

**Model Documentation Report:  
Transportation Sector Model of the  
National Energy Modeling System**

February 1997

Office of Integrated Analysis and Forecasting  
Energy Information Administration  
U.S. Department of Energy  
Washington, DC

## NEMS TRANSPORTATION MODEL DOCUMENTATION UPDATES

Over the past year, several modifications have been made to the NEMS Transportation Model, incorporating greater levels of detail and analysis in modules previously represented in the aggregate or under a profusion of simplifying assumptions. This document is intended to amend those sections of the Model Documentation Report (MDR)<sup>1</sup> which describe these superseded modules.

Significant changes have been implemented in the LDV Fuel Economy Model, the Alternative Fuel Vehicle Model, the LDV Fleet Module, and the Highway Freight Model. The relevant sections of the MDR have been extracted from the original document, amended, and are presented in the following pages. A brief summary of the modifications follows:

- ◆ In the Fuel Economy Model, modifications have been made which permit the user to employ more optimistic assumptions about the commercial viability and impact of selected technological improvements. This model also explicitly calculates the fuel economy of an array of alternative fuel vehicles (AFV's) which are subsequently used in the estimation of vehicle sales.
- ◆ In the Alternative Fuel Vehicle Model, the results of the Fuel Economy Model have been incorporated, and the program flows have been modified to reflect that fact.
- ◆ In the Light Duty Vehicle Fleet Module, the sales of vehicles to fleets of various size are endogenously calculated in order to provide a more detailed estimate of the impacts of EPACT legislation on the sales of AFV's to fleets.
- ◆ In the Highway Freight Model, the previous aggregate estimation has been replaced by a detailed Freight Truck Stock Model, where travel patterns, efficiencies, and energy intensities are estimated by industrial grouping.

Several appendices are provided at the end of this document, containing data tables and supplementary descriptions of the model development process which are not integral to an understanding of the overall model structure.

- ◆ Appendix A contains a description of the characteristics of automotive technologies in the

---

<sup>1</sup>*Model Documentation Report: Transportation Sector Model of the National Energy Modeling System*, DOE/EIA-M070, Energy Information Administration, Washington, D.C., March 1994.

standard and more optimistic scenarios.

- ◆ Appendix B summarizes the characteristics of alternative fuel vehicles which have been used in estimating their fuel economy.
- ◆ Appendix C provides a description of the characteristics of light-duty vehicle fleets and the methodology used in estimating future sales and the impact of legislative mandates on alternative fuel vehicle purchases.

## **3A. Light Duty Vehicle Module**

### ***3A-1. Fuel Economy Model***

The Fuel Economy Model (FEM) is a subcomponent of the Light Duty Vehicle segment of the NEMS Transportation Model. FEM produces estimates of new light duty vehicle fuel efficiency which are then used as inputs to other components of the Transportation Model.

#### **RATIONALE**

The FEM is a significant component of the Transportation Model because the demand for automotive fuel is directly affected by the efficiency with which that fuel is used. Due to the disparate characteristics of the various classes of light duty vehicle, this model addresses the commercial viability of up to sixty-one separate technologies within each of fourteen vehicle market classes, four corporate average fuel economy (CAFE) groups, and thirteen fuel types. The seven automobile market classes include five classes based on interior passenger volume, ranging from "minicompact" to "large", and classes for "sports" and "luxury" cars. The seven classes of light truck are based mainly on utility and inertia weight and include vans, pickups, utility vehicles and mini-trucks. Market classes for automobiles and light trucks are described in more detail in Appendix A, Table A-2. The four groups for which CAFE standards are set are: Domestic Cars, Import Cars, Domestic Trucks, and Import Trucks.

The fuel economy of the fleet of new vehicles can change as a result of four factors:

- 1) A change in technological characteristics of each vehicle
- 2) A change in the level of acceleration performance of vehicles
- 3) A change in the mix of vehicle classes sold
- 4) A change in vehicle safety and emission standards.

