TRUCK5.1: Heavy Vehicle Market Penetration Model Documentation

Prepared for:

NATIONAL PETROLEUM COUNCIL

July 2, 2012

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List of Acronyms

AEO	Annual Energy Outlook
ANL	Argonne National Laboratory
CEF	Cost Effectiveness Factor (TRUCK4.0 calculation)
DOE	U.S. Department of Energy
EIA	Energy Information Administration, U.S. DOE
FTF	Future Transportation Fuels study
GPRA	Government Performance and Results Act
MAF	Market Acceleration Factor (TRUCK4.0 parameter)
NPC	National Petroleum Council
NPV	Net present value
PF	Preference Factor
TAE	TA Engineering, Inc.
VIUS	Vehicle Inventory and Use Survey
VTP	U.S. DOE Vehicle Technologies Program

1.0 Introduction

This report provides background on the TRUCK5.1 model, documents the model methodology, and provides instructions for using the model. The TRUCK5.1 heavy vehicle market penetration 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 fuel savings and vehicle cost. The model calculates market shares separately within three distinct markets based on size class and truck configuration. Calculations are made at annual time steps from the present through 2050. The model provides estimates of market share and does not estimate total sales nor does it track in-use stock. However, the TRUCK5.1 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 TRUCK5.1 model consists of two Microsoft Excel spreadsheets, each with multiple input, data, calculation, and output worksheets. The model structure and methodology is based on the TRUCK4.0 model used by the U.S. Department of Energy's Vehicle Technologies Program (VTP) and the TRUCK5.0 model currently in development for VTP. Version 5.0 includes a number of structural changes and some simplifications in methodology compared to version 4.0 (see TAE, 2010). Due to the requirements of the FTF, TRUCK5.1 differs from 5.0 in market segmentation. Since the TRUCK5.0 modifications have not been documented previously, they are fully described here along with the differences between versions 5.0 and 5.1.

1.1 Model History

Under sub-contract to ANL, TAE developed the TRUCK market penetration model for the U.S. Department of Energy's Vehicle Technologies Program. Among other applications, VTP uses the model for annual analysis of program benefits as described in Section 1.2.[1] Versions of TRUCK have been in use by VTP since 1997 and have been subject to both internal and external review. In 2006, TRUCK3.0 methodology and sample results were presented to the 21st Century Truck Validation Working Group, which included both government and industry members.

The TRUCK model has been frequently modified to reflect changes in program focus, update market data, and otherwise improve the model function and reporting. Enhancements incorporated in TRUCK5.0 that were of interest to the NPC were:

- Ability to analyze four technologies simultaneously – one baseline vehicle and up to three alternatives, and
- Flexibility of fuel used for all of the alternatives.

In addition to these enhancements, the NPC required that the model be capable of competing gasoline and diesel engine platforms in a single market. In TRUCK4.0, the baseline vehicle in

[1] For a more detailed description of the TRUCK model's use by VTP, see *TRUCK 4.0 Heavy Truck Market Penetration Model Description* (TAE, 2010).

weight classes 7 and 8 was required to be diesel, while class 3-6 gasoline and diesel trucks were analyzed as separate market segments. Therefore, additional algorithms were developed specifically to allow competition of both gasoline and diesel. These algorithms are included in both 5.0 and 5.1. Version 5.1 also combines the underlying market data for gasoline and diesel class 3-6 trucks into a single fleet. Version 5.0 keeps these vehicles in separate markets.

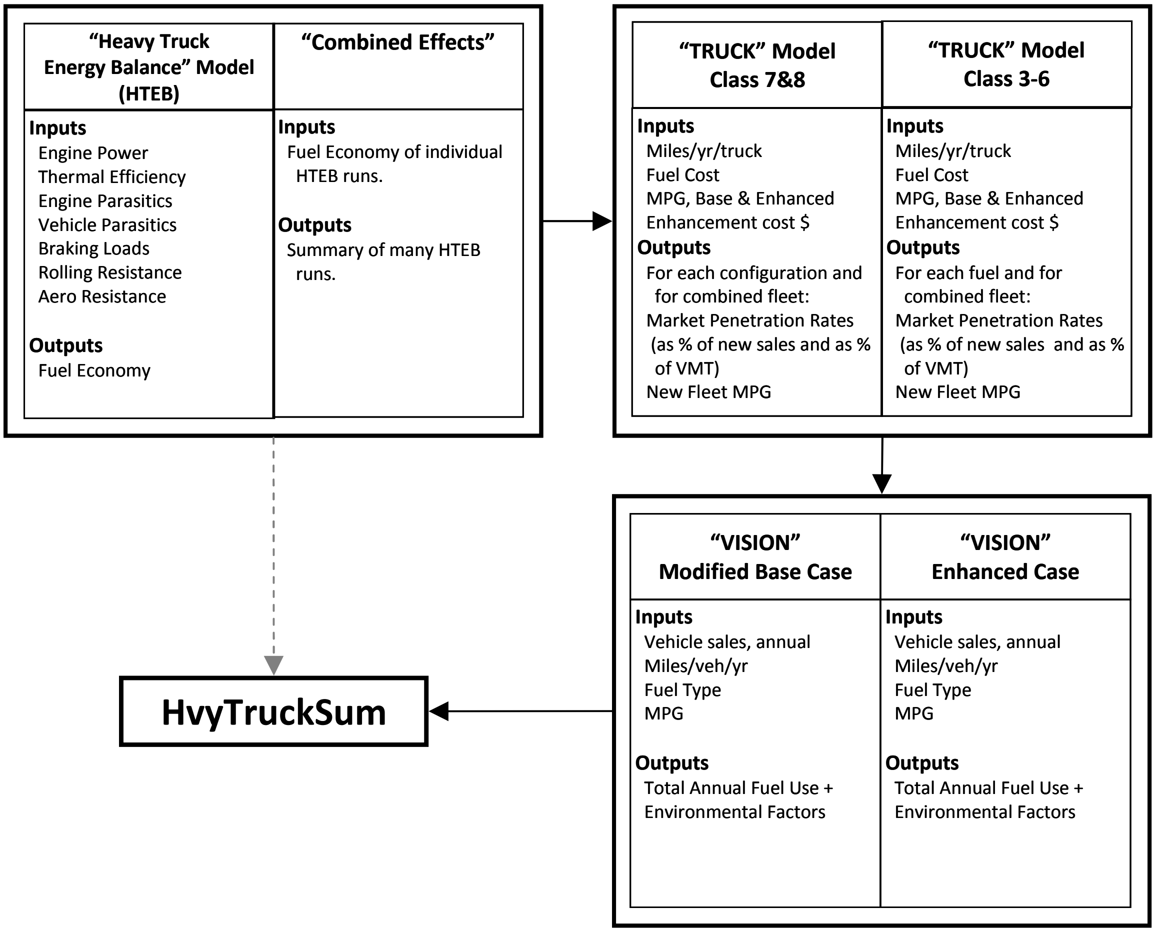
1.2 Analytical Context

The TRUCK model is one component of the Heavy Truck Energy Modeling System (HTEMS), as illustrated in Figure 1-1. HTEMS was developed for the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), Vehicle Technologies Program. HTEMS consists of a set of linked Excel workbooks that are used to calculate the annual energy consumption of heavy trucks in weight classes 3 through 8 with projections from the current year up through the year 2050. The primary purpose of the modeling system is to estimate energy, environmental, and economic benefits of VTP heavy vehicle program elements using a market based approach. This analysis is performed annually in support of Government Performance and Results Act (GPRA) reporting requirements. HTEMS and its individual components also have been used to analyze the impact of various policy and technology scenarios.

Figure 1-1 shows the relationship of the four principle elements of HTEMS. The Heavy Truck Energy Balance (HTEB) model estimates the effect on fuel economy of changing the engine efficiency or the various loads and losses within the engine/vehicle system. Based on these changes in fuel economy, estimates of associated technology costs, and future fuel price assumptions, the TRUCK model estimates the market potential of these technology changes and calculates the fuel economy of the new truck fleet. The VISION model then uses sales projections and historical scrappage rates to project the future stock of heavy vehicles, the fuel economy of the in-use fleet, and total consumption of traditional and alternative transportation fuels.[2] The Heavy Truck Summary workbook compares the baseline and program VISION runs, calculates benefits, and provides summary reports and graphics of assumptions and results.

[2] The VISION model is maintained by Argonne National Laboratory. For further information or to download the VISION model, see http://www.transportation.anl.gov/modeling_simulation/VISION/.

Figure 1-1: Heavy Truck Energy Modeling System



1.3 Market Segmentation

As shown in Figure 1-1, the truck market is divided into two distinct segments based on gross vehicle weight rating (GVWR), class 7&8 and class 3 – 6, each of which is handled in a separate Excel workbook.[3] In version 4.0 and earlier, each segment is further subdivided within each model according to configuration or fuel type as follows:[4]

- Class 7&8 - heavy duty trucks, GVWR 26,001 lbs and larger
  - Combination Units - separate tractor and trailer or chassis,
  - Single Units - driver/engine compartment and trailer on a single chassis, and
  - Hybrid drive-train – placeholder; not implemented.

[3] This segmentation is adopted from the U.S. Federal Highway Administration's vehicle classification system and from the U.S. Census Bureau's 2002 Vehicle Inventory and Use Survey (U.S. DOC, 2004).

[4] Both of the TRUCK4.0 workbooks contain a placeholder market sub-segment intended for hybrid trucks. The assumption was that this class of trucks would have a drive cycle and population distribution by annual VMT that differs from the other sub-segments within the weight class. This feature was never fully implemented.

- Class 3-6 - medium duty trucks, GVWR 10,001 – 26,000 lbs.
  - Diesel fueled (compression ignition engine) vehicles,
  - Gasoline-fueled (spark ignition engine) vehicles, and
  - Hybrid drive-train – placeholder; not implemented.

Each of the sub-segments is characterized by typical operating weight, drive cycle, and population distribution by annual mileage. The baseline class 7&8 truck market is assumed to be diesel fueled and is segmented only according to truck configuration. Alternative technologies may use other fuels. Class 3-6 trucks are all assumed to be single units with both driver/engine compartment and trailer on a single chassis. Trucks in this class are segmented only according to fuel used - gasoline or diesel. Alternatives in both sub-segments may use other fuels. In version 5.1, class 3-6 is not sub-divided according to fuel and is treated as a single market segment.

In both weight classes and all market sub-segments, the underlying market data is further divided into centrally refueled fleets and non-centrally re-fueled trucks. The model calculates market penetrations separately for trucks with each of these re-fueling options. This allows the user to construct inputs that differ for the two refueling options, run them separately, and combine the results in a single file.

1.4 Summary of Changes Relative to TRUCK 4.0

Version 5.0 of the TRUCK model incorporates a number of structural and methodological changes relative to version 4.0. These changes simplify the implementation of the algorithms and streamline the model operation but do not alter the underlying approach or algorithms. However, a number of new algorithms and parameters were required to implement these changes. Also, several new features were added to the model to account for aspects of consumer decision-making that were not previously included. For most of the new functions, the user can specify inputs that remove the impact of the new feature and approximate the behavior of TRUCK4.0. Results and their presentation are similar to version 4.0 and the model remains generally compatible with the VISION model, with the caveats discussed below.

1.4.1 Model Structure

As with version 4.0, versions 5.0 and 5.1 consist of one workbook for each weight class. In Version 5.0, class 7&8 trucks are divided into sub-markets according to configuration and class 3-6 trucks are divided into sub-markets according to baseline truck fuel (gasoline or diesel) as before. In version 5.1, class 3-6 trucks are not sub-divided but are treated as a single market.

