓
Dedicated LPG	✓		
Fuel Cell Vehicles			
Methanol Fuel Cell	✓		
Hydrogen Fuel Cell	✓	✓	✓[4]
Gasoline Fuel Cell	✓		
Electric Vehicles			
Dedicated All-Electric	✓	✓	✓

[1] LVChoice includes two additional technology "slots," one of which is grouped with dedicated alternative fuel vehicles and one which is grouped with fuel cell vehicles. Additional modeling would be required to fully incorporate these additional technologies.

[2] VISION (2010 version) includes one spark-ignited plug-in HEV for which the user may specify the fuel type (gasoline, E85, or hydrogen) and the all-electric range. VISION also includes a diesel PHEV for which the user may specify the all-electric range.

[3] VISION includes two spark ignited HEVs, one using gasoline and one using either E85 or hydrogen.

[4] VISION includes one fuel cell vehicle for which the user may specify the fuel type (gasoline, diesel, natural gas, ethanol, hydrogen, or methanol).

3.3.3 Additional LVChoice Simplifications

In addition to the reduced number of vehicle size classes and technologies, the LVChoice model incorporates a number of analytical simplifications in comparison to the NEMS AEO methodology. First, NEMS calculates technology market shares for nine census regions using regional fuel prices and availability. The LVChoice model makes calculations for a single region using inputs representing national fuel prices and availability based on the AEO reference case. If a detailed geographic analysis is desired, the user could conceivably construct regional inputs and run the model for each set of inputs.

Second, the NEMS CVCS is fully integrated with other transportation submodules and, when run for the AEO analysis, also is fully integrated with other modules representing the U.S. economy, fuel production, other energy demand sectors, etc. As a result, some of the data calculated internally in NEMS must be treated as an exogenous input for the LVChoice model. Most of the main inputs – the vehicle attributes – are determined by the Manufacturer Technology Choice Submodule (MTCS), run iteratively with the CVCS to achieve convergence on: production volumes and resulting vehicle prices; incorporation of fuel saving technologies, resulting fuel economy, and CAFE compliance; and other variables. The user must therefore consider manufacturer behavior and internal consistency when constructing alternative inputs.

In addition, some data calculated by NEMS and used internally cannot be treated as an input since it depends on the results of the choice model. For example, NEMS calculates vehicle sales based on macroeconomic activity then uses cumulative sales and in-use vehicle stock of alternative technology vehicles to project fuel availability. LVChoice is not integrated with an economic model that projects sales nor with a stock model (this is the function of VISION). Therefore, the algorithm used by NEMS to determine fuel availability could not be applied to LVChoice.

4.0 Methodology

The LVChoice spreadsheet applies a nested MNL model to the problem of the consumer's choice of vehicle from among a fixed number of possible technology options. The model estimates the percentage market share of one conventional and eight alternative technology platforms based on vehicle and fuel attributes.[5] The computations described in this section are calculated annually between 2007 and 2050. They are applied separately to each of the five size classes shown in Table 3-2, resulting in market shares within each size class. Technology market shares as a fraction of the entire light vehicle market are calculated using input on the distribution of the light vehicle market among the size classes. Since the LVChoice model does not estimate these size class shares, it cannot be used to project shifts in size class preferences based on the attributes of the vehicles within those classes.

4.1 Multi-Nomial Logit Algorithm

The LVChoice MNL model estimates market shares of vehicle choices as a function of the vehicle and fuel attributes according to the core equation:

$$P_{i,t} = \frac{e^{\sum_j \beta_j \cdot x_{i,j,t}}}{\sum_i^N e^{\sum_j \beta_j \cdot x_{i,j,t}}}$$

Where:

$P_{i,t}$ = probability the modeled consumer will purchase technology i in year t

$x_{i,j,t}$ = value of attribute j for advanced vehicle i in year t

β_j = logit coefficient for attribute j

N = total number of vehicle technology options

Since the equation is normalized, the sum of all probabilities at a given time step ($\Sigma_i P_{i,t}$) is 100%. At the heart of this methodology is an equation representing the utility the consumer derives from the vehicles attributers. The logit coefficients (β_j) therefore represent the consumer's relative weighting of each attribute. The total consumer utility derived from selecting technology i in year t is:

$$U_{i,t} = \sum_j \beta_j \cdot x_{i,j,t}$$

Consumers differ in their valuation of vehicle attributes and the LVChoice model uses a different set of coefficients for each vehicle class. This approach recognizes that, on average, buyers of vehicles in one size class differ in their valuation of vehicle attributes from buyers of

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[5] LVChoice includes two additional technology "slots," one of which is grouped with dedicated alternative fuel vehicles and one which is grouped with fuel cell vehicles. Additional modeling would be required to fully incorporate these additional technologies.

vehicles in the other classes. For example, small car buyers may place a higher value on fuel economy than large car and light truck buyers do. However, the model does not further distinguish among consumers, such as by separately modeling early adopters of new technologies, "imitators" that follow the majority trend, and risk-averse buyers. The logit coefficients therefore represent the average consumer of vehicles in a given size class. Since the coefficients are constant during the analysis period, relative consumer valuation of vehicle attributes is assumed to be stable over time.

4.2 MNL Coefficients

The LVChoice MNL coefficients were adapted from the NEMS CVCS model used for AEO 2010 as documented in Table 3-1. Since LVChoice uses fewer vehicle size classes, it was necessary to arithmetically combine the coefficients from more than one NEMS class to arrive at a single value for one LVChoice class. The resulting coefficients are shown in Table 4-1. For a description of the application of these coefficients, the reader is referred to Section 4.4.

For the Small Car, Large Car, and Pickup size classes, an adjustment was necessary only for the multi-fuel general cost (MFGC) coefficient. The value of this coefficient was set equal to the simple average of the values used in the constituent NEMS size classes. The remaining size classes were more complicated. NEMS assumes that buyers of compact vans and standard vans have the same valuation of all attributes except the MFGC. A similar assumption applies to buyers of compact and standard SUVs. The FTF study team agreed that compact van (mini-van) buyers were more likely to have valuations similar to small SUV buyers, while standard van buyers were more likely to have valuations similar to standard SUV buyers. Meanwhile, the valuations for small vans and SUVs versus large vans and SUVs would not be similar. The grouping of size classes selected for LVChoice reflects this judgment. Since minivans account for only 10% of the LVChoice small SUV class and sales of this vehicle class are generally falling, the NEMS coefficients for small SUVs were used for this class. The coefficients for the LVChoice large SUV class were calculated as the weighted average of the NEMS coefficients for standard vans and standard SUVs, using size class sales shares as the weighting factors.