Over the last 15 years, the single factor with the largest effect on fuel economy was the changing technological characteristics of cars. Except for the period immediately following the second oil shock of 1979, the vehicle class mix has not had a very large effect on fuel economy since the mix changes have not been large. In the last five years, rapidly increasing performance levels have had a significant impact on fuel economy.

The Fuel Economy Model developed for NEMS considers each of the first three factors when projecting fuel economy in the future. To forecast technological change, the entire fleet of new cars and light duty trucks are disaggregated into fourteen market classes (seven each for cars and light

trucks) that are relatively homogenous in terms of consumer perceived attributes such as size, price and utility. Technological improvements to each of these market classes are then forecast based on the availability of new technologies to improve fuel economy as well as their cost effectiveness under two user-specified alternative scenarios. The central assumptions involved in this technological forecast are as follows:

- 1) All manufacturers can obtain the same benefits from a given technology, provided they have adequate lead time (i.e., no technology is proprietary to a given manufacturer in the long term).
- 2) Manufacturers will generally adopt technological improvements that are perceived as cost-effective to the consumer, even without any regulatory pressure. However, the term cost-effectiveness needs to be interpreted in the manufacturer's context.

These forecasts also account for manufacturer lead time and tooling constraints that limit the rate of increase in the market penetration of new technologies. Users of the model are able to specify one of two scenarios under which these forecasts are made. The first, identified as the "Standard Technology Scenario", permits the consideration of fifty-six automotive technologies whose availability and cost-effectiveness are either well-documented or conservatively estimated. The second, identified as the "High Technology Scenario", augments the Standard Scenario with five additional technologies, and modifies selected characteristics of the original matrix to render a more optimistic assessment of the cost and availability of technological improvements. All of the considered technologies and their associated characteristics are tabulated in Appendix A. Based on the technological improvements adopted, a fuel economy forecast assuming constant performance is developed for each of the market classes.

The fuel economy forecast must then be adjusted to account for changes in consumer preference for performance. The demand for increased acceleration performance for each size class is estimated based on an econometric equation relating fuel prices and personal disposable income to demand for performance or horsepower, by market class. This relationship is used to forecast the change in horsepower, which is then used to forecast the change in fuel economy through an engineering relationship that links performance and fuel economy.

Finally, the change in the mix of market classes sold is forecast as a function of fuel price and personal disposable income only and is documented in Appendix E, page E-1, of this report. The sales mix by class is used to calculate fleet fuel economy. The econometric model was derived from regression analysis of historical sales mix data over the 1978-1990 period. The model forecasts sales mix for

the 7 car classes and the 7 light truck classes, while import market shares are held at fixed values by market class based on EEA estimates.

The model also allows specification of Corporate Average Fuel Economy (CAFE) standards by year, and of differential standards for domestic and import vehicles, as well as the penalty (in dollars) per car per mile per gallon below the standard. The standards are accounted for in the forecast by incorporating the penalty into the technology cost-effectiveness calculation. Hence, if the penalty is not large, the model assumes that manufacturers will adopt fuel-saving technology as long as it is cost-effective; that is, until the point where it becomes cheaper to pay the penalty for noncompliance. Thus, the model allows companies to choose non-compliance with CAFE standards as a cost-minimizing strategy, as may occur if penalties are set at unrealistic levels relative to the difficulty of achieving the CAFE standards.

Finally, the model also accounts for all known safety and emission standard changes during the forecast period. These are generally limited to the 1990-2005 time frame, however. Emission standards and safety standards increase vehicle weight, and in some cases decrease engine efficiency. The model accounts for the 1994 Tier I emission standards as well as the 2001+ Tier II emission standards, but does *not* envisage that the California "Low Emission Vehicle" standards will be adopted nationwide. Safety standards include fuel economy penalties for air bags, side intrusion and roof crush (rollover) strength requirements that are mandatory over the next ten years. Separately, anti-skid brakes are assumed to be incorporated in all vehicles, although they are not required by law.