Each workbook contains separate input and calculation worksheets for each market sub-segment. The placeholder worksheets for hybrid trucks have been omitted. All truck sub-segments within a weight class are processed in one workbook and the model is exercised from a single 'Run Model' worksheet.

As in version 4.0, macro buttons are provided to run the entire model or run it individually for each sub-segment. Version 5.0 retains the ability to also run it individually for centrally re-fueled or non-centrally refueled trucks within each market sub-segment. This last option was not necessary in 5.1 and therefore was not implemented. Both versions 5.0 and 5.1 have an additional macro button that dynamically generates a cost lookup table. If the costs have not changed since the previous run, the user may choose to update only the market penetration calculations for one or more sub-segments.

Due to changes in calculation methodology, versions 5.0 and 5.1 contain some additional worksheets that are described in Section 4.2.

1.4.2 Alternative Technology Analysis Capabilities

Within each market segment, defined by weight class and configuration, TRUCK4.0 was capable of analyzing two alternative vehicles, A and B, relative to a baseline truck. Version 5.0 expands the analysis to include one additional alternative in each market segment. Incorporating one additional technology required development of a new algorithm to combine the market shares for each individual technology in competition with the baseline into market shares for all four technologies (baseline, A, B, and C) in full competition.

Due to its evolution based on VTP heavy vehicle program focus and the need for compatibility with VISION, TRUCK4.0 had fairly restrictive requirements regarding the technologies to be analyzed. Class 7&8 baseline trucks in both market sub-segments were required to be diesel. Of the two alternative technologies, A also was required to be diesel-fueled and could not be a hybrid diesel-electric drive-train. Technology B could be of any fuel and could be hybrid. The class 3-6 trucks were segmented into two markets, one with a baseline gasoline-fueled truck and the other with a baseline diesel-fueled truck. In both sub-markets, technology A was required to be of the same fuel-type as the baseline and could not be a hybrid drive-train. Technology B could be of any fuel type and could be a hybrid.

TRUCK5.0 relaxes these requirements by allowing any fuel type to be used for the baseline and alternative technologies. If desired, both conventional gasoline and conventional diesel technologies may be included within a single market sub-segment. The only requirement is that the baseline vehicle must have the lowest purchase price.

While the model can accommodate inputs for any type of fuel, the market data used by the model reflects historical population distributions by fuel type. For both size classes, the user should take care to construct inputs that, for the historical years included in the model, yield results that approximate historical data. According to 2002 data, 90% of class 7&8 single unit trucks and nearly all (99.8%) of combination unit trucks sub-segments were diesel fueled (USDOC, 2004). Model calculations for 2007-2010 therefore should result in similar market shares for conventional diesel fueled trucks.

In version 5.0, class 3-6 trucks are still segmented into a gasoline and a diesel market in terms of the underlying data. In version 5.1, these trucks are combined into a single market segment with a population distribution that reflects all trucks in this class. Market data shows that, as of 2002, 84% of class 3-6 trucks were diesel-fueled and the remaining 16% were gasoline-fueled (USDOC, 2004). Since 2002, the distribution has likely shifted toward more gasoline vehicles due to the added expense of diesel emission control technologies. However, model calculations for 2007-2011 should not result in a diesel market share lower than 50% of the total class 3-6 sales fleet.

The added flexibility in the fuel type for alternative technologies adds some complication to the model's compatibility with VISION. VISION tracks specific vehicle/fuel-type fleets separately and does not have the ability to handle all possible vehicle types analyzed in TRUCK5.0 and 5.1. Therefore, users may be required to perform additional analysis to incorporate their results into VISION if the fuel types modeled do not align to the fleets tracked, which for VISION 2011 included the following:

- Class 3-6
  - Gasoline,
  - Diesel,
  - Natural Gas, and
  - Diesel-Electric Hybrid.
- Class 7&8
  - Single Unit Conventional, mix of gasoline and diesel,
  - Single Unit Natural Gas,
  - Single Unit Diesel-Electric Hybrid,
  - Combination Unit Diesel, and
  - Combination Unit LNG.

1.4.3 Buyer Preference for Payback Period

The TRUCK model methodology is based on truck buyers' preferences for payback periods as reported in a 1997 survey of 224 motor carriers performed by the American Trucking Associations (ATA, 1997). In prior versions, the model applied the results as published with one-year increments in payback periods. Since the coarse resolution could result in large differences in adoption rates between mileage cohorts, the prior algorithms were developed to smooth out the behavior of the model. Based on feedback from industry experts, the algorithms were also structured to slow market penetration rates relative to the survey data to be more representative of observed market behavior. The user had the flexibility to select the magnitude of this adjustment.

Versions 5.0 and 5.1 incorporate a new implementation of the ATA survey data. The payback period preferences are applied in a smoothed curve of payback periods at one-month increments. The model allows the user to select from one of three different adoption rate curves. The most optimistic curve most closely fits the survey data while the remaining two curves represent increasing levels of risk aversion. The new methodology is analytically simpler, computationally less demanding, and more transparent to the user.

1.4.4 Payback Algorithm Adjustments

In prior versions of the TRUCK model, the scope of economic benefit was limited to fuel cost savings associated with improvements in fuel economy or switching to a different fuel. Other benefits and costs, such as differences in engine life, repair and maintenance costs, vehicle resale value, and non-cost attributes were not considered within the structure of the model. The model was technology neutral and assumed all technologies had equal market potential. In addition, the magnitude of the technology cost did not influence market adoption rates as long as the fuel cost savings paid back in four years or less.

In contrast, versions 5.0 and 5.1 can, at the user's discretion, consider the following additional issues:

- Differences in routine maintenance and anticipated repair costs,
- Assumed buyer preferences for or against a technology, and
- Decreasing market acceptance with increasing technology cost.

The user specifies maintenance and repair costs as a function of accumulated miles and the model calculates a monthly repair budget based on annual mileage. The user may choose to account for differences in engine life by including anticipated engine rebuild or replacement costs for each technology. Any repair cost savings relative to the baseline vehicle are added to the monthly fuel cost savings while additional repair costs are subtracted from the savings. The user may remove the impact of this function by entering values of $0 for the maintenance and repair costs or entering identical values for the baseline truck and all alternatives.

Biases for or against a technology are considered using a new function called the preference factor (PF). The PF can be used to account for non-cost vehicle attributes (e.g. engine torque), inherent technology limitations, fuel infrastructure limitations, lack of information or experience, and risk averse behavior. The PF is used in several of the algorithms in versions 5.0 and 5.1. The user can remove the impact of the PF by specifying inputs that are technology neutral as described in Section 3.2.

Finally, a sigmoid curve is used to reduce the calculated technology adoption rate as the purchase cost increases. When the cost of the alternative technology reaches twice the cost of the baseline vehicle, the adjusted adoption rate is only 6.2% of the value determined by the payback algorithm. In version 5.1, the impact of this feature cannot be removed by the user.

1.4.5 Indifference Algorithm

The payback period methodology results in market penetration of alternatives when they confer economic benefits compared to a baseline truck. However, this approach is unable to explain market sharing of technologies with similar purchase and fuel costs. In particular, it is unable to account for the fact that the class 3-6 truck market is shared by gasoline and diesel engines. Because the NPC was interested specifically in competing conventional gasoline and diesel trucks in a single class 3-6 market, a new algorithm was developed. The "indifference algorithm" applies when the difference in purchase and fuel costs between an alternative and the baseline are within user-specified tolerances. When costs are within these tolerances, the preference factor is used to determine market shares.

The ranges of cost differences specified by the user are phased in using sigmoid curves to avoid discontinuous model behavior. Therefore, the indifference algorithm overlaps with the payback algorithm when a technology conveys small fuel cost savings relative to the baseline truck. In this case, the model returns an adoption rate equal to the maximum value from the two algorithms.

1.5 Document Contents

The remainder of this document provides a detailed description of the TRUCK5.1 model. Section 2.0 provides an overview of the model, including its purpose, a summary of the approach, and brief description of the user interface. Section 3.0 provides details on the methodology used, including model algorithms. Section 4.0 provides a description of the model structure including a list of model inputs and outputs and instructions for running the model. Section 5.0 documents the model benchmarking against version 4.0.

2.0 Model Overview

This section explains the TRUCK5.1 model purpose, describes the model structure and methodological approach, and provides an overview of the user interface.

2.1 Purpose

The TRUCK version 5.1 Heavy Vehicle Market Penetration Model estimates annual market penetration rates of proposed energy-saving technologies. The market penetration rates of such enhancements increases with their relative economic benefit and decreases with their relative economic cost. These projections can be used to estimate future energy savings that are grounded in actual market data and based on decision-making rules commonly used by businesses. This market-based approach avoids the need to make assumptions about market success that may be difficult to defend.

TRUCK5.0 was developed for DOE's Vehicle Technology Program but with the needs of the NPC's Future Transportation Fuel Study in mind. Version 5.1 was developed specifically for the FTF. These needs include:

- The ability to analyze four technologies simultaneously,
- Flexibility in specifying the fuel used for all of the alternatives, and
- The ability to compete conventional gasoline and diesel engine platforms in a single market.

2.2 Approach

Within the TRUCK model, the scope of economic benefits covers the expected fuel cost savings derived from improvements in fuel economy or from switching to a new fuel or fuel additive. In addition, differences in expected maintenance costs are considered. At the user's discretion, these costs may include engine rebuild or replacement in order to account for differences in engine life. Vehicle resale value is not considered within the structure of the model. However, it is possible to manually account for this and other effects within the inputs.

TRUCK includes two separate workbooks: one for weight class 3-6 trucks and one for class 7 and 8 trucks. In version 5.0 and prior models, the class 3-6 trucks are subdivided into those with the baseline using gasoline and those using diesel. In general, trucks in the class 3-6 diesel market travel more miles annually than those in the gasoline market. In version 5.1, this class is not subdivided. Class 7&8 trucks are subdivided into two segments - combination unit tractor trailers and single unit trucks. The segmentation of the weight classes allows for differences in operating weight, drive cycle (urban, mixed, and highway), and usage (annual mileage) between the sub-segments. Since fuel cost savings depend on usage, each of the vehicle sub-segments is analyzed by further disaggregating it into mileage cohorts from 0 to 200,000+ annual miles of vehicle travel in 20,000 mile increments. Historical market data on the percentage of new vehicles in each sub-segment and cohort are used in this analysis.

The analysis proceeds according to the following methodology which is described briefly here and in detail is Section 3.0:

1. Generate payback lookup table.
2. For each market sub-segment and cohort, determine the individual market share of each alternative (A, B, or C) in competition with the baseline vehicle:
   a. Determine adoption rate based on payback period of fuel and maintenance cost savings.
   b. Adjust adoption rate based on buyer preferences and magnitude of incremental cost.
   c. For alternatives with costs similar to the baseline truck, determine adoption rate based on "indifference" algorithm.
   d. Calculate individual market share as maximum of two adoption algorithms above.
3. Calculate sub-segment and cohort market shares for technologies in full competition (baseline, A, B, and C).
4. Use market data to calculate market shares for:
   a. Fueling option within sub-segment,
   b. Sub-segment, and
   c. Weight class.
5. Calculate fleet fuel economies

For each market sub-segment, model inputs include the fuel economy and retail price of a baseline vehicle and up to three alternatives. The baseline vehicle must be the least expensive option so that each alternative has a zero or positive additional purchase cost (the incremental cost). For a proposed alternative within a weight class, sub-segment, and mileage cohort, TRUCK calculates monthly fuel cost savings relative to the baseline truck using the fuel economy of the alternative vehicle, the fuel economy of the baseline vehicle, annual miles of travel, and a fuel price projection. With the exception of annual mileage, all of these factors are permitted to change over time and the model projects market penetrations from 2007 through 2050. Monthly fuel cost savings plus any savings in (or less any additional) monthly budgeted maintenance costs are compared to the incremental purchase cost to determine the alternative technology payback period. The payback calculation applies a user-specified discount rate to the future stream of savings and maintenance costs.