Table 4-1: LVChoice Logit Coefficients

Attribute	Units	Coef. Symbol	Cars		Trucks		
			Small	Large	Pickups	Sm SUV	Lg SUV
Vehicle Price	1990$	β_{vp}	-0.00131	-0.00082	-0.00134	-0.00079	-0.00085
Fuel Cost	1990 cents/mile	β_{fc}	-0.62159	-0.38981	-0.63878	-0.37566	-0.40365
Range	Miles	β_{rng}	-155.398	-97.4525	-159.694	-93.9161	-100.913
Battery Replacement Cost	1990$	β_{batt}	-0.00082	-0.00052	-0.00085	-0.00050	-0.00054
Acceleration, 0-60 mph	Seconds	β_{acc}	-0.28482	-0.24085	-0.32869	-0.20003	-0.20809
Home Refueling for EVs	index to conventional, 0-1.0	β_{hrf}	0.66045	0.39085	0.76493	0.44728	0.46943
Maintenance Cost	1990$/yr	β_{mc}	-0.00397	-0.00249	-0.00408	-0.00240	-0.00258
Luggage Space	index to conventional, 0-1.0	β_{lug}	2.35530	1.72322	2.82382	1.66069	1.78441
Fuel Availability 1	index to gasoline, 0-1.0	β_{fa1}	-9.81375	-6.15436	-10.0851	-5.93103	-6.37289
Fuel Availability 2	index to gasoline, 0-1.0	β_{fa2}	-20.1490	-20.1490	-20.1490	-20.1490	-20.1490
Make/Model Availability	dummy, 0 or 1	β_{mma}	0.3	0.3	0.3	0.3	0.3
Technology Set Gen. Cost	NA	β_{gc}	-0.00065	-0.00041	-0.00067	-0.0004	-0.0004
Multi-Fuel Gen. Cost	NA	β_{mf}	-2.98935	-2.60729	-2.19942	-2.22007	-1.77606

4.3 Technologies and Groups

The LVChoice model uses the NEMS five technology groups populated with the technologies described below:

Group 1. Conventional-fuel capable vehicles:

- Conventional - gasoline ICE,
- TDI - turbo direct injection diesel, and
- ETOH Flex - gasoline/ethanol flex-fuel.

Group 2. Hybrids:

- PHEV10 - plug-in gasoline/electric hybrid, 10 mile all-electric range,
- PHEV40 - plug-in gasoline/electric hybrid, 40 mile all-electric range, and
- Gasoline HEV - gasoline/electric hybrid.

Group 3. Dedicated alternative fuel vehicles:[6]

- CNG - dedicated CNG.

Group 4. Fuel cell vehicles:[7]

- H2 FCV - hydrogen fuel cell.

Group 5. Electric vehicles:

- Electric - dedicated all-electric.

[6] Additional technology slot in this group reserved for future modeling.
[7] Additional technology slot in this group reserved for future modeling.

4.4 *Nested MNL Structure*

The nesting structure of the LVChoice model follows that used in the NEMS CVCS, incorporating three levels of nesting. The nested structure does not necessarily reflect actual consumer decision-making, but rather groups related alternatives within a nest. Each nest makes conditional probability calculations and the analysis therefore proceeds from the highest level of specificity to lowest. This order likely is opposite to the chronology of consumer decision-making. However, it facilitates determination of the average attributes of vehicle technologies or technology groups which are required for the next set of calculations.

The first nest to be calculated estimates the consumer's choice of fuel for vehicles capable of using more than one fuel, *conditional on* (or assuming) selection of a bi- or flex-fuel vehicle. This calculation determines the cost of driving which is then used within the next level of calculations. The second nest estimates the consumer choice probabilities among vehicles within each of five groups of technologies with similar characteristics, conditional on the choice of that technology group. This results in market shares within each technology group and the overall utility derived from the technology group. The third and final nest estimates the probability of choosing each of the technology groups, based on the overall utility of each group. Finally, the results of the second and third nests are used to calculate the market share of each technology within a vehicle size class.

This section describes the operations performed within each nest in the order in which they occur. The calculations are applied separately to each vehicle size class. In all the equations shown below, the coefficients and variables are unique to the size class and technically have one additional subscript. However, the subscript for size class has been omitted for simplicity.

4.4.1 Nest 1: Multi-Fuel Vehicle Fuel Use

The first nest makes calculations only for those vehicle technologies capable of operating on more than one fuel: ETOH Flex, PHEV10, and PHEV40. The purpose of this nest is to determine the proportion of miles the consumer will drive on each fuel. This in turn determines the cost to drive a mile, which is required in the subsequent nest. Nest 1 calculations proceed as follows:

1. For each flex-fuel or bi-fuel vehicle, calculate the fuel-related utility $UF_{i,j,t}$ of technology i at time t on each of the two possible fuels j:

$$UF_{i,j,t} = \beta_{mf} * \frac{p_{j,t}}{mpg} + \frac{\beta_r}{Rng_{i,t}} + \beta_{fa1} * e^{\left(\beta_{fa2} * SFA_{j,t}\right)}$$

Where:

$p_{j,t}$ = price of fuel j in cents/gasoline equivalent gallon (125,000 BTU)

$$\beta_r = \beta_{mf} * \frac{\beta_{rng}}{\beta_{cf}}$$

$Rng_{i,t}$ = vehicle range on a tank of fuel in miles

$SFA_{j,t}$ = station fuel availability (% of stations) of fuel j

2. Calculate the percentage of miles $P_{i,j,t}$ that technology i is driven on fuel j at time t using the logit formulation:

$$P_{i,j,t} = \frac{e^{UF_{i,j}}}{\sum_j e^{UF_{i,j}}}$$

3. Calculate the "multi-fuel general cost" $mfcgen_{i,t}$ of driving as:

$$mfcgen_{i,t} = \frac{\ln\left(\sum_j e^{UF_{i,j}}\right)}{\beta_{mf}}$$

4.4.2 Nest 2: Market Shares within Technology Groups

Nest 2 calculates the market shares for the technologies within each technology group as a percentage of that group. As such, it is the probability that a consumer will select that technology, assuming that the consumer decides to purchase within that technology group. Each group is considered separately as follows:

1. Calculate consumer utility of each technology using the full complement of vehicle and fuel attributes. For flex- and bi-fuel vehicles, the utility $U_{i,t}$ of technology i at time t is calculated as:

$$U_{i,t} = \beta_{vp} * VP_{i,t} + \beta_{fp} * mfcgen_{i,t} + \beta_{batt} * Cbatt_{i,t} + \beta_{ac} * AccTime_{i,t} + \beta_{hrf} * HomeFuel_{i,t} + \beta_{mc} * Cmain_{i,t} + \beta_{lug} * LugSpace_{i,t} + \beta_{mma} * \ln(MMA_{i,t}) + \varepsilon_{i,t}$$

Where:

$VP_{i,t}$ = vehicle price (1990$)
$mfcgen_{i,t}$ = multi-fuel general cost as calculated in Nest 1
$Cbatt_{i,t}$ = battery replacement cost (1990$)
$AccTime_{i,t}$ = 0-60 mph acceleration time (sec)
$HomeFuel_{i,t}$ = home refueling capability for EVs and PHEVs (dummy 0 or 1)
$Cmain_{i,t}$ = maintenance cost (1990$)
$LugSpace_{i,t}$ = luggage space (index to conventional, 0-1.0)
$MMA_{i,t}$ = make and model availability relative to conventional (index, 0-1.0)
$\varepsilon_{i,t}$ = calibration coefficient that accounts for omitted variables

For all other technology types, the utility is calculated as:

$$U_{i,t} = \beta_{vp} * VP_{i,t} + \beta_{fc} * Cfuel_{i,t} + \frac{\beta_{rng}}{Rng_{i,t}} + \beta_{batt} * Cbatt_{i,t} + \beta_{ac} * AccTime_{i,t} + \beta_{hrf} * HomeFuel_{i,t}$$

$$+ \beta_{mc} * Cmain_{i,t} + \beta_{lug} * LugSpace_{i,t} + \beta_{fa1} * e^{(\beta_{fa2} * SFA_{j,t})} + \beta_{mma} * \ln(MMA_{i,t}) + \varepsilon_{i,t}$$

Where:

$Cfuel_{i,t}$ = fuel cost of driving (1990¢/mile)
$Rng_{i,t}$ = vehicle range on a tank of fuel (miles)
$SFA_{j,t}$ = availability of fuel j used by technology i (% of stations)

The LVChoice model allows the user to select one of two choices for the calibration coefficient, $\varepsilon_{i,t}$: a value for each technology that is constant over time as specified in the NEMS transportation module input file (tranldv.xml) used for AEO 2010; or values for each technology that vary over time as specified in the NEMS transportation module FORTRAN code (file tran.f) for the AEO 2010 reference case.[8] These values are documented in the Appendix.