#### ALTERNATIVE SPECIFICATIONS

The methodology described is implemented in the Fuel Economy Model (FEM) which builds from the earlier Technology/Cost Segment Model (TCSM) which was developed for the Department of Energy. The FEM, however, has two changes relative to the TCSM, as detailed below:

- 1) The FEM forecast aggregates all manufacturers by domestic and import, while the TCSM forecasts fuel economy by manufacturer for all domestic and several select import manufacturers
- 2) The FEM technology data is more recently updated, and captures technologies that could be available over the next 40 years, whereas the TCSM incorporates only near term technology data.

As a result of its longer term focus, the FEM incorporates a more sophisticated technology adoption

and market penetration calculation algorithm than the one incorporated in the TCSM. The adoption algorithm accounts for real world effects when cost-ineffective technologies are introduced in luxury cars for image or for performance reasons.

The forecasts are calculated at the most disaggregate level of manufacturer type (domestic/ import), vehicle type (car/light truck) and market class. Cars and light trucks are each separated into seven market classes. Each market class represents an aggregation of vehicle models that are similar in size and price, and are perceived by consumers to offer similar attributes. The car classes are similar to the EPA size classes except for the addition of sports and luxury classes that are not defined on the basis of interior volume. In addition, the classes utilized here are based on passenger volume, not passenger and trunk volume as per EPA, which results in some hatchback models differing in classification. Truck classification is essentially identical to the EPA classification. This leads to a total of 28 possible classes (7 classes x 2 vehicle types x 2 manufacturer types) but some have no vehicles, e.g., there are no domestic minicompact cars. The net result is 22 different classes which are individually forecast to 2030.

### MODEL STRUCTURE

The Fuel Economy Model (FEM) uses a straightforward algorithm to forecast fuel economy by vehicle class. FEM begins with a baseline, describing the fuel economy, weight, horsepower and price for each vehicle class in 1990. In each forecast period, the model identifies technologies which are available in the current year. Each available technology is subjected to a cost effectiveness test which balances the cost of the technology against the potential fuel savings and the value of any increase in performance provided by the technology. The cost effectiveness is used to generate an economic market share for the technology.

In certain cases there are adjustments which must be made to the calculated market shares. Some of these adjustments reflect engineering limitations to what may be adopted. Other adjustments reflect external forces that require certain types of technologies; safety and emissions technologies are both in this category. All of these adjustments are referred to collectively as "Engineering Notes." There are four types of engineering notes: *Mandatory*, *Requires*, *Synergistic* and *Supersedes*. These are described in detail in the following sections.