The payback period, in months, is compared to the adoption rate curve to determine the percentage of buyers that would be willing to purchase the alternative technology instead of the baseline vehicle. An additional calculation is made for alternatives that are similar to the baseline truck in terms of purchase cost and monthly fuel costs. If these costs are within user-specified tolerances compared to the baseline vehicle, an "indifference" curve is used to calculate the adoption rate for the alternative. The "final" individual technology adoption rate is the maximum of either the payback adoption rate or the indifference adoption rate.

Once the adoption rate has been calculated for each of the three alternatives relative to the baseline vehicle, TRUCK applies user-specified preferences for each technology to calculate the market shares for all four possible truck options (baseline, A, B, and C). This calculation results in market shares within a mileage cohort, market sub-segment, and weight class. Data on new truck population distributions are used to scale these market shares up at each level, finally yielding market shares within the weight class. The market shares as a percentage of new vehicle miles then are used to calculate new vehicle fleet fuel economies

2.3 User Interface

As noted above, the TRUCK5.1 model consists of two workbooks: one for class 7&8 and one for classes 3-6. The normal user interface with the model occurs in both models on the 'Inputs' and 'Run Model' worksheets. Input cells are indicated by yellow shading. Within each workbook there is one 'Inputs' worksheet for each market sub-segment. This section briefly describes the inputs. For more detail, see Section 4.2.

On the 'Inputs' worksheets, the user provides details on the technologies modeled. The top of the worksheet contains data used throughout the analysis, including technology descriptions, fuel type, preference factors, and maintenance costs. The remainder of the worksheet contains time dependent assumptions about technology costs and fuel economy. For the class 7&8 workbook, there are two input worksheets that represent market sub-segments according to truck configuration:

(1) 'Inputs 7&8 Comb' – combination trucks, commonly known as tractor trailers, and

(2) 'Inputs 7&8 SU' – single unit trucks, including box and vocational trucks.

For the class 3-6 workbook, all trucks are single unit or box-type trucks and the market is not further subdivided in TRUCK5.1. There is one input worksheet:

(1) 'Inputs 3-6' – All class 3-6 trucks.

On the 'Run Model' worksheet, the user specifies a descriptive title and specifies a discount rate to apply to the stream of future fuel cost savings and any additional maintenance costs or savings. The user also selects the market adoption rate curve to use for the payback algorithm.

After all inputs are specified, the calculations detailed in Sections 3.3 and 3.4 must be run iteratively for each market sub-segment, each of two refueling strategies, and each mileage cohort. This is automated by clicking on the "Run All" button on the 'Run Model' worksheet. If changes have been made to only one sub-segment with no changes in incremental costs, the user may update the results for the sub-segment individually by clicking on the macro button for that sub-segment.

Note: Due to the nature of the macros used to run the model, the user should not rearrange data or add or delete rows or columns anywhere in the model. The user also should not edit or delete named ranges.

3.0 Methodology

Section 2.2 provided a brief overview of the model approach and program flow. This section provides a detailed description of the methodology and algorithms.

3.1 Payback Data

TRUCK5.0 and 5.1 incorporate a simplified application of the payback calculation and adoption rate methodology used in earlier versions. In TRUCK 4.0 and earlier, the model calculates net present value (NPV) at annual increments up to four years for every technology, mileage cohort, refueling option, and market sub-segment. The NPV is then compared to the purchase cost to determine if the investment has broken even during the period. If so, the technology met the payback period requirement and the adoption rate could be determined. This process was somewhat time-consuming and generated a large quantity of data that was stored on the calculations and results worksheets.

Versions 5.0 and 5.1 approach the payback calculation from the opposite direction. For a specified discount rate and each user input on incremental purchase cost, the model calculates the associated monthly savings necessary to just break even at monthly intervals of one to 85 months. This data is used to populate a lookup table. For each technology, mileage cohort, refueling option, and market sub-segment, the model finds the projected monthly savings on the lookup table to determine the payback period in months. This approach results in quicker model calculations and allows application of a smoother (monthly) adoption rate curve.

To generate the payback lookup table, the user must first populate the 'Inputs' worksheets and specify a discount rate on the 'Run Model' worksheet. The user then must activate the model macros using either the 'Run All' or 'Generate Cost Table' button on the 'Run Model' worksheet. TRUCK generates an array of unique incremental cost data and copies it onto the 'Payback Lookup' worksheet.

Note: The data on the 'Payback Lookup' worksheet are used by the model as a lookup table. The user should not make changes on this worksheet and especially should not add or delete columns or rows.

3.2 Preference Factor

Version 5.0 introduces a new concept to the TRUCK model which is termed the Preference Factor (PF). The PF captures positive and negative non-cost truck attributes and user biases, such as engine torque, re-fueling infrastructure, and past experience. The PF is used in several of the model algorithms and features prominently in combining the market adoption rates of each technology in competition with the baseline into adoption rates for full competition among all technologies. The impact of the PF can be removed by specifying technology neutrality as explained below.

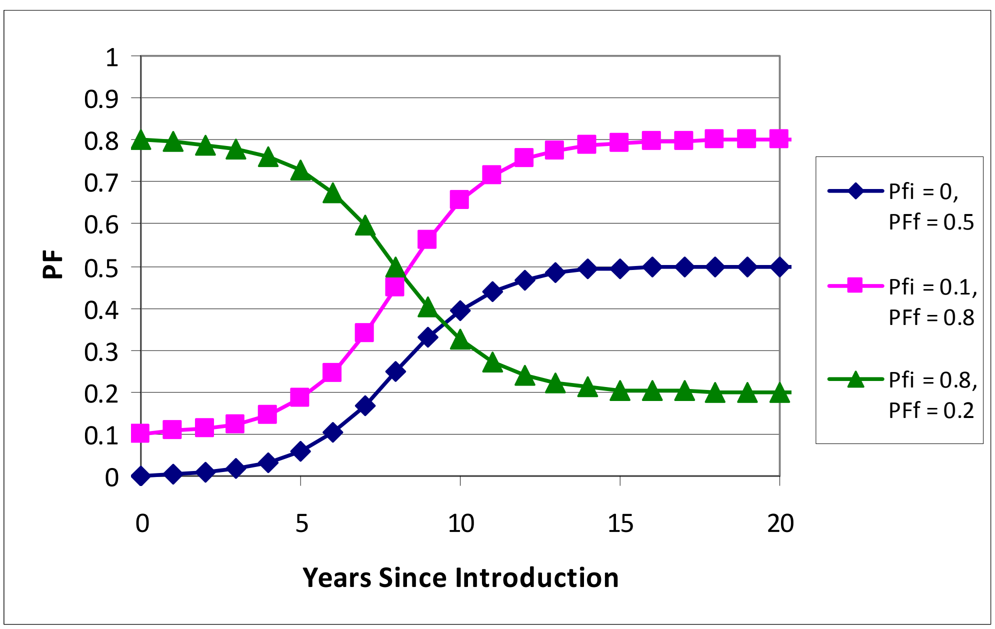
For each technology, the user specifies the initial year and initial value for the PF that is effective in that year. The user also specifies a final value for the PF and the model phases in the value from the initial to the final value using a sigmoid curve. The sigmoid curve is parameterized to reach saturation in about 16 years. If desired, the user can adjust this parameterization in cells B5:B6 on the 'S-Curves' worksheet.

The PF is a decimal value between zero and 1.0 that represents the fraction of the market that the technology option would achieve if its cost attributes (purchase price and fuel costs) were identical to the baseline. Therefore, a value of 0.5 is technology neutral – half of buyers would choose the alternative technology if it cost the same to buy and operate as the baseline vehicle. PF values higher that 0.5 are biased toward the technology and those less than 0.5 are biased against the technology.

Note: ***To simulate technology neutrality, enter PF = 0.5.***
To simulate bias against a technology, enter 0 < PF < 0.5.
To simulate bias toward a technology, enter 0.5 > PF < 1.

Figure 1-1 illustrates several sample preference factor curves with the user inputs for initial and final PF values indicated in the legend. The lowest curve (blue diamonds) illustrates a technology going from complete lockout to market neutrality: PF = 0→0.5. The middle curve (magenta squares) illustrates the situation of market bias against a technology evolving into market bias toward the technology: PF = 0.1→0.8. The last curve (green triangles) represents a possible input when competing diesel against gasoline and shows market bias toward a technology evolving into market bias against it: PF = 0.8→0.2.

Figure 3-1: Sample Preference Factors



Note that the actual market share may be smaller or larger than the preference factor. When a technology is close in cost to the baseline vehicle, the model will calculate a market share that is less than or equal to the PF. When a technology confers cost savings with a payback period less than four years, the calculated adoption rate will be less than or equal to twice the value of the PF, for a maximum of 1.0. For details on the relationship between the preference factor and market potential, see Sections 3.3.2 and 3.3.3.

Note: The maximum market share attainable by a technology is 2*PF (max of 1.0). When using the PF to model infrastructure limitations, the user should enter a PF of half the anticipated maximum potential market.

3.3 Individual Technology Adoption Rate

3.3.1 Payback Algorithm

The annual fuel and maintenance cost savings for each class, configuration or fuel type, and mileage cohort is calculated for each year of the analysis (present through Year 2050). Each savings value is compared to the projected vehicle purchase cost to determine its market penetration potential. TRUCK5.0 and 5.1 can investigate up to three simultaneous alternatives and compare the relative market penetrations of each.

The basic approach used by the TRUCK model is based on survey data from the American Trucking Associations (ATA). This survey of 224 motor carriers indicated the relative preferences of truck owners for energy-saving investments that have payback periods of one, two, three or four years. Each owner was asked what the "maximum" payback period would be for him or her to consider purchasing the technology. The survey results are shown in Table 3-1.