2. Calculate market shares within each technology group. For each of the technology groups listed in 4.3, the market share $P_{i,t}$ for technology i at time t is:

$$P_{i,t} = \frac{e^{U_{i,i}}}{\sum_i e^{U_{i,i}}}$$

Note that the summation in the denominator includes only those technologies within the group under consideration.

2a. For the hybrid technologies (group 2), an additional step is required to apply limits to the market share attained by plug-in hybrids (PHEVs). This limitation reflects assumptions about the availability of home recharging infrastructure. The limit is applied as a scale factor and was set equal to 0.5 for both PHEV10 and PHEV40 in AEO 2010. However, any value between 0 and 1.0 may be specified by the user. Any reductions in market share are reallocated to traditional hybrid vehicles. The adjusted shares of hybrids are calculated as:

$$P'_{phev10,t} = L_{phev10} * P_{phev10,t}$$
$$P'_{phev40,t} = L_{phev40} * P_{phev40,t}$$
$$P'_{hev,t} = P_{hev,t} + (1 - L_{phev10}) * P_{phev10,t} + (1 - L_{phev40}) * P_{phev40,t}$$
$$= 1 - (Padj_{phev10,t} + Padj_{phev40,t})$$

Where:

$P_{phevxx,t}$ = market shares calculated in step 2 above
L_{phevxx} = PHEV limit factors

3. Calculate the “generalized cost” $GC_{k,t}$ for each technology group, k.

[8] The user could also overwrite the static values and specify the calibration coefficient to be used.

$$GC_{k,t} = \frac{\ln\left(\sum_i e^{U_{i,i}}\right)}{\beta_{vp}}$$

The generalized cost of group k basically monetizes the utility that consumers derive from all the technology choices within the group, based on all the vehicle and fuel attributes. This technology group attribute is required for the calculations in the subsequent nest.

4.4.3 Nest 3: Market Shares within Size Class

Nest 3 calculates the market shares of all the technology choices within the size class. This nest first calculates the market share of each technology group, based on the generalized cost of the groups. The share of each technology with the size class is then calculated using the technology's share within its group and the group's share within the class.

1. Calculate the utility $Ugroup_{k,t}$ of technology group k at time t:

$$Ugroup_{k,t} = \beta_{gc} * GC_{k,t}$$

Where:
$GC_{k,t}$ = generalized cost of technology group k from Nest 2

2. Calculate the market share $Pgroup_{k,t}$ of technology group k within the size class:

$$Pgroup_{k,t} = \frac{e^{Ugroup_{k,i}}}{\sum_k e^{Ugroup_{k,i}}}$$

3. Calculate the market share $S_{i,t}$ of technology i within the size class:

$$S_{i,t} = P_{i,t} * Pgroup_{k,t}$$

Where $P_{i,t}$ is the market share for technology i within its technology group, k, calculated in Nest 2. For the hybrid technologies, the adjusted shares $P'_{i,t}$ are used.

4.5 Maximum Market Share Limitations

After all NMNL calculations are complete, the LVChoice applies market share limitations to the shares within each vehicle size class. The limit function is a sigmoid curve, determined separately for each technology and size class, which begins at zero in the year in which the technology is introduced and increases to a specified maximum value. As discussed in Section 3.2.5, the sigmoid curve is intended to approximate historic technology diffusion patterns. This historic pattern arises from several factors, some of which are included in the MNL model while others are not. Factors which are not modeled may include consumer risk aversion, initial limited consumer awareness, and short- or long-term maximum market potential. Maximum market potential may be due to refueling infrastructure limitations as well as vehicle functionality. Since the utility equations in the LVChoice model represent average consumers within each vehicle size class, it is unable to capture limits to a technology's appeal due to functionality.

For each technology and size class, the user specifies the maximum value of the limit curve (0-1.0), the number of years until the sigmoid reaches half of the maximum value, and a shape coefficient that determines the slope of the curve. The limit curve $L_{i,sc}(y)$ for technology i in size class sc is calculated from a generalized saturation function as:

$$L_{i,sc}(y) = L\max * \frac{y^{\lambda}}{yhalf^{\lambda} + y^{\lambda}}$$

Where:

$Lmax$ = limit function maximum value (0-1.0, user specified)

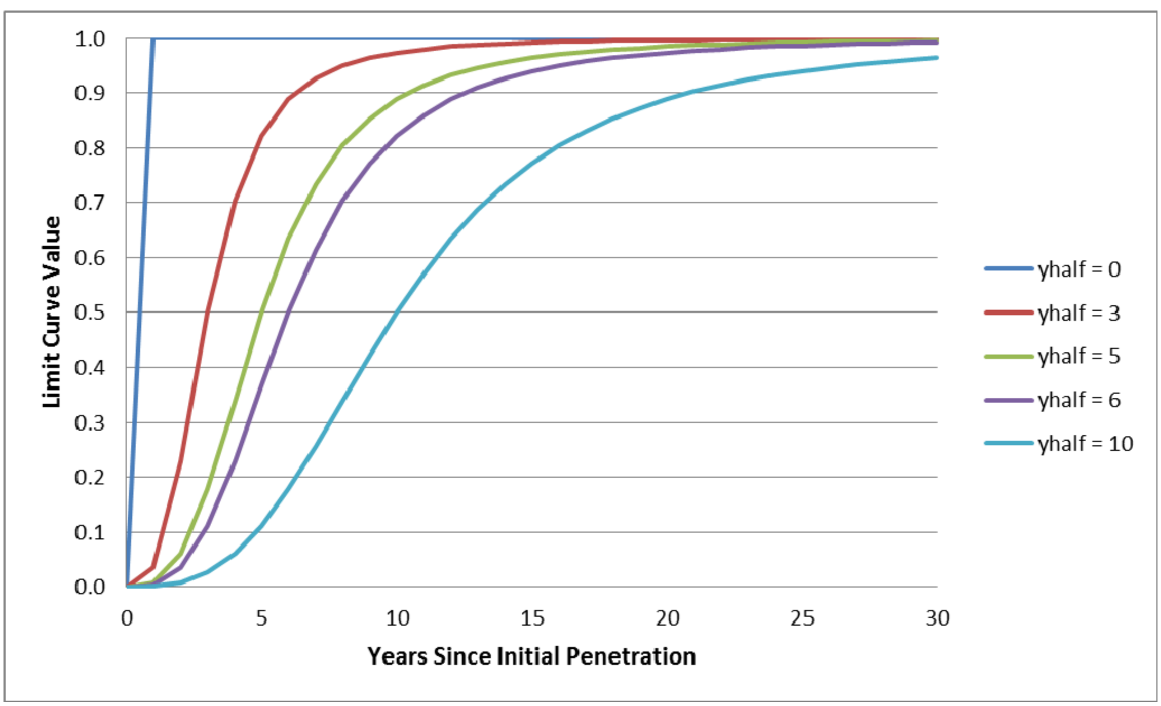
y = years since introduction

λ = shape coefficient (2.0-20.0, user specified)

$yhalf$ = years to half maximum value (user specified)

Figure 4-1 illustrates the limit curve for a maximum value of 1.0, a shape coefficient λ of 3.0 and varying values of *yhalf*.