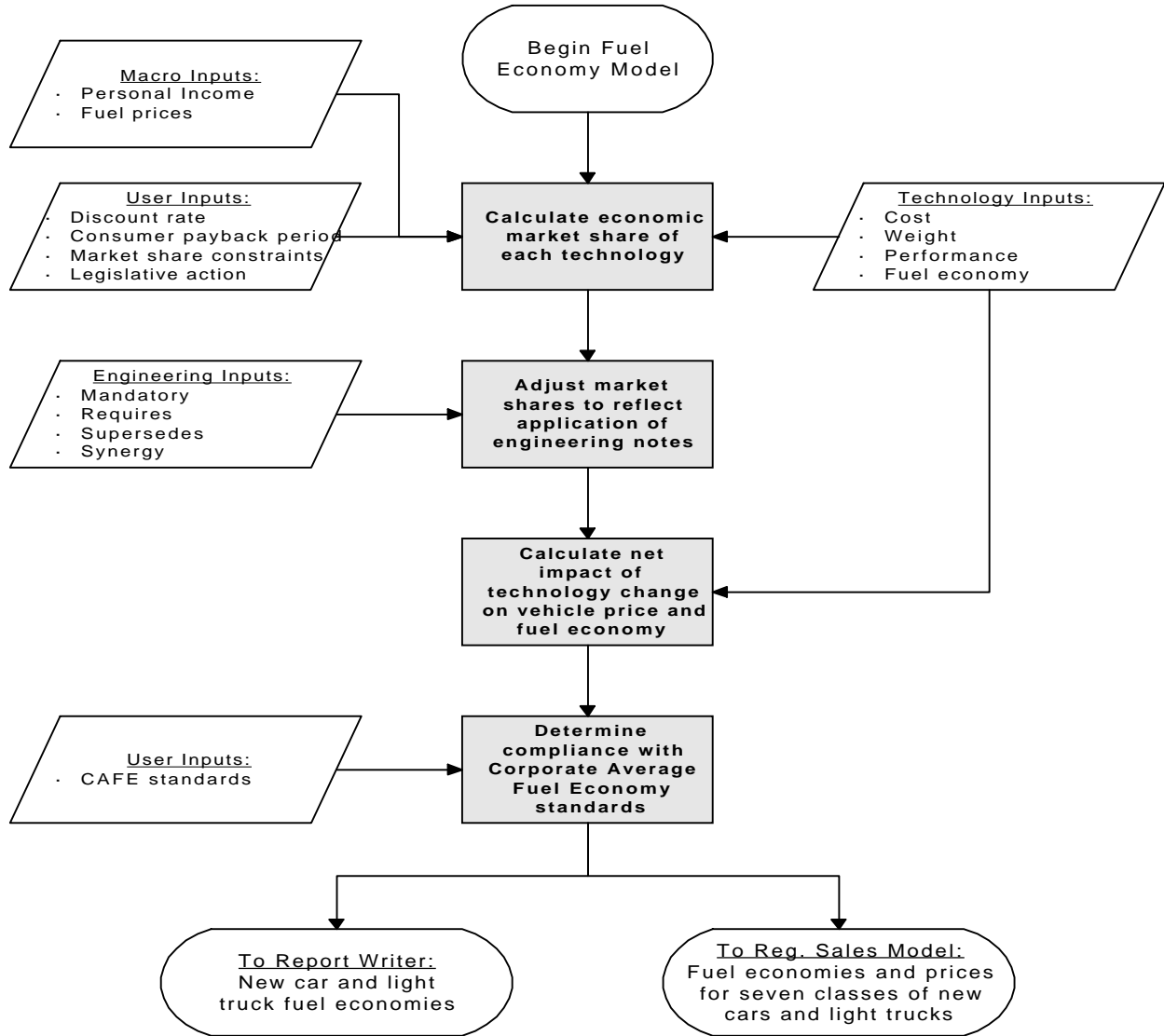
After all of the technology market shares have been determined, the baseline values for the vehicle class are updated to reflect the impact of the various technology choices on vehicle fuel economy, weight and price. Next, based on the new vehicle weight, a no-performance-change adjustment is made to horsepower. Then, based on income, fuel economy, fuel cost, and vehicle class, a perfor-

mance-change adjustment is made to horsepower. Finally, the fuel economy is adjusted to reflect the new horsepower.

Once these steps have been taken for all vehicle classes, the Corporate Average Fuel Economy (CAFE) is calculated for each of the four groups: Domestic Cars, Import Cars, Domestic Trucks and Import Trucks. Each group is classified as either passing or failing to meet the CAFE standard. When a group fails to meet the standard, penalties are assessed to all of the vehicle classes in that group, which are then reprocessed through the market share calculations. In this second pass, the technology cost effectiveness calculation is modified to include the benefit of not having to pay the fine for failing to meet CAFE. After this second pass the CAFEs are recalculated. No further action is taken to force CAFE compliance; vehicles in failing groups are assumed to simply pay the fine.



**Figure 3A-1. Fuel Economy Model**



I. ESTABLISH AFV CHARACTERISTICS RELATIVE TO GASOLINE ICE

The initialization subroutine, AFVADJ, calculates the base year price, weight, fuel economy and horsepower for the alternative fuel vehicles. Most of these are set relative to the gasoline vehicle values as shown in the following equations. All of the incremental adjustments used for alternative fuels have been exogenously determined and are included in the Block Data section of the code.