Table 3-1: ATA Survey Results: Truck Investment Payback Requirements

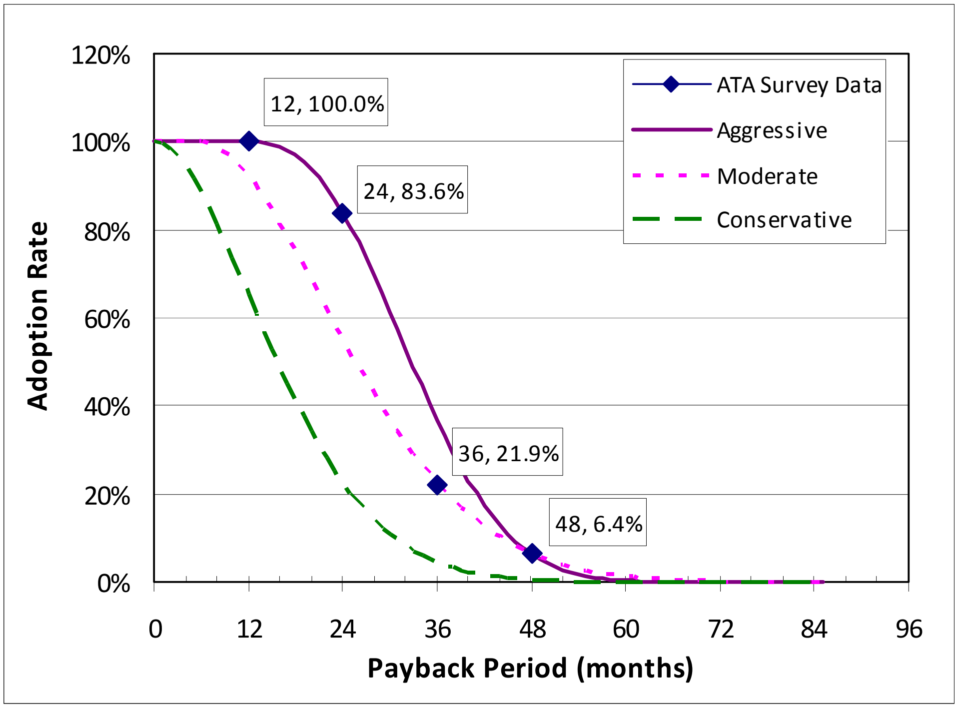
Maximum Acceptable Payback Period (years)	Percent of Respondents	Cumulative Percent
4	6.4%	6.4%
3	15.5%	21.9%
2	61.7%	83.6%
1	16.4%	100.0%

Only a few (6.4%) truck owners indicated they would purchase an enhancement for their truck if it took four or more years for the savings to equal the cost. If the payback period decreased to three years (either by being cheaper to install or by saving more fuel), the number of truck owners who indicated that they would purchase it increased to 21.9%. Only when the payback period dropped to two years did the total preference become large at 83.6%.

While the ATA survey provides a starting point to estimate buyers' behavior, actual outcomes in the marketplace often differ from the "stated preferences" expressed by survey respondents.

Several heavy vehicle experts expressed the opinion that the penetration rates indicated by the ATA survey are too high. Therefore, the model allows the user the option of selecting from one of the three adoption rate curves shown in Figure 3-2. The most optimistic curve, labeled "aggressive," most closely replicates the ATA survey data.

Figure 3-2: Payback Algorithm Adoption Decision



For a given market sub-segment, refueling option (central or non-central), and mileage cohort, the TRUCK model first calculates the monthly fuel cost savings of each technology. Any monthly maintenance cost savings are added to this value, while maintenance costs higher than the baseline truck are subtracted from the savings. This value is then compared to the payback lookup table to determine the payback period in months. The model then uses the adoption rate curve selected by the user to determine the market potential for the single technology in competition with the baseline truck.

This methodology replaces calculation of the cost effectiveness factor (CEF) and application of the market acceleration factor (MAF) used in version 4.0. In older versions of TRUCK, the use of coarse resolution payback periods of 1, 2, 3 or 4 years sometimes resulted in large differences in adoption rate between mileage cohorts. The CEF-based algorithms were structured to attenuate this behavior but were somewhat complex. The use of a monthly resolution on the adoption decision also attenuates this behavior. The MAF was applied to adjust market adoption rate relative to the stated preferences of the ATA survey data and is replaced in version 5.0 and 5.1 with the choice of one of three different adoption decision curves. The new methodology is analytically simpler, computationally less demanding, and more transparent to the user.

3.3.2 Payback Algorithm Adjustments

The ATA survey asked owners only about acceptable payback periods for an unspecified fuel saving technology. Therefore, the results of the survey and of the payback algorithm described above are neutral to technology and to the magnitude of initial technology cost. Actual market behavior reveals that owners may not adopt a technology because of non-cost truck attributes and user biases, such as engine performance, fuel availability, lack of knowledge or experience, or negative past experience. In addition, buyers may lack access to capital to invest in relatively expensive technologies with attractive payback periods and the potential for long-term economic gains. Finally, investment in a new technology carries real and perceived risks relating to uncertainty in fuel prices; unknown repair and maintenance costs; uncertain technology life; and the possibility for equipment damage or loss before costs are recovered.

Prior versions of the TRUCK model did not account for these issues, though the user could construct inputs that were consistent with assumptions about them. Versions 5.0 and 5.1 include adjustments to the payback algorithm that account for both buyer preferences and for declining interest in a technology as purchase cost increases.

The preference factor, described in Section 3.2, is applied to the payback algorithm to account for buyer biases. The adjusted adoption rate $AR_{pb1,j}$ for technology *j* is calculated as:

$$AR_{pb1,j} = \min\left(\frac{PF_j}{0.5} * AR_{pb,j}, 1.0\right)$$

Where:

PF_j = the preference factor for technology *j*
$AR_{pb,j}$ = the adoption rate for technology *j* from the payback algorithm

The value of 0.5 in the denominator represents the market preference for the baseline truck. In essence, this adjustment simply scales the calculated adoption rate by the user-specified preference for the alternative technology relative to the baseline. Entering a PF = 0.5 results in no adjustment to the adoption rate and therefore is technology neutral. PF values between 0.0 and 0.5 result in a downward adjustment and values between 0.5 and 1.0 result in an upward adjustment. If the payback algorithm returns an adoption rate of 100%, the adjusted market share is 2*PF or 100%, whichever is smaller. Therefore, for a PF less than 0.5, 2*PF represents the maximum market potential for a technology.

Note: The maximum market potential for a technology is 2*PF or 100%, whichever is smaller.

A second adjustment is made to the calculated adoption rate to taper off market penetration as a technology's purchase cost increases. As Figure 3-3 illustrates, the adoption rate is adjusted downward based on the magnitude of the incremental cost relative to the cost of the baseline truck. The adjusted rate, $AR_{pb2,j}$ for technology *j* is calculated as:

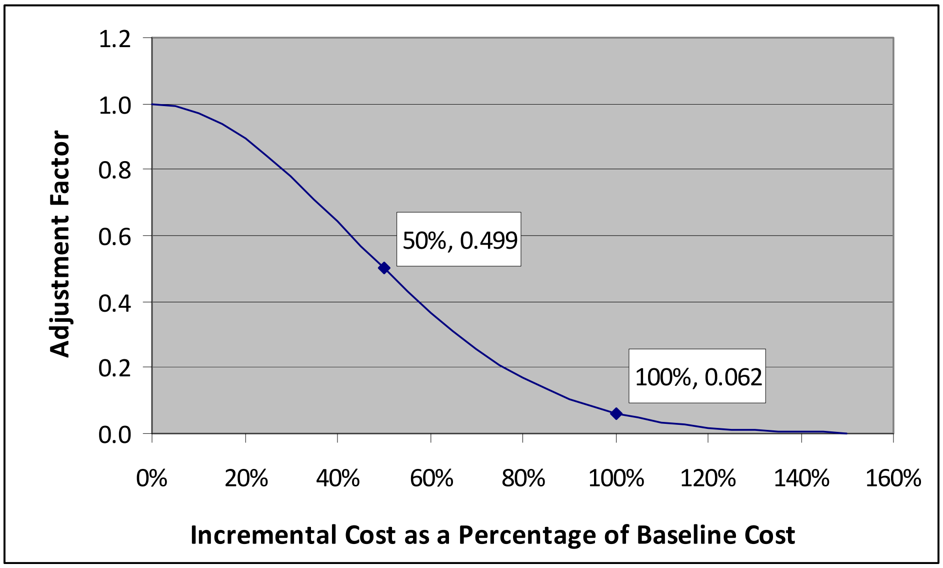
$$AR_{pb2,j} = k_{ic,j} * AR_{pb1,j}$$

Where:

$k_{ic,j}$ = incremental cost adjustment factor for technology *j*

$AR_{pb1,j}$ = adoption rate for technology *j* after adjustment for buyer preferences

Figure 3-3: Adoption Rate Adjustment for Magnitude of Incremental Cost



As shown in Figure 3-3, the adjustment factor curve is parameterized such that if a technology costs 50% more than the baseline truck, the adjustment factor is about 0.5. In other words, of the buyers who find the payback period acceptable, only half will actually purchase the truck. If the alternative's incremental cost is 100% of the baseline truck cost (i.e., the alternative is twice as expensive) the adjusted adoption rate is only 0.062 times the calculated rate. The user may alter the parameters for the adjustment curve using cells Z4:Z6 on the 'S-Curves' worksheet.

3.3.3 Indifference Algorithm

The payback algorithm results in market penetration of alternatives when they confer economic benefits compared to the baseline truck. However, this approach is unable to explain market sharing of similar cost technologies generally or the existence of the class 3-6 diesel truck market specifically. Gasoline engines have lower purchase price and provide comparable, or lower, fuel costs. In fact, the payback algorithm would result in 100% adoption of an alternative if it paid back in 12 months or less (using the aggressive adoption curve), no matter how small the fuel cost benefits relative to the baseline truck. If fuel prices were to shift slightly, the market could swing back to 100% baseline.

Because the NPC was interested specifically in competing conventional gasoline and diesel trucks in a single class 3-6 market, a new algorithm was developed. The "indifference algorithm" applies when the difference in purchase and fuel costs between an alternative and the baseline are within user-specified tolerances. These "indifference costs" are phased in using sigmoid curves to avoid discontinuous model behavior.

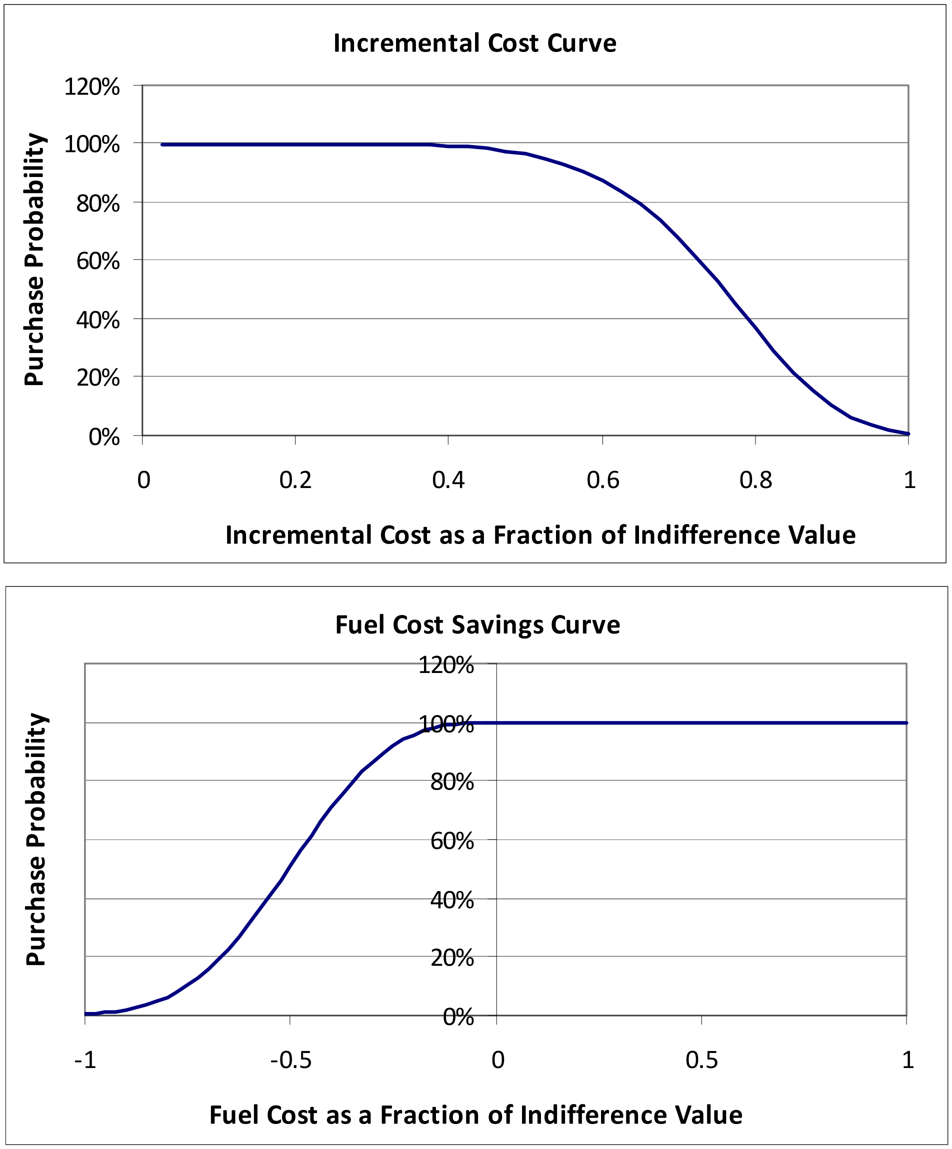
Figure 3-4 illustrates the determination of the purchase probability based on the indifference algorithm. The calculated market share depends on the preference factor (see Section 3.2) and both the alternative's purchase cost premium (incremental cost) and fuel cost savings, if any. The calculated market share, $AR_{indiff,j}$, for technology j is:

$$AR_{indiff,j} = P_{ic,j} * P_{fc,j} * PF_j$$

Where:

$P_{ic,j}$ = purchase probability from the incremental cost curve
$P_{fc,j}$ = purchase probability from the fuel cost curve
PF_j = preference factor

Figure 3-4: Indifference Algorithm Purchase Probabilities



As Figure 3-4 shows, the cost curves return values of 100% when the incremental and fuel costs are identical to the baseline, resulting in an adoption rate equal to the preference factor. As costs increase, the adoption rate declines. If either fuel costs or incremental costs are equal to the user-specified tolerance values, the adoption rate is 0%. As an example, consider a technology with a preference factor of 0.5 and an incremental cost equal to 60% of the value of the user-specified purchase cost tolerance value. The truck has higher fuel costs than the baseline and the extra monthly costs are equal to 40% of the fuel cost tolerance value. The incremental cost curve returns a purchase probability P_{ic} of 88% and the fuel cost curve returns a value of P_{fc} = 71%. Therefore, the indifference algorithm returns an adoption rate of 0.88*0.71*0.5 = 0.31. In other words, 31% of buyers would purchase the alternative even though purchase and fuel costs are somewhat higher relative to the baseline.

User control of the indifference function occurs through specification of the indifference cost tolerances on the 'Inputs' worksheet. Entering values of zero for these costs will disable the indifference algorithm. However, this may result in erratic model behavior and is not recommended. If desired, the user may also alter the parameterization of the sigmoid curves shown in Figure 3-4. These parameters are found in cells M4:M6 and O4:O6 on the 'S-Curves' worksheet.

3.3.4 Final Individual Adoption Rate

For each alternative, the adoption rate ARI_j of the technology (*j*) in competition with only the baseline truck is calculated as the maximum of either the payback algorithm (adjusted) or the indifference algorithm:

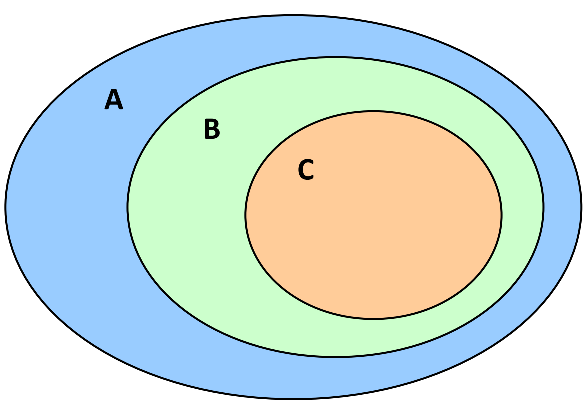
$$ARI_j = \max(AR_{pb2,j}, AR_{indiff,j})$$

3.4 Market Penetration in Full Competition

Once the adoption rates are calculated for each alternative in competition with the baseline, TRUCK calculates market penetration for all technologies in full competition. These calculations are made for each mileage cohort, refueling option, and market sub-segment.

The total market share of all the alternatives combined is assumed to be equal to the maximum share attained by any one of the alternatives. In essence, this assumes that the markets for the alternatives overlap entirely as illustrated in Figure 3-5. This approach ensures that the inclusion of more technologies does not automatically expand the market for alternatives. For example, including two technologies that offer identical economic benefits should result in the same total alternative market as including just one of the technologies. In this case, the market for alternatives that would occur with only one technology is simply split in half when there are two, assuming identical preference factors.

Figure 3-5: Overlap of Market for Alternatives



$ARI_A > ARI_B > ARI_C$

All buyers who, based on payback period, find technology C acceptable would also find technologies B and A acceptable.

Since the individual adoption rates reflect their relative economic attractiveness, the final market shares of the alternatives are determined as a weighted average, using the preference factors as weighting factors. The final market share MS_j of alternative j and MS_{base} of the baseline truck are:

$$MS_j = \left(\frac{PF_j \cdot ARI_j}{\sum_n PF_n \cdot ARI_n} \right) \cdot \max_n (PF_n \cdot ARI_n)$$

$$MS_{base} = 1 - \sum_n MS_n = 1 - \max_n (PF_n \cdot ARI_n)$$

Where n = A, B, C.

3.5 Total Shares within Market Segment and Sub-Segment

The calculations described in Sections 3.3 and 3.4 are repeated for each mileage cohort, refueling strategy, and market sub-segment. The results are tabulated on the calculations and results worksheet for each sub-segment. Using market data from the U.S. Census Bureau's 2002 Vehicle Inventory and Use Survey (VIUS) (USDOC, 2004), TRUCK then calculates the total adoption rate of each alternative, summed over all mileage cohorts, for each sub-segment and segment. Results are tabulated on separate worksheets for market share as a percentage of total new vehicles and as a percentage of total new vehicle miles. Market penetration as a percentage of vehicles (i.e., sales) provides a good indicator of relative market success. However, market shares will be higher among trucks that drive more miles annually on average. Therefore, penetration as a percentage of vehicle miles provides a better indication of the impact of a technology on fuel and energy consumption.

Market share as a percentage of vehicle miles is then used to calculate fleet fuel economies within each market sub-segment and for the weight class. A new worksheet is provided in version 5.0 and 5.1 that tabulates the fuel economy in gallon gasoline equivalent for the fleet of all vehicles using each fuel. This tabulation may be helpful for constructing VISION inputs when the modeled technologies do not align with the fleets tracked in that model.

4.0 Model Structure

This section provides details of the TRUCK5.1 model structure. Section 4.1 provides an overview of the model segmentation based on market characteristics. Section 4.2 provides a description of the model worksheets, including user inputs and model outputs.

4.1 Market Segmentation

The TRUCK model utilizes real-world market data to disaggregate the truck population according to weight class, configuration, fuel, refueling strategy and annual mileage. All market data is taken from the 2002 VIUS (USDOC, 2004). The reasons for this approach relate to model purpose and accuracy.

First, dividing the model by weight class, configuration and fuel facilitates the modeling of advanced and alternative fuel technologies attributes that are appropriate for each market sub-segment. Second, it was initially theorized that alternative fuel vehicles likely would be adopted first by fleets that were centrally-refueled. By installing their own refueling infrastructure, these fleets could sidestep the "chicken-and-egg" problem posed by the relative unavailability of the alternative fuel early in the vehicle technology's lifecycle. Modeling the fuel savings calculations separately for each refueling strategy allows the user to introduce an enhancement into just one of the two markets. Alternatively, the user may apply different introductory dates and other input parameters for each market as separate runs to simulate the transition to alternative fuels. Finally, disaggregating the truck population by mileage allows for a more accurate calculation of technology adoption rates and fuel savings than would be possible using the average mileage for all trucks within a category.

4.2 Model Organization

The model is divided into two separate workbooks representing two heavy truck market segments, classes 7&8 and classes 3-6. Each workbook contains worksheets for three sub-segments described below.

Workbook 1, Class 7&8:

- Heavy duty trucks, weight classes 26,001 lbs GVWR and larger.
- Two sub-segments modeled separately:
    - Combination unit trucks,
    - Single unit trucks, and
- Baseline trucks in each sub-segment are all diesel fueled.

Workbook 2, Class 3-6:

- Medium duty trucks, weight classes 10,001 – 26,000 lbs GVWR.
- No sub-division; includes diesel and gasoline single unit trucks with various body types.

The two workbooks employ a common layout for each market segment and sub-segment:

1. **'Inputs' worksheets** – one worksheet for each sub-segment containing unique input data for that sub-segment.
2. **'Fuel Prices' worksheet** – one worksheet containing a single dataset used by all sub-segments.
3. **'Run Model' worksheet** – one worksheet containing input selections for all sub-segments and controls to run model macros for all sub-segments.
4. **Calculation and results worksheets** – one worksheet for each market sub-segment containing calculations and detailed analysis results unique to that sub-segment.
5. **Output worksheets** – four output summary worksheets:
   a. 'Market Penetration' worksheet
   b. 'Mkt Pen Veh-Mi' worksheet
   c. 'New MPG' worksheet
   d. 'MPG by Fuel' worksheet
6. **'Market Data' worksheet** – one worksheet containing VIUS data for all sub-segments.
7. **'Adoption Decision' worksheet** – contains ATA survey data, model adoption curves, and lookup tables used by the model.
8. **'Payback Lookup' worksheet** – lookup table of incremental costs and monthly savings for payback periods from 1 to 85 months; populated by the macros accessed from the "Run All" and "Generate Cost Table" buttons.
9. **'S-Curves' worksheet** – contains phase in curves and look-up tables used by the model.
10. **'Cost Array' worksheet** – a temporary workspace required by the macros accessed from the "Run All" and "Generate Cost Table" buttons.

These worksheets are described in more detail in below.

4.2.1 Inputs Worksheets

Each workbook contains an individual 'Inputs' worksheet for each market sub-segment. On each input sheet, the user may specify up to three alternative technologies for the given sub-segment: enhancements A, B, and C. For all four vehicles, the user specifies the fuel used and inputs assumptions about vehicle maintenance costs, price, and fuel economy. For the alternatives, the user also specifies an initial year for the preference function, initial and final values for the preference curves, and indifference tolerance values for incremental cost and monthly fuel costs.

The user may specify any fuel type for the baseline and the alternatives, but the baseline must be the technology with lowest purchase price. The user may also specify a cost subsidy for the alternative technologies as a percentage of vehicle incremental cost (the difference between the purchase price of the alternative and that of the baseline truck).

For the class 7&8 workbook, there are two input worksheets that represent market sub-segments according to truck configuration:

(1) 'Inputs 7&8 Comb' – combination trucks, commonly known as tractor trailers, and

(2) 'Inputs 7&8 SU' – single unit or box trucks.

For the class 3-6 workbook, all trucks are single unit or box-type trucks and the market is not further subdivided in TRUCK5.1. There is one input worksheet:

(1) 'Inputs 3-6' – All class 3-6 trucks.