Figure 4-1: Sample Limit Curves for Lmax = 1 and λ=3



The limit curve, $L_{i,sc}(y)$, is applied at the user's specification as either a maximum value or a scale factor. The choice of methodology depends on the user's theoretical basis for limiting market shares. The maximum value methodology represents fixed limits to the market share of a technology which may arise from limits to refueling infrastructure, limited market availability, or market appeal beyond the average consumer. The scale factor methodology is more representative of risk aversion and limited consumer awareness. In this latter case, while the technology may appeal to a large number of buyers based on the utility function, only a fraction of these will actually buy it. The limit curve, then, represents this fraction of potential demand that is actually realized.

The adjusted shares based on the limit curve are calculated in two stages. In the first stage, market shares are recalculated for those technologies that are limited. In the second stage, "deferred" shares of limited alternative technologies are reallocated to unlimited alternative technologies and to the conventional vehicle. The methodology for the two user options are described below.

4.5.1 Maximum Value Limit Curve

If the user has selected the option to apply the limit curve as a maximum value, the following equations are used.

1. Calculate stage 1 adjusted shares:

$$AS1_{i,t} = \min\left(L_{i,t}, S_{i,t}\right)$$

2. Calculate "deferred" shares:

$$D_t = 1 - \sum_i AS1_{i,t}$$

3. Calculate adjustment factor:

$$AF_t = 1 + \frac{D_t}{\sum_n AS1_{n,t}}$$

Where n represents the set of technologies whose shares were not limited.

4. Calculate stage 2 (final) adjusted shares. For the limited technologies, the final shares are the stage 1 adjusted shares. The final adjusted shares of the non-limited alternative technologies na are:

$$AS2_{na,t} = \min\left(L_{na,t}, AF_t * AS1_{na,t}\right)$$

The minimum formulation is necessary to prevent the reallocation of deferred shares to a non-limited technology from causing the final adjusted share to exceed the limit for that technology. Since there may have been some additional limiting during this second adjustment, the final market share of the conventional vehicle is calculated as:

$$AS2_{conv,t} = 1 - \sum_{a} AS2_{a,t}$$

Where a represents the set of all alternative (non-conventional) technologies, both limited and not limited.

4.5.2 Scale Factor Limit Curve

If the user has selected the option to apply the limit curve as a scale factor, the following equations are used.

1. Calculate stage 1 adjusted shares $AS1_{i,t}$:

$$AS1_{i,t} = L_{i,t} * S_{i,t}$$

2. Calculate "deferred" shares D_t:

$$D_t = 1 - \sum_{i} AS1_{i,t}$$

3. Calculate adjustment factor AF_t:

$$AF_t = 1 + \frac{D_t}{\sum_{i} AS1_{i,t}}$$

Where i represents the full technology set, including all alternatives (limited and not limited) and the conventional vehicle.

4. Calculate stage 2 (final) adjusted shares $AS2_{i,t}$. For the limited technologies, the final shares are the stage 1 adjusted shares. The final adjusted shares of the non-limited alternative technologies are:

$$AS2_{n,t} = AF_t * AS1_{n,t}$$

Where n represents the set of technologies whose shares were not limited, including the conventional vehicle.

4.6 Fleet Level Results

The nested MNL model calculations result in market shares for each of eight technologies within each of five size classes. These results are aggregated to report market shares and fuel economy for the new car, new truck, and total light vehicle markets. Since the LVChoice model does not project sales or sales shares of each size class, this aggregation is accomplished by applying user inputs on sales for each size class. The sales inputs included with the model are derived from AEO 2010 reference case outputs. Fleet level market shares of each technology are calculated by multiplying the technology's market share within the size class by the market share of the size class within the fleet. Fleet level fuel economies are calculated as harmonic averages, using sales shares as weighting factors. This calculation inherently assumes that vehicles of all technologies and size classes are driven an equal number of miles annually.

5.0 User Notes

This section provides an overview of running the LVChoice model. Due to limited funding, the user interface has not been developed for ease use. Therefore, inputs are located on a number of worksheets as described below. Input cells generally are indicated with yellow highlighting, with the exception of the vehicle attribute worksheets for which most cells are inputs. The model is delivered with AEO 2010 reference case values for all inputs and the user should retain a copy of the original model as a reference. Any changes made to the model can be returned to the default AEO values only by copying the values from the original model.

In general, the user should only make changes within the input cells and should not move data or add or delete rows since this may adversely affect the model functionality.

For the simplest application of the LVChoice model, the user may wish to alter the various vehicle attributes and fuel prices while retaining all other the inputs supplied by the AEO 2010 analysis. In more complicated analyses, additional assumptions may be applied. All potential user inputs are discussed in Section 5.1. Section 5.2 describes the model calculation worksheets and Section 5.3 describes the results worksheets.

5.1 Inputs

5.1.1 Vehicle Attributes

The vehicle attributes for each technology and size class represent the main user inputs for a model run. The model is delivered with the vehicle attributes derived from the AEO 2010 reference case as described in Section 6.1. These inputs are found on separate worksheets for each size class:

- ‘Sm Car’ Small cars, including two-seaters, sub-compact, and compact cars.
- ‘Lg Car’ Large cars, including midsize and large cars.
- ‘Pickups’ Compact and standard pickup trucks.
- ‘Sm SUV’ Compact SUVs, minivans, and crossovers (all light trucks built on car platforms).
- ‘Lg SUV’ Large SUVs and standard vans (light trucks other than pickups built on truck platforms).

The user should not add rows or columns or reorder the rows on the vehicle attribute worksheets, since doing so may adversely affect the model functionality. Also, altering the technology names will not change the actual technology type since it will not change the fuel used or how the technology is treated within the nested MNL structure.

Each attribute worksheet follows the same layout as described below. Italic typeface indicates cells that are calculated and should not be altered by the user.