1) Calculate AFV base year values for automobile prices at different production levels.

a) Mini, Sub-Compact, Sports and Compacts at 2,500 units/year

$$PRICE_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + AFVADJPR_{FuelType,1} \quad (1)$$

where:

AFVADJPF(,1) = the incremental price adjustment for a low production AFV car

b) Midsize and Large at 2,500 units/year

$$PRICE_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + \frac{AFVADJPR_{FuelType,1} + AFVADJPR_{FuelType,2}}{2} \quad (2)$$

where:

AFVADJPF(,2) = Incremental price adjustment for a low production AFV truck

c) Luxury vehicles at 2,500 units/year

$$PRICE_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + 2 * AFVADJPR_{FuelType,1} \quad (3)$$

d) Mini, Sub-Compact, Sports and Compacts at 25,000 units/year

$$PRICEHI_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + AFVADJPR_{FuelType,3} \quad (4)$$

where:

AFVADJPF(,3) = Incremental price adjustment for a high production AFV car

e) Midsize and Large at 25,000 units/year

$$PRICEHI_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + \frac{AFVADJPR_{FuelType,3} + AFVADJPR_{FuelType,4}}{2} \quad (5)$$

where:

AFVADJPF(,4) = Incremental price adjustment for a high production AFV truck

f) Luxury at 25,000 units/year

$$PRICEHI_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + 2 * AFVADJPR_{FuelType,3} \quad (6)$$

2) Calculate AFV base year values for light duty truck prices at different production levels.

a) Standard Pickups, Standard Vans and Standard Utility at 2,500 units/year

$$PRICE_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + AFVADJPR_{FuelType,2} \quad (7)$$

b) Mini, Compact Pickup, Compact Van and Compact Utility at 2,500 units/year

$$PRICE_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + \frac{AFVADJPR_{FuelType,1} + AFVADJPR_{FuelType,2}}{2} \quad (8)$$

c) Standard Pickups, Standard Vans and Standard Utility at 25,000 units/year

$$PRICEHI_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + AFVADJPR_{FuelType,4} \quad (9)$$

d) Mini, Compact Pickup, Compact Van and Compact Utility at 25,000 units/year

$$PRICE_{BaseYear, FuelType} = PRICE_{BaseYear, Gasoline} + \frac{AFVADJPR_{FuelType,3} + AFVADJPR_{FuelType,4}}{2} \quad (10)$$

3) Calculate base year prices for all electric hybrid vehicles.

Electric Hybrid vehicles have an additional price adjustment in addition to those made above. This adjustment applies to both cars and trucks. Note that these adjustments refer to the cost reduction learning curve for Ni-MH batteries. This is because the EV/Hybrid cost reduction curve begins at the same time and proceeds at the same rate as that for Ni-MH batteries.

a) Electric Hybrid at 2,500 units/year

$$CE_{BaseYear, ElectricHybrid} = NIMHY\$COST_{BaseYear} * PRICE_{BaseYear, ElectricHybrid} + AFVADJPR_{ElectricHybrid,3} * \frac{WEIGHT_{BaseYear, Gasolin}}{WEIGHT_{Midsize, BaseYear, Ga}} \quad (11)$$

where:

AFVADJPF(11,3) = Incremental price adjustment for a midsize car EV/Hybrid

WEIGHT<sub>Midsize</sub> = Weight of a midsize car.

NIMHY\$COST = Cost reduction learning curve for a Ni-MH battery

b) Electric Hybrid at 25,000 units/year (note different PRICE subscript)

$$CEHI_{BaseYear, ElectricHybrid} = NIMHY\$COST_{BaseYear} * PRICE_{BaseYear, Gasoline} + AFVADJPR_{ElectricHybrid,3} * \frac{WEIGHT_{BaseYear, Gasolin}}{WEIGHT_{Midsize, BaseYear, Gas}} \quad (12)$$

4) Calculate base year values for such AFV characteristics as fuel economy, weight, and horsepower.

a) Fuel Economy Calculation

$$FE_{BaseYear, FuelType} = FE_{BaseYear, Gasoline} * (1 + AFVADJFE_{FuelType}) \quad (13)$$

where:

AFVADJFE = Fuel economy adjustment, relative to gasoline, for an AFV

b) Weight Calculation

$$WEIGHT_{BaseYear, FuelType} = WEIGHT_{BaseYear, Gasoline} * (1 + AFVADJWT_{FuelType}) \quad (14)$$

where:

AFVADJWT = Weight adjustment, relative to gasoline, for an AFV

### c) Horsepower Calculation

$$HP_{BaseYear, FuelType} = HP_{BaseYear, Gasoline} * (1 + AFVADJHP_{FuelType})$$

where:

AFVADJHP = Horsepower adjustment, relative to gasoline, for an AFV

## II. CALCULATE TECHNOLOGY MARKET SHARES

FEM first determines the cost effective market shares of technologies for each vehicle class and then calculates the resulting Fuel Economy, Weight, Horsepower and Price through the subroutine FEMCALC. In each forecast period this function is called twice. During the first pass, technology market shares are calculated for all vehicle classes. In the second pass, the technology market shares are recalculated for vehicles in groups failing to meet the CAFE standards. During this pass, the cost effectiveness calculation is adjusted to include the regulatory cost of failing to meet CAFE<sup>2</sup>. If a vehicle group continues to fail to meet CAFE standards after the second pass, no further adjustments to technology market shares are made. Rather, it is assumed that the manufacturers simply pay the penalty.

For each vehicle class, FEMCALC follows these steps:

- A. Calculate the economic market share for each technology
- B. Apply the engineering notes to control market penetration
  - Adjust the economic market shares through application of the mandatory, supersedes and requires engineering notes
  - Adjust the fuel economy impact through application of the synergy engineering notes
- C. Calculate the net impact of the change in technology market share on fuel economy, weight

---

<sup>2</sup> See the variable REGCOST in Equation 6. During pass 1 REGCOST has a value of 0. During pass 2 it is set to REG\$COST, which is a user input.

and price

- D. Adjust horsepower based on the new fuel economy and weight
- E. Readjust fuel economy based on the new horsepower, and price based on the change in horsepower

Each step is described in more detail below. Readers should note that all of the calculations in this section take place within loops by Group, Class, and Fuel Type. In the interest of legibility, these dimensions are not shown in the subscripts.

**A: Calculate the economic market share for each technology**

The cost effective market share calculation for each technology is based on the cost of the technology, the present value of the expected fuel savings and the perceived value of performance. These are addressed in turn below.

Fuel Savings Value

The "expected" price of fuel is based on the rate of change of fuel prices over a two year period prior to the year when the technology adoption decision is made. The time decision to introduce a particular technology is made at least three years before actual introduction in the marketplace, and is based on the expected fuel prices at the time of introduction rather than actual fuel prices. The expected present value of fuel savings is dependant on the "expected" price of fuel, how long the purchaser is willing to wait to recover the initial investment (the payback period); and the distance driven over the period. This estimation involves the following three steps:

- 1) Calculate the fuel cost slope (PSLOPE), used to extrapolate linearly the expected fuel cost over the desired payback period, constraining the value to be equal to or greater than zero:

$$PSLOPE = \frac{MAX(0, FUELCOST_{YEAR-3} - FUELCOST_{YEAR-5})}{2} \quad (16)$$

- 2) Calculate the expected fuel price (PRICE\$EX) in year i (where i goes from 1 to PAYBACK):

$$PRICE\$EX_i = PSLOPE * (i+2) + FUELCOST_{YEAR-3} \quad (17)$$

- 3) Calculate the expected present value of fuel savings (FUELSAVE) over the payback period:

$$\begin{aligned}
FUELSAVE_{itc} = & \sum_{i=1}^{PAYBACK} VMT_i * \left( \frac{1}{FE_{itc,YEAR-1}} - \frac{1}{(1 + DEL\$FE_{itc} * FE_{itc,YEAR-1})} \right) \\
& * PRICE\$EX_i * (1 + DISCOUNT)^{-i}
\end{aligned} \tag{18}$$

where:

- VMT = Annual vehicle-miles traveled
- itc* = The index representing the technology under consideration
- FE = The fuel economy of technology *itc*
- DEL\$FE = The fractional change in fuel economy associated with technology *itc*
- PAYBACK = The user-specified payback period
- DISCOUNT = The user-specified discount rate

### Technology Cost

Technology cost has both absolute and weight dependant components. The absolute component is a fixed dollar cost for installing a particular technology on a vehicle. Most technologies are in this category. The weight dependant component is associated with the material substitution technologies. In these technologies a heavy material is replaced with a lighter one. The technology cost is a function of the amount of material, which is in turn a function of how heavy the vehicle was to begin with. The technology cost equation includes both components, although in practice one or the other term is always zero:

$$TECHCOST_{itc} = DEL\$COSTABS_{itc} - \left( DEL\$COSTWGT_{itc} * DEL\$WGTWGT_{itc} * WEIGHT_{BASEYR} \right) \tag{19}$$

where:

- TECHCOST = The cost per vehicle of technology *itc*
- DEL\\$COSTWGT = The weight-based change in cost (\$/lb)
- DEL\\$WGTWGT = The fractional change in weight associated with technology *itc*
- WEIGHT = The original vehicle weight

### Performance Value

Although there are a number of technological factors which affect the perceived "performance" of a vehicle, in the interests of clarity and simplicity it was decided to use the vehicle's horsepower as a proxy for the general category of performance. An increase in horsepower is assumed to reduce the fuel economy based on the relationship given in Equation 21. The perceived value of performance is also a factor in the cost effectiveness calculation. The value of performance for a given technology is positively correlated with both income and vehicle fuel economy and negatively correlated with fuel prices. In addition, purchasers of sports and luxury vehicles tend to place a higher value on performance:

$$VAL\$PERF_{itc} = VALUEPERF_{itc} * \frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} * \frac{FE_{YEAR-1} * (1 + DEL\$FE_{itc})}{FE_{YEAR-1}} * \frac{FUELCOST_{YEAR-1}}{PRICE\$EX_1} * DEL\$HP_{itc} \quad (20)$$

where:

VAL\$PERF = The dollar value of performance of technology *itc*  
 VALUEPERF = The value associated with an incremental change in performance  
 FE = Vehicle's fuel economy  
 DEL\$FE = The fractional change in fuel economy of technology *itc*  
 DEL\$HP = The fractional change in horsepower of technology *itc*  
 FUELCOST = The actual price of fuel (in the previous year)

### Economic Market Share

The market share of the considered technology is determined by first evaluating the cost effectiveness of technology *itc* as a function of the values described above:

$$COSTEFFECT_{itc} = \frac{FUELSAVE_{itc} - TECHCOST_{itc} + VAL\$PERF_{itc} + (REGCOST * FE_{YEAR-1} * DEL\$FE_{itc})}{ABS(TECHCOST_{itc})} \quad (21)$$

where:

COSTEFFECT = A unitless measure of cost effectiveness  
 REGCOST = A factor representing regulatory pressure to increase fuel economy, in \$ per MPG

and:

$$ACTUAL\$MKT_{itc} = MMAX_{itc} * PMAX_{itc} * \left(1 + e^{-2 * COSTEFFECT_{itc}}\right)^{-1} \quad (22)$$

where:

ACTUAL\$MKT = The economic share, prior to consideration of engineering or regulatory constraints.  
 MMAX = The maximum market share for technology *itc*  
 PMAX = The institutional maximum market share, which models tooling constraints on the part of the manufacturers, and is set in a separate subroutine. This subroutine (FUNCMAX) sets the current year maximum market share based on the previous year's share. The values are tabulated in Appendix A, Table A-3.