The input ranges are shaded in yellow and described below:

1.	C6:E9	Brief description of the technologies (baseline and alternatives). Examples are Conventional Diesel ICE and Diesel Electric Hybrid. This description is merely a title that carries through the worksheet pages.
2.	F6:F10	Fuel type: select from the drop down menu. The selection here determines fuel prices used in the analysis.
3.	G7:G9	Initial year for preference factor for alternatives A, B, and C. This value is used to construct the preference factor curve. To simulate an existing technology such as conventional diesel ICE, either enter a low value for the initial year (e.g. 1900) or enter analysis start year (2007) and the same value for initial and final preference factor values (cells H7:I9).
4.	H7:H9	Initial value for preference factor curve, to be applied in introduction year.
5.	I7:I9	Final value for preference factor curve. For the default parameterization of the preference curve, the final value is reached approximately 16 years after introduction.
6.	J7:J9	Indifference tolerance value for vehicle incremental cost. Enter a dollar figure that represents the difference in purchase cost between the alternative and the baseline above which the buyer will not be willing to purchase the option if there are no fuel cost savings.
7.	K7:K9	Indifference tolerance value for monthly fuel cost. Enter a dollar figure that represents the maximum increase in monthly fuel cost for the alternative relative to the baseline above which the buyer will not be willing to purchase the alternative, assuming purchase costs are identical.
8.	L6:L9	Mileage dependent maintenance costs. Enter a dollar figure for expected maintenance costs at the mileage interval entered in M6:M9.
9.	M6:M9	Mileage interval for maintenance costs specified in L6:L9, in 1,000 miles.
10.	C20:C63	Baseline truck purchase cost in 2008$.

11. D20:D63 Baseline truck fuel economy in miles per gasoline gallon equivalent.

12. E20:E63 Alternative A incremental cost in 2008$. Enter the difference in purchase cost between alternative A and the baseline truck.

13. F19 Government subsidy for alternative A as % of incremental cost. This value is used for all analysis years and is subtracted from the purchase cost.

14. H20:H63 Ratio of alternative A fuel economy to the baseline truck fuel economy for both fuel economies in miles per gasoline gallon equivalent.

15. I20:I63 Alternative B incremental cost in 2008$. Enter the difference in purchase cost between alternative A and the baseline truck.

16. J19 Government subsidy for alternative B as % of incremental cost. This value is used for all analysis years and is subtracted from the purchase cost.

17. L20:L63 Ratio of alternative B fuel economy to the baseline truck fuel economy for both fuel economies in miles per gasoline gallon equivalent.

18. M20:M63 Alternative C incremental cost in 2008$. Enter the difference in purchase cost between alternative A and the baseline truck.

19. N19 Government subsidy for alternative C as % of incremental cost. This value is used for all analysis years and is subtracted from the purchase cost.

20. P20:P63 Ratio of alternative C fuel economy to the baseline truck fuel economy for both fuel economies in miles per gasoline gallon equivalent.

Note: The user should only make changes to cells that are highlighted in yellow.

All costs are in constant 2008$.

All fuel economies are assumed to be in gasoline gallon equivalents.

4.2.2 Fuel Prices Worksheet

Fuel price inputs used for all market sub-segments are contained in the ‘Fuel Prices’ worksheet. This data is the same in both the class 7&8 and class 3-6 workbooks and is updated annually based on the Reference Case from the latest *Annual Energy Outlook* (AEO). As released for the FTF, version 5.1 contains projections through 2035 that are taken directly from AEO 2010 (EIA, 2010). Fuel prices for years 2036 – 2050 are extrapolated from the reference case by applying the 5-year average annual growth rate from 2030 to 2035 using the following formula:

$$P_t = P_{t-1} * \left(\frac{P_{2035}}{P_{2030}} \right)^{\frac{1}{5}}$$ Equation (11)

Where:

P_t = fuel price in year t, for t = 2036, 2037, · · · 2050.

AEO 2010 gives prices as constant 2008 dollars per million BTU. These values are converted to 2008 dollars per gasoline-gallon equivalent using higher heating values, which for gasoline is 125,000 BTU/gallon.

The user may wish to make alternate assumptions about future fuel prices. These assumptions should be specified in cells B9:I52 in constant dollars per million BTU. The choice of year (e.g. 2008$) should be consistent with what is used for specifying vehicle purchase and maintenance costs on the 'Inputs' worksheet(s).

Note: The data on the 'Fuel Prices' worksheet are used by the model as a lookup table. The user should not add or delete columns or rows on this worksheet. The user also should not change the column headers for the data in gasoline gallon equivalents.

4.2.3 Market Data Worksheet

Each workbook contains a single 'Market Data' worksheet that tabulates and analyzes truck mileage characteristics from the 2002 VIUS (USDOC, 2004) for each sub-segment and refueling strategy (centrally or non-centrally refueled). The upper part of the worksheet shows the distribution of trucks by annual mileage in 5,000 mile increments as provided in VIUS. Thus, the first data row, labeled 0 miles, includes trucks that travel 0 to 4,999 miles per year. The second data row includes trucks that travel 5,000 to 9,999 miles per year, etc. Trucks that are centrally refueled are tabulated separately from those that are not. The yellow shaded columns show the number of trucks in each mileage grouping while the un-shaded columns show the average mileage driven by trucks in that group.

Below this tabulation are calculations that aggregate the trucks into 20,000 mile/year cohorts. The first two columns show the number of trucks in each 5,000 mile grouping as a percentage of the total number of trucks in the 20,000-mile cohort. The total number of trucks in each 20,000-mile cohort is shown below the distribution for that cohort. The third and fourth columns show the average mileage for trucks in each 5,000-mile group and calculate the weighted average for each cohort is using the percentages shown in columns one and two. The last tabulation on this worksheet summarizes the weighted average mileage for all 20,000-mile cohorts. This weighted average mileage in 20,000-mile increments is used in the payback calculations described in detail in Section 3.3.

The data on the 'Market Data' worksheet are used by the model as a lookup table. The user should not add or delete columns or rows on this worksheet.

4.2.4 'Run Model' Worksheet

Each workbook contains a 'Run Model' worksheet which is used to specify parameters that apply to all sub-segments and is also used to exercise the model. This process is performed in three steps:

(1) Enter Run ID / Description: Enter a descriptive title that will be repeated on the output worksheets.

(2) Enter Economic Parameters:

   a) Discount Rate - Specify a discount rate to be used for calculating the present value of budgeted maintenance costs or savings and fuel cost savings.

   b) Market Adoption Curve – Select one of the three available curves from the drop-down menu.

(3) Run Macros: The user must generate the payback lookup table and run the calculations described in Sections 3.3 and 3.4 iteratively for each market sub-segment, each of the two refueling strategies, and each of the 20,000-mile cohorts. This process is automated by clicking on the 'Run All' macro button on the 'Run Model' worksheet.

   If changes have been made to only one sub-segment and there have been no changes in vehicle costs, the user may update the results for the sub-segment individually by clicking on the macro button for that sub-segment. Version 5.1 does not include an option to run the model separately for each refueling strategy as prior versions do.

Note: Due to the nature of the macros used to run the model, the user should not rearrange data or add or delete rows or columns anywhere in the model.

Input ranges on the 'Run Model' worksheet are indicated in yellow shading and described below:

1. B3:D3 — Run ID: enter a descriptive title for the model run. This title is repeated on each results worksheet.
2. C6 — Discount rate. Enter % value to be used to discount stream of future maintenance costs and fuel cost savings.
3. C7 — Market adoption rate curve. Select curve from the drop-down menu.

4.2.5 Calculation and Results Worksheets

Each workbook contains an individual calculation and results worksheet for each market sub-segment that includes detailed tabulations of the calculations described in Sections 3.3 and 3.4. On execution of the individual macros accessed on the 'Run Model' worksheet, the model performs the calculations for each mileage cohort of the specified sub-segment and each refueling strategy. As the model steps through each cohort, it overwrites the interim calculations displayed in the upper portion of the worksheet. Thus, after running the macro, the interim calculations are displayed only for the last mileage cohort. Utilizing the 'Run All' macro button sequentially runs the macro for each sub-segment and refueling strategy, leaving interim calculations for the last mileage cohort on each worksheet.

However, the worksheet retains and tabulates the final adoption rate for each refueling strategy, mileage cohort, and alternative (A, B, and C). The model then calculates the total adoption rate of each alternative, summed over all mileage cohorts, as a percentage of total new vehicles and as a percentage of total new vehicle miles for each refueling strategy. Market penetration as a percentage of vehicles (i.e., sales) provides a good indicator of relative market success. However, penetration as a percentage of vehicle miles provides a better indication of the impact of a technology on fuel and energy consumption.

In general, the data on this worksheet is not needed by the user since the results are summarized on the output summary worksheets described in Section 4.2.6. However, the tabulations are useful for debugging runs and for a deeper understanding of the model results.

For the class 7&8 workbook, there are two sub-segment calculations and results worksheets:

(1) '7&8 Comb' – combination trucks, and

(2) '7&8 SU' – single unit box trucks.

For the class 3-6 workbook, there is only one calculations and results worksheet:

(1) '3-6' – all class 3-6 trucks.

4.2.6 Output Summary Worksheets

Each workbook includes four worksheets that provide a summary of the model results as described below:

(1) 'Market Penetration' – This worksheet provides a summary tabulation of the annual market shares of the modeled technologies. Annual market penetrations are calculated as a percentage of sales for each of the market sub-segments and as a percentage of the entire market segment (class 7&8 or class 3-6). These penetration rates provide a good indicator of the technologies' market success.

(2) 'Mkt Pen Veh-Mi' – This worksheet provides a summary tabulation of the annual market share of the modeled technologies as a percentage of total annual vehicle miles for new trucks. Again, market penetration is calculated as a percentage of total vehicle miles driven by all new trucks within the sub-segment and as a percentage of the vehicle miles driven by the entire market segment (class 7&8 or class 3-6). These penetration rates provide a good indicator of the technologies' impact on fuel and energy use.

(3) 'New MPG' – This worksheet tabulates the fuel economy (in gallon gasoline equivalent) of the baseline and alternative vehicles for each market sub-segment. The table reports the fuel economy of the new vehicles by technology, the sales fleet for each sub-segment, and the sales fleet for the entire segment (class 7&8 or class 3-6). Fuel economy ratios compared to baseline vehicles are calculated for the sub-segment fleet and the total segment fleet. If the baseline vehicle modeled is consistent with the VISION baseline and the alternatives are also consistent with the fleets tracked in VISION, these results serve as the required inputs for the VISION model.

(4) 'MPG by Fuel' – This worksheet tabulates the fuel economy (in gallon gasoline equivalent) for the fleet of all vehicles using each fuel. If more than one of the technologies modeled uses a particular fuel, these vehicle technologies are combined into a single fleet. For example, conventional diesel ICE and hybrid diesel-electric trucks would be combined for the diesel fleet. This tabulation may be helpful for constructing VISION inputs when the modeled technologies do not align with the fleets tracked in the VISION model.

4.2.7 Model Lookup Data Worksheets

The remaining worksheets in the model contain model functions and lookup data which generally do not require user input. In some cases, the advanced user may wish to adjust the function parameters used to generate model lookup tables. However, it is the users' responsibility to ensure that the altered functions provide reasonable results. Each of these data sheets is described below.

(1) 'Adoption Decision' – This worksheet displays the adoption rate curves and contains the adoption rate lookup table for the payback algorithm. Three columns of data are provided, one for each of three possible curves – "aggressive," "moderate," and "conservative." The user selects the curve to use on the 'Run Model' worksheet. The parameters for the three curves are contained in cells D8:F10. The user may change this parameterization but it is not recommended since this would in essence create a different model.