1. B5:AS15 Vehicle price (2008$)
2. *B18:AS28 Vehicle price in 1990$, calculated from B5:AS15*
3. B31:AS41 Fuel economy (miles per gasoline equivalent gallon)
4. B44:AS54 Range on a tank of fuel and/or full battery charge (miles).
5. *B57:AS67 Acceleration time (sec), calculated from horsepower and weight.*
6. B70:AS80 Luggage space (index to conventional). AEO default values are constant over time and Column B is linked to worksheet 'AEO Inputs'.
7. B83:AS93 Battery replacement cost (1990$), set to $0 since this attribute is included in the AEO maintenance cost
8. B96:AS106 Maintenance cost (1990$/year). AEO default values are constant over time and Column B is linked to worksheet 'AEO Inputs'.
9. A109:BS119 Make/model availability (index to conventional). Linked to AEO default values on worksheet 'AEO Inputs'.
10. *B122:AS132 Calibration coefficients. Choice of either static or time variable values from AEO selected on worksheet 'Coef'. No inputs are necessary on the vehicle attribute worksheet.* ***The user should not alter or delete the index values in range AT122:AT132.***
11. B135:AS145 Horsepower (hp)
12. B148:B158 Vehicle weight (lbs)

5.1.2 AEO 2010 Input File and Output Table Data

Inputs taken from the AEO NEMS transportation module input file (tranldv.xml) and the AEO 2010 output tables for the reference case are included on worksheet 'AEO Inputs'. Data used by the model which the user may want to change to define a scenario are indicated in yellow highlighted cells and listed below:

1. A4:AS9 Fuel prices (2008$ per million BTU)
2. A14:AS15 Light vehicle sales (1,000s)
3. D26 Conversion of 2008$ to 1990$. This conversion factor is used for vehicle and fuel prices. If prices are specified in current $ for another year, this factor should be adjusted accordingly.
4. A29:AS30 Car size class sales shares (% of cars)
5. A32:AS34 Light truck class sales shares (% of trucks)

6. B46:46 — PHEV all electric share of VMT. Per AEO 2010, these values overwrite the nest 1 multi-fuel vehicle calculations for PHEVs and are used for all analysis years.
7. B49 — Fraction of consumers who can plug in a PHEV at home.
8. N57:BE72, N76:BE91 — Make / Model availability (index to conventional). This attribute may be changed here or on the vehicle size class worksheets (A109:BS119).
9. D96:E111, K96:K111, N96:O111 — Default maintenance costs (1996$/year).
10. B94 — Factor to convert 1990$. Update this value if maintenance costs on this sheet are specified in current $ other than 1996$.
11. D117:E132, K117:K132, N117:O132 — Default luggage space (index to conventional).

5.1.3 Market Share Limitation Curve Inputs

The user has the option to specify market share limitation curves for each technology type for each vehicle size class. Required inputs, specified on worksheet 'Max Penetration', are:

1. E4 — Methodology
   Enter a 1 or 2 to select the method in which the limit curve will be applied (see Section 4.5):
   1 = Maximum value method.
   2 = Scale factor method.
2. E5 — Shape coefficient
   Enter a decimal value between 2.0 and 20 to change the shape of the limit curve. Higher values have a steeper slope at the inflection point and result in more rapid saturation after the halfway point.
3. C10:G19 — Maximum value of the limit curve
   For each technology type and size class, enter decimal values between 0 and 1.0.
4. H11:H12 — Market penetration limit for PHEVs within hybrid technology group (nest 2, see Section 4.4.2). Enter a decimal value between 0 and 1.0 (AEO 2010 default is 0.5).
5. C22:G31 — Years to half saturation.
   For each technology type and size class, enter the number of years, measured from introduction, until the limit curve reaches half its maximum value.

6. L6:N6 — To graph the limit curves you have specified, select a size class from the drop-down menu.

The user should not alter data in B38:M75. This data is used to graph the limit curves for a size class, as selected from the drop-down menu in L6:N6.

5.1.4 Additional Inputs

Additional user inputs are located on the 'Lists' and 'Coef' worksheets as described below.

The 'Lists' worksheet contains parameters used by the model. Most changes on this worksheet will change the vehicle technology description and generally will not be necessary. Therefore, few changes are expected to the following inputs:

1. E22:E24 — Method for calculating fuel shares for flex- and bi-fuel vehicles.
   1 = apply fixed shares
   2 = apply the MNL utility methodology (see Section 4.4.1).
   Fixed shares must be specified for PHEV10 and PHEV40 vehicles and default values are applied from AEO 2010. The 'Lists' spreadsheet refers to the default AEO values which are found at 'AEO Inputs'!B46:B47.
2. F20:F30 — Fuel 1
   Specify the fuel used by the vehicle using the index shown in Table 5-1. Note that electricity used by PHEVs is distinguished from electricity used by electric vehicles because AEO 2010 made different assumptions about charging infrastructure. While PHEVs were assumed to only recharge at home, dedicated EVs are assumed to charge at publically available stations.
3. G22:G24 — Fuel 2
   Specify the second fuel used by flex- and bi-fuel vehicles using the index shown in Table 5-1. See note above for Fuel 1.
4. H22:I24 — Fuel fractions
   Enter the fixed proportions of Fuel 1 and Fuel 2 if method 1 is applied for calculating fuel shares for flex- and bi-fuel vehicles. ***Do not enter values here if method 2 is selected. Fixed shares must be specified for PHEV10 and PHEV40 vehicles*** and default values are applied from AEO 2010. The 'Lists' spreadsheet refers to the default AEO values which are found at 'AEO Inputs'!B46:B47.

Table 5-1: Fuel Specification

Index	Fuel
1	Gasoline
2	Diesel
3	E85
4	CNG
5	Electricity
6	Electricity (PHEV)
7	H2

Note: PHEVs have a very limited range in all-electric mode (10 and 40 miles) and the MNL model would estimate 0% VMT on electricity. Therefore, PHEVs are not treated as bi-fuel vehicles within the nested structure. The user must apply fixed fuel proportions for PHEVs.

The 'Fuel' worksheet contains calculations that references data in the other input worksheets. One of these calculations is an estimate of alternative fuel availability that depends on prior year projections of alternative vehicle market shares. Fuel availability is initialized with 2007 values taken from the AEO 2010 NEMS transportation module input (file tranldv.xml). The algorithm is taken from the VCM and calibrated to the AEO 2010 reference case availability for E85. Annual growth in availability is limited to two percent of stations. The user may wish to alter these assumptions and can change both the calibration factor in cell F13 (default value is 5) and the maximum growth rate in cell B13.

The 'Coef' worksheet contains the MNL coefficients used by the model. There is one user input on this worksheet:

- D23 Select calibration coefficients:

  1 = apply the constant values, shown in B25:F40, from the AEO 2010 NEMS transportation module input (file tranldv.xml), or

  2 = apply the time-dependent values from the NEMS transportation module FORTRAN code (file tran.f) for the AEO 2010 reference case.

For documentation of the calibration coefficients, see the Appendix.

Note: Changes to the MNL coefficients are not recommended. The values used in the model are derived from the NEMS transportation module and intended to be used as a set. Changing the magnitude of one coefficient changes the relative importance of all the coefficients. Therefore, any changes would require both a theoretical basis and internal consistency.

5.2 Calculations

Fuel related calculations generic to all size classes are contained on worksheet 'Fuel'. Nested MNL calculations for each size class are contained on the following worksheets:

- 'SCChoice' - small cars, including two-seaters, sub-compact, and compact cars.
- 'LCChoice' – large cars, including midsize and large cars.
- 'PUChoice' – compact and standard pickup trucks.
- 'SSUChoice' – compact SUVs, minivans, and crossovers (all light trucks built on car platforms).
- 'LSUChoice' – large SUVs and standard vans (light trucks other than pickups built on truck platforms).

For each size class worksheet, final market shares are calculated in rows 253-263. Graphs of the technology market shares are shown below the calculations beginning in row 265. The top graphic displays the shares before the penetration limit curve is applied and the bottom graphic displays the shares afterward.

5.3 Results

Final market shares by size class are tabulated on worksheet 'Mkt Shares' in rows 66-132. Using inputs on annual car and light truck sales (see Section 5.1.2), fleet level market shares by technology are calculated for:

1. B7:AS16 Light vehicle market
2. B28:AS38 Car market
3. B42:AS52 Light truck market

The fuel economy for new vehicles sales fleets are calculated on worksheet 'MPG':

1. B6:AS8 Car fleet, light truck fleet, and all light vehicles
2. B11:AS16 All light vehicles by size class
3. B19:AS30 All light vehicles by technology
4. B33:AS44 All cars by technology
5. B47:AS58 All light trucks by technology
6. B62:AS129 Retabulation of fuel economy inputs (by technology within size class) with size class totals.
7. B133:AS200 Calculation area

AEO 2010 reference case results are reported on worksheet 'AEO Market Shares' for comparison. Total light vehicle market shares by technology type were aggregated to represent the technologies modeled in LVChoice. Section 6.0 compares the LVChoice results using all AEO inputs to the AEO 2010 reference case results.

6.0 Model Benchmark

The LVChoice was benchmarked against NEMS AEO 2010 reference case inputs and results. The AEO reports technology sales for cars and light trucks, but does not report technology sales shares within size classes. Therefore, this comparison addresses only the aggregate car, truck, and light vehicle fleets. However, the lack of technology sales shares by size class also complicates the development of vehicle attribute inputs for the benchmark. This section describes the development of vehicle attribute inputs, compares model projections, and discusses reasons for differences in the results.

6.1 Vehicle Attribute Inputs

The vehicle attributes provided in the AEO 2010 documentation were combined to consolidate the twelve NEMS size classes to the five LVChoice size classes shown in Table 3-2. Ideally, size class shares within the technology types would have been used to construct weighted averages of the NEMS classes that constitute the LVChoice class. However, the AEO documentation does not report information that would allow calculation of these shares. Therefore, sales shares of conventional vehicles by size class were used to construct the weighted averages. The methodology for each technology type i at each time step is described below:

1. For each NEMS size class nsc, calculate the ratio of the advanced technology vehicle attribute x_i to the conventional vehicle attribute x_{conv}:

   $$r_{i,nsc} = \frac{x_{i,nsc}}{x_{conv,nsc}}$$

2. For all NEMS size classes included in the LVChoice size class, calculate the weighting factor:

   $$w_{nsc} = \frac{S_{conv,nsc}}{\sum_{nsc}^{Nsc} S_{conv,nsc}}$$

   Where

   $S_{conv,nsc}$ = Sales of conventional vehicles in class nsc

   Nsc represents the set of constituent NEMS size classes for which technology i has been introduced.

3. Calculate the weighted average attribute ratio $ravg$ of the LVChoice size class lsc:

   $$ravg_{i,lsc} = \sum_{nsc}^{Nsc} w_{nsc} * r_{i,nsc}$$

4. Calculate the conventional vehicle attribute for LVChoice class lsc:

   $$x_{conv,lsc} = \frac{\sum_{nsc}^{Nsc} S_{conv,nsc} * x_{conv,nsc}}{\sum_{nsc}^{Nsc} S_{conv,nsc}}$$

5. Calculate the LVChoice sales class lsc vehicle attribute x_i:
   $x_{i,lsc} = ravg_{i,lsc} * x_{conv,lsc}$

This approach using weighted average ratios instead of weighted average attributes provided better results when the alternative technology had not been introduced in all constituent NEMS size classes. For example, in some cases, a technology had higher fuel economy within the NEMS large car class but had not been introduced in the midsize car class. When these classes were aggregated using weighted average attributes, the resulting fuel economy for the alternative technology was lower than the conventional vehicle.

6.2 Results

Since the AEO 2010 analysis included a larger technology set than LVChoice, it was also necessary to consolidate the market share results for comparison purposes. As shown in Table 6-1, the LVChoice conventional, TDI diesel, PHEV10, PHEV40, ETOH flex, electric, and H2 FCV technology types each were compared to one NEMS vehicle technology. The NEMS dedicated and bi-fuel CNG sales were added together to compare to the LVChoice CNG (dedicated) sales share. Similarly, the NEMS diesel/electric and gasoline/electric hybrid sales were added together to compare to the LVChoice HEV (gasoline/electric hybrid) sales share. The remaining NEMS technologies attained negligible market penetration and were omitted from the results comparison.

This consolidation assumes that the introduction of more options within a technology group, as treated within the nested MNL, does not change the overall market share of the group. This assumption is imperfect, since some of the options included in NEMS may have increased a technology set's total utility. A more accurate benchmark would have been to model the LVChoice technologies in NEMS and omit all other technologies from the analysis. However, such an analysis was beyond the scope of this task.

Table 6-1: Technology Market Share Results Consolidation

NEMS (AEO 2010)	LVChoice
Gasoline	Conventional
TDI Diesel	TDI Diesel
PHEV10	PHEV10
PHEV40	PHEV40
E85 flex	ETOH flex
Bi-fuel CNG	CNG
Dedicated CNG	
Dedicated All Electric	Electric
Diesel/Electric HEV	Gasoline HEV
Gasoline/Electric HEV	
Hydrogen Fuel Cell	H2 FCV
LPG Bi-Fuel	*Omitted*
Dedicated Ethanol	*Omitted*
Dedicated LPG	*Omitted*
Methanol Fuel Cell	*Omitted*
Gasoline Fuel Cell	*Omitted*

The results of the LVChoice model benchmark are summarized in Table 6-2 through Table 6-4 and displayed graphically in Figure 6-1. By 2035, the overall distribution of shares among the technologies is generally consistent between the two models, with the LVChoice model generally having more optimistic projections for the alternative technologies. Compared to AEO 2010, the LVChoice model estimates higher shares of TDI diesel cars and slightly lower shares of TDI trucks. LVChoice also estimates slightly higher market penetration of gasoline hybrid vehicles in the light truck market. The differences between the two models are more pronounced for PHEV vehicles, with the LVChoice projecting more than twice the market share for PHEVs within cars and about 50% higher market share within trucks. However, the total share of PHEVs projected by the LVChoice model is fairly small at around 6% of the light vehicle market. The two models agree well on estimates of ethanol flex-fuel vehicle shares in both the car and light truck markets. The LVChoice model projects no market penetration for CNG vehicles, while the AEO has some small penetration. However, the NEMS model includes estimates of fleet sales which are not included in the LVChoice projections.

The differences between the LVChoice and AEO 2010 results can be attributed to the simplifications described in Section 3.3. First, the LVChoice model has been run using inputs that reflect national averages. Meanwhile, NEMS runs regionally, which captures geographic differences in fuel prices. Second, LVChoice does not have access to all the variables used within NEMS, particularly in-use stock of new technologies which is used to calculate fuel availability. Finally, LVChoice uses fewer size classes and, more significantly, has fewer technologies. Because of the aggregation of size classes, the attributes modeled in LVChoice are not exactly the same as those modeled in NEMS. In addition, the modeled technologies do not compete against the full suite of options included in NEMS. This impact of this last simplification could be partially quantified by running NEMS with only those technologies modeled in LVChoice. While this test is beyond the scope of this task, it would be worthwhile to pursue in the future.