(2) 'Payback Lookup' – This worksheet contains the monthly savings required for each user-specified value of incremental cost and payback periods of 1 to 85 months. The worksheet is populated by the model macros and is used as a lookup table by the payback algorithm. ***The user should not make any changes on this worksheet.***

(3) 'S-Curves' – This worksheet contains parameters and lookup data for the preference function, the indifference costs curves, and incremental cost adjustment function. Each curve is displayed graphically. In general, the user does not need to make any changes to this worksheet but may adjust the function parameters if desired. See the discussion on methodology for the corresponding function in Section 3.0.

(4) 'Cost Array' – This worksheet is used as a temporary workspace by the model macros. ***The user should not make any changes on this worksheet.***

5.0 Model Benchmark

The TRUCK5.1 model workbook for class 7&8 was benchmarked against TRUCK4.0 results from the VTP GPRA 2013 analysis. The inputs were selected to remove the impact of the new features of version 5.1 and simulate the behavior of version 4.0. This essentially tested only the changes in the implementation of the payback methodology. This section briefly describes the inputs used and presents a comparison of the results.

5.1 Inputs

The version 5.1 workbook for class 7&8 trucks was populated with incremental cost and fuel economy inputs used in the GPRA 2013 high case analysis. The baseline truck in each of the two class 7&8 markets was a conventional diesel truck. Baseline fuel economies were calculated from the AEO 2011 reference case with the impact of VTP supported technologies removed. The baseline combination truck was assumed to cost $150,000. The baseline single unit truck was assumed to cost somewhat more at $175,000 to account for the cost of specialized bodies. Two alternative technologies were simulated in each market sub-segment: an advanced conventional diesel and a diesel-electric hybrid. Incremental costs ranged from about $8,000 to $60,000 and fuel economy multipliers ranged from about 1.2 to 1.7.

Fuel prices were updated to the AEO 2011 reference case (EIA, 2011). The same discount rate (7.5%) was used in both models. Inputs for all other parameters were selected to be consistent with version 4.0 assumptions and inputs:

- In TRUCK4.0, the user specifies the MAF between 1 and 20, with lower values associated with lower adoption rates for a given payback period. Since a value of 1 was used for the GPRA analysis, the most conservative adoption rate curve was applied in version 5.1.
- All preference factors were set to 0.5 to simulate technology neutrality and remove the impact of the PF from the calculations.
- Purchase cost indifference values were set to $5,000 which is below the incremental cost in all cases. Since all simulated alternatives offered fuel cost savings, the fuel cost indifference value (set to $100) was irrelevant. Therefore, the impact of the indifference algorithm was removed.
- Maintenance costs were all set to $0 which removed the impact of this feature.

5.2 Results

Table 5-1 summarizes the market share results as a percentage of truck sales while Table 5-2 shows these results as a percentage of annual miles of travel. These results are depicted graphically in Figure 5-1 through Figure 5-4. The results of the two models are generally consistent, with version 5.1 estimating somewhat lower market penetration of the alternatives overall. This is partly explained by the inclusion of the adjustment for incremental cost in version 5.1. Another factor in the differences could be the difference in algorithm used to combine the market shares for the individual technologies in competition with the baseline into the full competition market shares. The algorithm used in version 4.0 allows the combined market share for alternatives to be larger than that for any one alternative in competition with the baseline. Version 5.1 restricts the total market for alternatives to the maximum achieved by any one alternative competing alone.

Table 5-1: Comparison of Version 4.0 and 5.1 Results: Market Share as % of Sales

TRUCK 4.0

	Baseline	A	B
Class 7&8 Combination			
2020	36.3%	57.6%	6.0%
2030	35.9%	50.6%	13.5%
2040	36.1%	47.3%	16.6%
2050	35.8%	46.6%	17.6%
Class 7&8 Single Unit			
2020	95.0%	3.4%	1.6%
2030	92.4%	3.2%	4.4%
2040	92.4%	2.9%	4.7%
2050	92.0%	2.9%	5.1%

TRUCK 5.1

	Baseline	A	B
Class 7&8 Combination			
2020	43.4%	46.5%	10.1%
2030	45.5%	38.6%	16.0%
2040	46.4%	36.0%	17.6%
2050	46.6%	34.7%	18.6%
Class 7&8 Single Unit			
2020	95.7%	4.0%	0.3%
2030	95.6%	3.7%	0.7%
2040	95.9%	3.3%	0.8%
2050	95.7%	3.4%	0.9%

Table 5-2: Comparison of Version 4.0 and 5.1 Results: Market Share as % of VMT

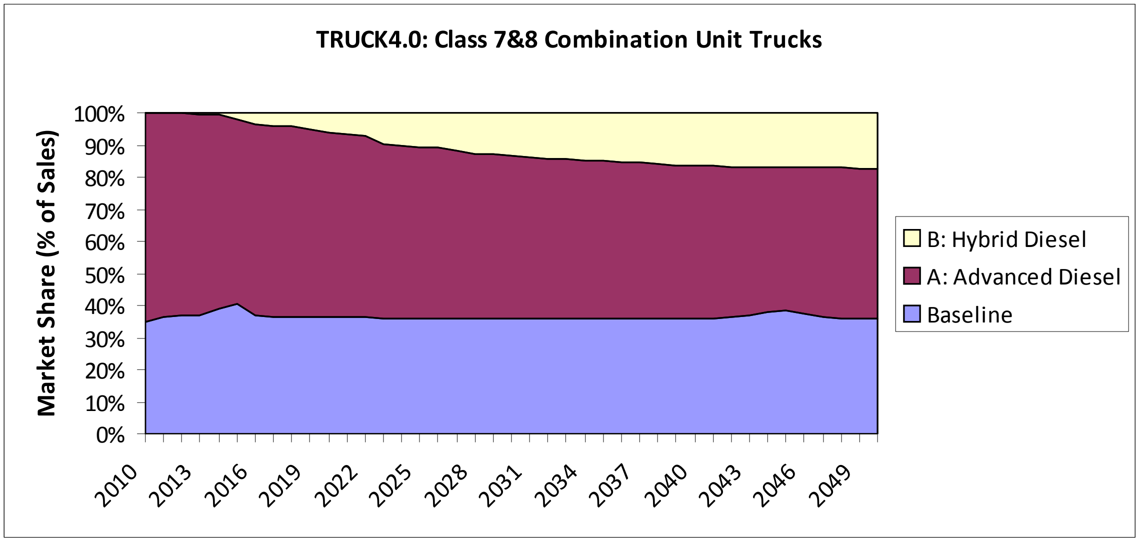
TRUCK 4.0

	Baseline	A	B
Class 7&8 Combination			
2020	23.9%	68.0%	8.1%
2030	24.0%	59.0%	17.0%
2040	24.4%	54.6%	21.1%
2050	24.0%	53.8%	22.1%
Class 7&8 Single Unit			
2020	83.1%	16.2%	0.7%
2030	84.7%	13.8%	1.5%
2040	85.1%	13.0%	1.9%
2050	84.6%	12.6%	2.7%

TRUCK 5.1

	Baseline	A	B
Class 7&8 Combination			
2020	32.8%	53.3%	13.9%
2030	35.1%	44.4%	20.5%
2040	36.1%	41.7%	22.3%
2050	36.3%	40.3%	23.4%
2020	86.9%	11.7%	1.4%
2030	86.8%	10.5%	2.7%
2040	87.5%	9.3%	3.2%
2050	87.1%	9.5%	3.4%

Figure 5-1: Comparison of Class 7&8 Combination Unit Market Share as % of Sales



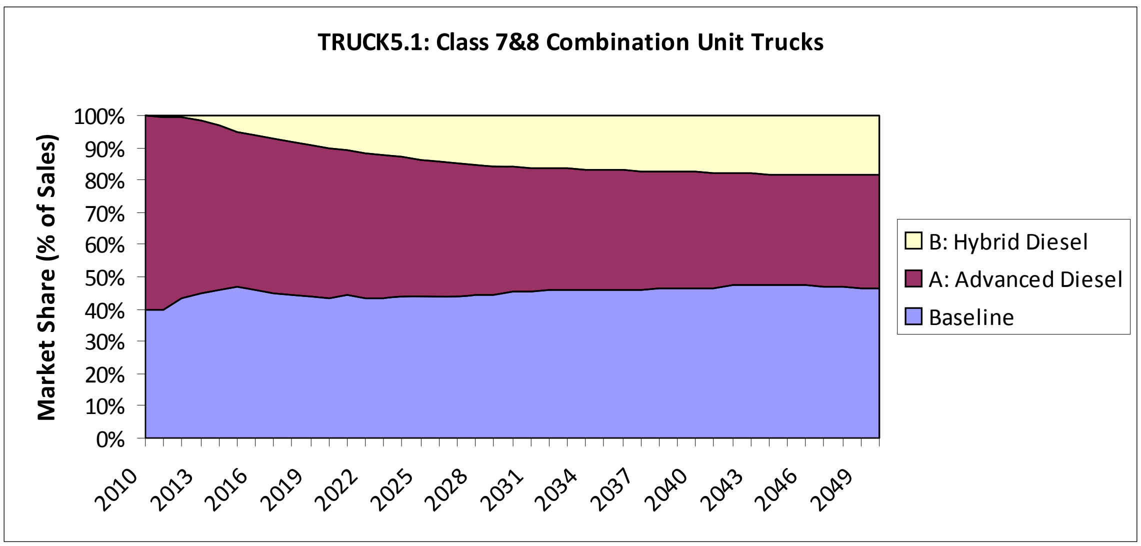
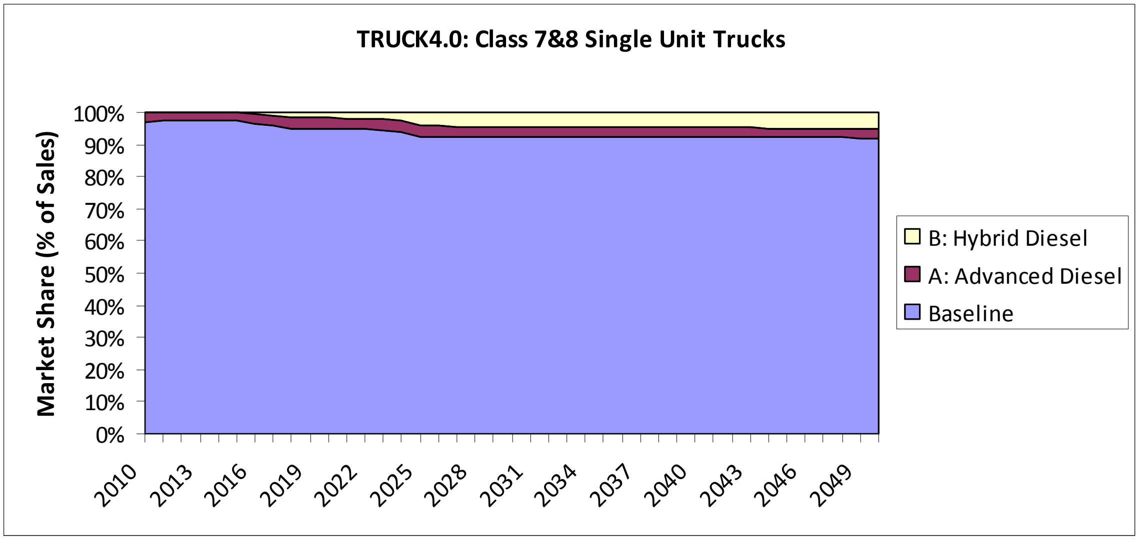