Table 6-2: Light Vehicle Market Shares, AEO 2010 versus LVChoice

AEO 2010	2015	2025	2035
Gasoline ICE	**74.2%**	**66.9%**	**63.8%**
TDI	1.0%	3.3%	4.4%
PHEV10	0.5%	1.3%	2.2%
PHEV40	0.1%	0.3%	0.5%
ETOH flex	19.6%	20.8%	20.1%
CNG (Ded. & Bifuel)	0.1%	0.1%	0.1%
Electric	0.0%	0.0%	0.0%
HEV (Gas & Diesel)	4.5%	7.2%	9.0%
H2 FCV	0.0%	0.0%	0.0%
TOTAL	**100.0%**	**100.0%**	**100.0%**

LVChoice	2015	2025	2035
Conventional	**77.4%**	**64.5%**	**58.5%**
TDI	0.4%	2.6%	5.2%
PHEV10	0.3%	3.1%	5.4%
PHEV40	0.0%	0.4%	0.8%
ETOH flex	17.0%	21.0%	20.0%
CNG	0.0%	0.0%	0.0%
Electric	0.0%	0.0%	0.0%
Gasoline HEV	5.0%	8.4%	10.1%
H2 FCV	0.0%	0.0%	0.0%
TOTAL	**100.0%**	**100.0%**	**100.0%**

Table 6-3: Car Market Shares, AEO 2010 versus LVChoice

AEO 2010	2015	2025	2035
Gasoline ICE	**76.2%**	**71.6%**	**67.3%**
TDI	0.4%	2.7%	4.3%
PHEV10	0.4%	1.6%	2.6%
PHEV40	0.2%	0.5%	0.7%
ETOH flex	16.8%	15.0%	15.1%
CNG (Ded. & Bifuel)	0.1%	0.1%	0.1%
Electric	0.0%	0.0%	0.0%
HEV (Gas & Diesel)	5.8%	8.5%	9.9%
H2 FCV	0.0%	0.1%	0.1%
TOTAL	**100.0%**	**100.0%**	**100.0%**

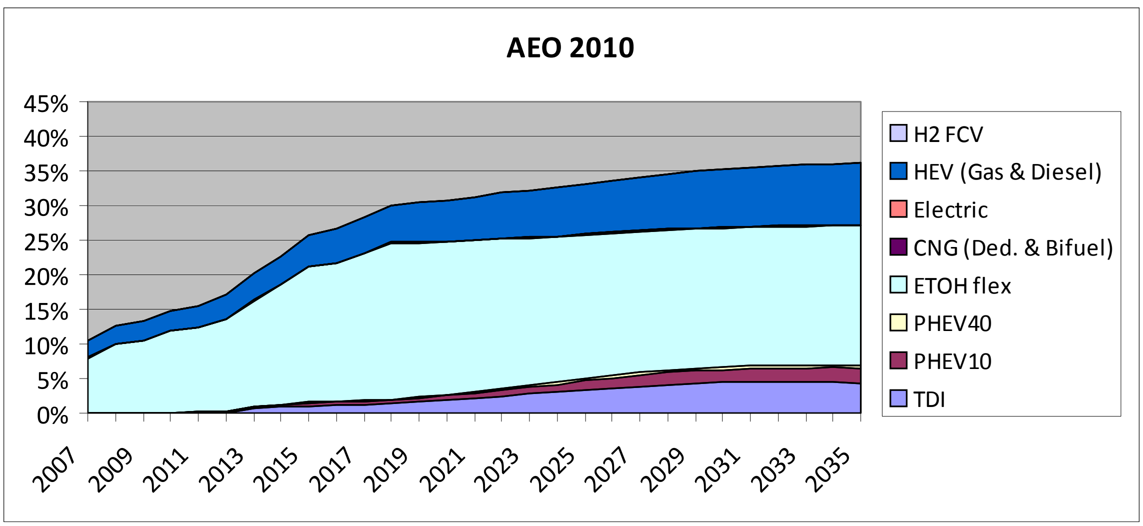
LVChoice	2015	2025	2035
Conventional	**78.4%**	**65.9%**	**59.4%**
TDI	0.6%	3.6%	6.3%
PHEV10	0.2%	3.9%	6.5%
PHEV40	0.0%	0.7%	1.2%
ETOH flex	14.4%	16.4%	15.9%
CNG	0.0%	0.0%	0.0%
Electric	0.0%	0.0%	0.0%
Gasoline HEV	6.5%	9.5%	10.7%
H2 FCV	0.0%	0.0%	0.0%
TOTAL	**100.0%**	**100.0%**	**100.0%**

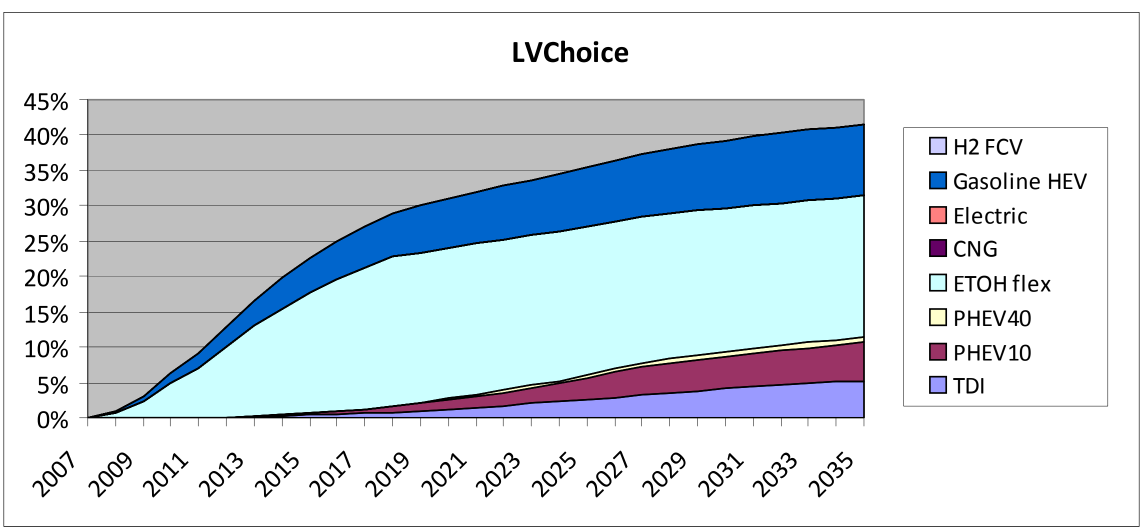
Table 6-4: Light Truck Market Shares, AEO 2010 versus LVChoice

AEO 2010	2015	2025	2035
Gasoline ICE	**71.6%**	**58.7%**	**57.0%**
TDI	1.8%	4.5%	4.5%
PHEV10	0.5%	0.8%	1.2%
PHEV40	0.0%	0.0%	0.0%
ETOH flex	23.1%	30.9%	30.0%
CNG (Ded. & Bifuel)	0.1%	0.1%	0.1%
Electric	0.0%	0.0%	0.0%
HEV (Gas & Diesel)	2.9%	5.0%	7.1%
H2 FCV	0.0%	0.0%	0.0%
TOTAL	**100.0%**	**100.0%**	**100.0%**

LVChoice	2015	2025	2035
Conventional	**76.1%**	**62.1%**	**56.6%**
TDI	0.1%	0.7%	3.0%
PHEV10	0.5%	1.7%	3.2%
PHEV40	0.0%	0.0%	0.0%
ETOH flex	20.2%	29.0%	28.0%
CNG	0.0%	0.0%	0.0%
Electric	0.0%	0.0%	0.0%
Gasoline HEV	3.1%	6.5%	9.1%
H2 FCV	0.0%	0.0%	0.0%
TOTAL	**100.0%**	**100.0%**	**100.0%**