Figure 5-2: Comparison of Class 7&8 Single Unit Market Share as % of Sales



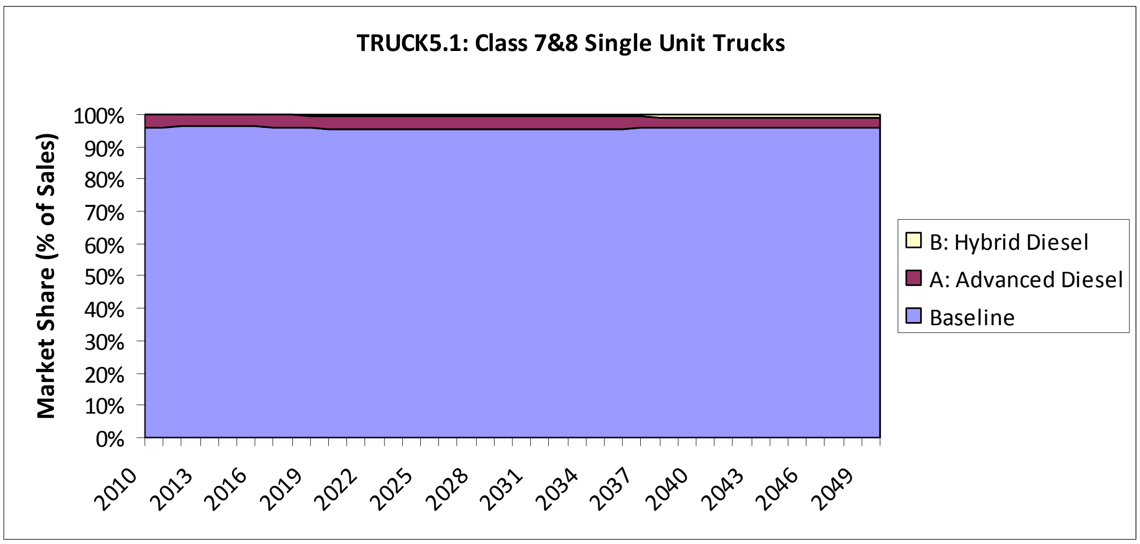
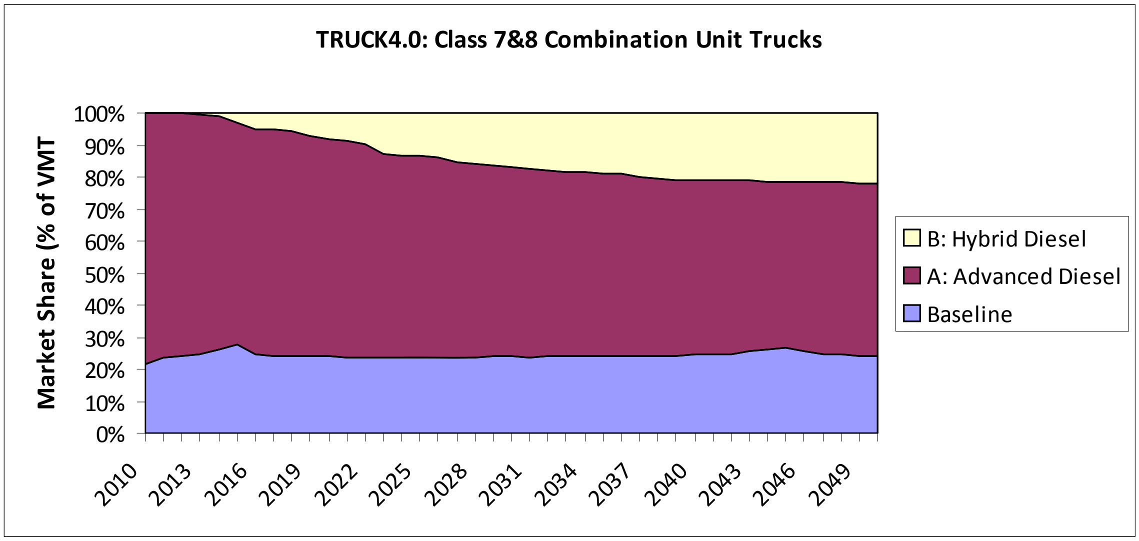


Figure 5-3: Comparison of Class 7&8 Combination Unit Market Share as % of VMT



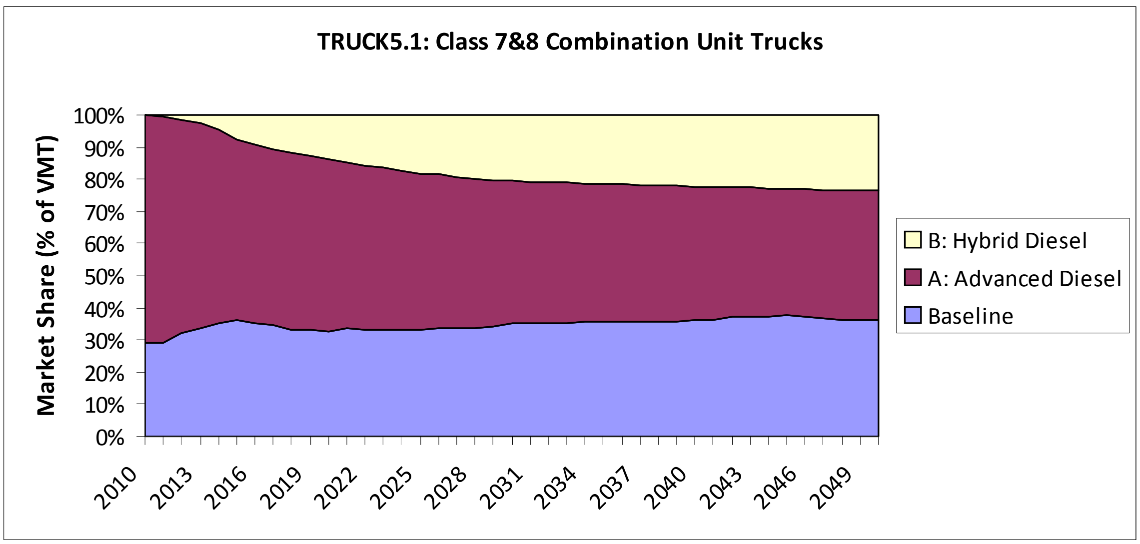
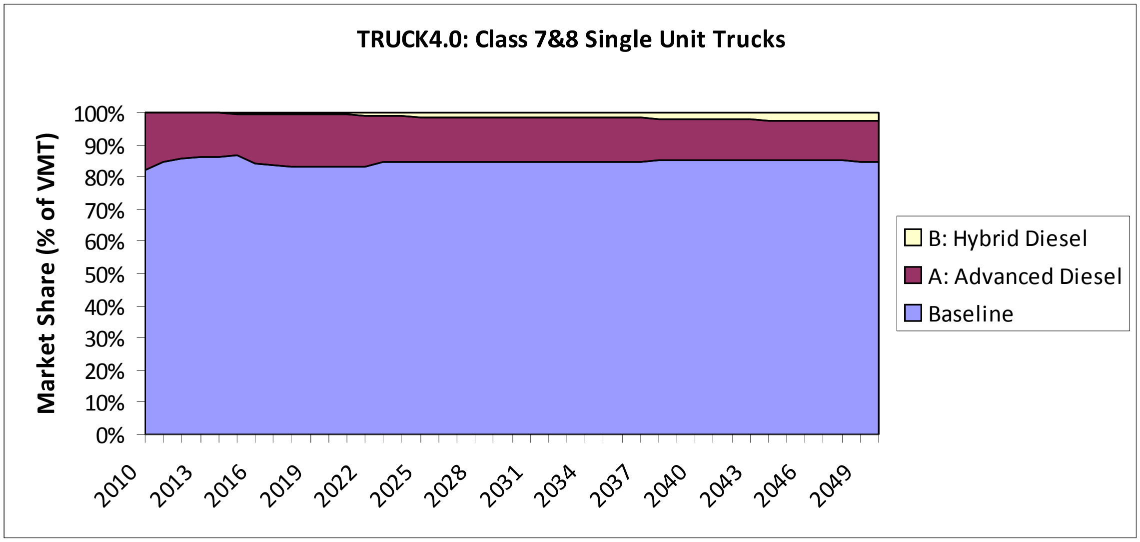
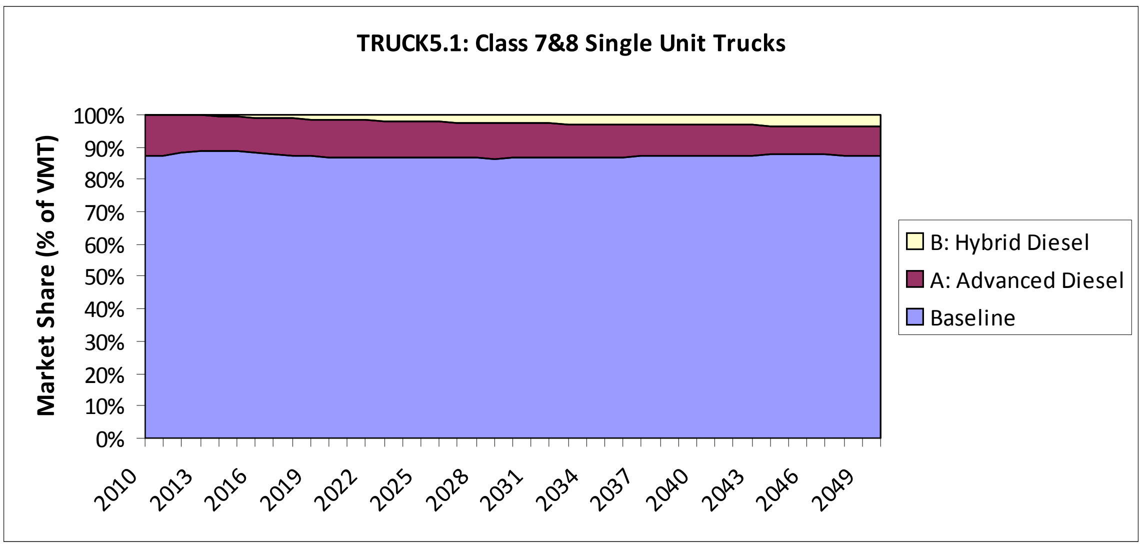


Figure 5-4: Comparison of Class 7&8 Single Unit Market Share as % of VMT





6.0 Summary

The TRUCK5.1 model is a spreadsheet tool for estimating market potential of fuel cost-saving heavy truck technologies. The model has a history of use within DOE VTP and has had considerable review by government and industry experts. The current version has been updated to be analytically simpler, computationally less demanding, and more transparent to the user. It also incorporates added capabilities, some of which were required for the FTF study. Updates included in version 5.1 relative to version 4.0 are:

- Simplification and increased resolution of the payback algorithm,
- Inclusion of differences in maintenance and repair costs in the payback calculation,
- Simultaneous competition of up to 4 technologies (1 baseline and 3 alternatives) in each sub-market,
- Complete flexibility in the fuel types allowed for each technology,
- Consolidation of the Class 3-6 gasoline and diesel truck markets, and
- Adjustments to market adoption rate for magnitude of incremental costs.

Most of the added features can be removed by the user if desired. When parameterized to be consistent with version 4.0, TRUCK5.1 provides generally consistent results. Some differences are expected due to the change in application of the basic payback period approach. Implementing the added features of the current version will provide results that diverge from version 4.0.

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