Figure 6-1: Light Vehicle Market Shares, AEO 2010 versus LVChoice





7.0 Summary

The LVChoice is a relatively simple spreadsheet model with a DOE legacy. Its development was based on the VCM model used by DOE in the late 1990s and early 2000s. In contrast to the VCM, the LVChoice model structure, algorithms, and equation coefficients are consistent with the NEMS vehicle choice model as used in AEO 2010. The model was developed for use by the NPC in the Future Transportation Fuels study and, compared to NEMS, includes a number of simplifications for quick analysis. It has fewer vehicle size classes and fewer alternative technologies; it runs for a single geographic region; it is not integrated with an economic model, manufacturers' choice model, or other economic sectors; it contains no internal feedbacks but relies totally on exogenous inputs. However, the LVChoice model provides results that are generally consistent with the NEMS vehicle choice model when AEO 2010 vehicle attributes are used as inputs. Since the LVChoice model is not integrated with other submodules or economic sectors, inputs that depart significantly from the AEO 2010 reference case should be constructed to be internally consistent.

Although constructed with the NPC FTF study in mind, the LVChoice model was developed using internal funds. It therefore remains the intellectual property of TA Engineering, Inc.

References

EIA (2010a) *Transportation Sector Module of the National Energy Modeling System: Model Documentation 2010*, DOE/EIA-M070, Office of Integrated Analysis and Forecasting, Energy Information Administration, U.S. Department of Energy, Washington, DC, June.

EIA (2010b) PC-compatible NEMS Archive for AEO 2010, aeo2010r.zip. Downloaded using a link on the EIA website (www.eia.doe.gov) on November 2, 2010. This link is no longer available. At the time of this publication, the EIA contact for information on the NEMS archive is Paul Kondis, 202-586-1469.

Greene, DL and SM Chin (2000) *Alternative Fuels and Vehicles (AFV) Model Changes*, Center for Transportation Analysis, Oak Ridge National Laboratory, Oak Ridge, TN, November.

Appendix: Calibration Coefficients

Static Calibration Coefficients

Technology	LVChoice Vehicle Size Class Small Car	Large Car	Pickups	Small SUV	Large SUV
Gasoline	0.0	0.0	0.0	0.0	0.0
Turbo DI Diesel	-3.5	-3.5	-0.6	-0.6	-0.6
Flex-Fuel Ethanol	-1.0	-1.0	-0.5	-0.5	-0.5
Dedicated Ethanol	-4.0	-4.0	-4.0	-4.0	-4.0
PHEV10	-2.5	-2.5	-2.5	-2.5	-2.5
PHEV40	-0.75	-0.75	-0.75	-0.75	-0.75
Dedicated Electric	-5.0	-5.0	-5.0	-5.0	-5.0
Diesel/Electric Hybrid	-3.65	-3.65	-4.85	-4.85	-4.85
CNG Bi-Fuel	-2.0	-2.0	-2.0	-2.0	-2.0
LPG Bi-Fuel	-5.0	-5.0	-5.0	-5.0	-5.0
Dedicated CNG	-4.5	-4.5	-4.5	-4.5	-4.5
Dedicated LPG	-4.0	-4.0	-2.5	-2.5	-2.5
Methanol Fuel Cell	0.08491	0.08491	0.28487	0.28487	0.28487
Hydrogen Fuel Cell	0.0573	0.0573	0.33103	0.33103	0.33103
Gasoline Fuel Cell	0.35955	0.35955	0.70237	0.70237	0.70237
Gasoline/Electric Hybrid	-3.65	-3.65	-4.85	-4.85	-4.85

Source: AEO 2010 NEMS transportation module input file tranldv.xml

Annual Calibration Coefficients

Technology	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Cars															
Conventional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TDI	-2.100	-1.670	-1.670	-1.670	-1.670	-1.470	-1.278	-1.094	-0.918	-0.750	-0.590	-0.438	-0.294	-0.158	-0.030
PHEV10	-2.50	-2.50	-2.50	-1.50	-1.40	-1.30	-1.20	-1.10	-2.10	-1.90	-1.70	-1.50	-1.30	-1.20	-1.13
PHEV40	-0.75	-0.75	-0.75	3.00	1.20	1.40	1.60	1.80	1.75	1.80	2.30	2.45	3.00	3.20	3.05
ETOH flex	-0.980	-0.280	-0.280	-0.200	-0.140	-0.100	-0.018	-0.016	-0.014	-0.012	-0.010	-0.008	-0.006	-0.004	-0.002
CNG	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5
Electric	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0
Gasoline HEV	-3.090	-2.970	-2.900	-2.900	-2.900	-2.850	-2.802	-2.756	-2.712	-2.670	-2.630	-2.592	-2.556	-2.522	-2.490
H2 FCV	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573
Trucks															
Conventional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TDI	-2.50	-2.41	-2.41	-2.41	-2.41	-2.26	-2.11	-1.96	-1.81	-1.66	-1.51	-1.36	-1.21	-1.06	-0.91
PHEV10	-2.50	-2.50	-2.50	-2.20	-2.15	-2.10	-2.05	-2.00	-1.95	-2.10	-2.03	-1.96	-1.75	-1.70	-1.65
PHEV40	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75
ETOH flex	0.04	0.15	0.15	0.15	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.75	0.75	0.75
CNG	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5
Electric	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0
Gasoline HEV	-4.250	-5.680	-5.120	-5.120	-5.120	-5.020	-4.922	-4.826	-4.732	-4.640	-4.550	-4.462	-4.376	-4.292	-4.210
H2 FCV	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103

Technology	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035-2050
Cars														
Conventional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TDI	0.090	0.202	0.306	0.402	0.490	0.570	0.642	0.706	0.762	0.810	0.850	0.882	0.906	0.922
PHEV10	-1.06	-0.99	-0.92	-0.90	-0.86	-0.82	-0.78	-0.74	-0.70	-0.66	-0.62	-0.58	-0.54	-0.50
PHEV40	3.05	2.90	2.85	2.80	2.55	2.40	2.45	2.52	2.60	2.61	2.62	2.63	2.64	2.65
ETOH flex	0.000	0.002	0.004	0.006	0.008	0.010	0.012	0.014	0.016	0.018	0.020	0.022	0.024	0.026
CNG	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5
Electric	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0
Gasoline HEV	-2.460	-2.432	-2.406	-2.382	-2.360	-2.340	-2.322	-2.306	-2.292	-2.280	-2.270	-2.262	-2.256	-2.252
H2 FCV	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573	0.0573
Trucks														
Conventional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TDI	-0.76	-0.61	-0.46	-0.31	-0.16	-0.01	0.14	0.29	0.44	0.59	0.74	0.89	1.04	1.19
PHEV10	-1.60	-1.55	-1.50	-1.40	-1.37	-1.34	-1.37	-1.32	-1.27	-1.22	-1.17	-1.12	-1.07	-1.02
PHEV40	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75	-0.75
ETOH flex	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
CNG	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5
Electric	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0
Gasoline HEV	-4.130	-4.052	-3.976	-3.902	-3.830	-3.760	-3.692	-3.626	-3.562	-3.500	-3.440	-3.382	-3.326	-3.272
H2 FCV	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103	0.33103

Source: AEO 2010 NEMS transportation module FORTRAN code, file tran.f, reference case.