### Market Share Overrides

Existing technologies are assumed to maintain their market shares unless forced out by later technologies. If the cost effectiveness calculation yields an economic market share which is below



the market share in the previous period then the calculated value is overridden:

$$ACTUAL\$MKT_{itc} = MAX ( MKT\$PEN_{YEAR-1} , ACTUAL\$MKT_{itc} ) \quad (23)$$

where:

MKT\$PEN = Temporary variable which stores value of ACTUAL\$MKT, calculated in Equation 7, from previous year

### ***B: Apply the Engineering Notes***

The engineering notes consist of a number of overrides to the economic cost effectiveness calculations done in the previous step. The first three types of notes (mandatory, supersedes and requires) directly affect the technology market share results obtained above. The fourth type of note, synergy, does not affect the market share and is applied after all other engineering notes have been applied.

#### **Mandatory Notes**

These are usually associated with safety or emissions technology which must be in place by a certain year. For example, air bags are mandatory in 1994. If the cost effectiveness calculations do not produce the mandated level of technology then those results are overridden as follows:

$$ACTUAL\$MKT_{itc} = MAX ( ACTUAL\$MKT_{itc} , MANDMKSH_{itc} ) \quad (24)$$

where:

MANDMKSH = Market share for technology *itc* which has been mandated by legislative or regulatory action

#### **Supersedes Notes**

These are associated with newer technologies which replace older ones. For example, 5-speed automatic transmissions supersede 4-speed automatics. Once the cost effective market share for the newer technology (e.g. 5-speed automatics) has been calculated, the market share(s) of the older technology(ies) (e.g. 4-speed automatics) are reduced, if necessary, to force the total market shares for the old and new technologies to add up to 100 percent.

For example, given a group of competing technologies A, B, and C, suppose that C is the oldest technology while A is the newest. After calculating the economic market share for each technology, and applying the *mandatory* notes as described above, the following steps are then taken:

- 1) Add the three market shares together:

$$SUM\$MKT = ACTUAL\$MKT_A + ACTUAL\$MKT_B + ACTUAL\$MKT_C \quad (25)$$

- 2) Identify the largest maximum market share for the group of technologies:

$$MMAX = MAX(MKT\$MAX_A, MKT\$MAX_B, MKT\$MAX_C) \quad (26)$$

where:

MKT\$MAX = Maximum market share of technology *itc*

- 3) If SUM\$MKT <= MMAX, then make no adjustments.
- 4) If SUM\$MKT > MMAX, then subtract market share from technology C until the sum of the market shares equals MMAX, or until ACTUAL\$MKT<sub>C</sub> = 0.
- 5) If SUM\$MKT is still greater than MMAX, subtract market share from technology B until the sum of the market shares equals MMAX.

### Requires Notes

These notes control the adoption of technologies which require that other technologies also be present on the vehicle. For example, since Variable Valve Timing II requires the presence of an Overhead Cam, the market share for Variable Valve Timing II cannot exceed the sum of the market shares for Overhead Cam 4, 6 & 8 cylinder engines. This note is implemented as follows:

- 1) For a given technology *itc*, define a group of potential matching technologies, one of which must be present for *itc* to be present.
- 2) Sum the market shares of the matching technologies (*req*):

$$REQ\$MKT = \sum_{req}^{RQ} ACTUAL\$MKT_{req} \quad (27)$$

where:

REQ\$MKT = The market share of required complementary technologies to technology *itc*.  
 req = Index referring to all required complementary technologies to technology *itc*.  
 RQ = Number of required complementary technologies to technology *itc*.

- 3) Compare REQ\$MKT to the market share of technology *itc*: ACTUAL\$MKT<sub>*itc*</sub>.
- 4) If ACTUAL\$MKT<sub>*itc*</sub> <= REQ\$MKT, then make no change.
- 5) If ACTUAL\$MKT<sub>*itc*</sub> > REQ\$MKT, then set ACTUAL\$MKT<sub>*itc*</sub> = REQ\$MKT

It is at this point that the adjusted economic market share, ACTUAL\$MKT<sub>*itc*</sub>, is assigned to the variable MKT\$PEN<sub>*itc,Year*</sub> for use in the remainder of the calculations.

### Synergistic Notes

Synergistic technologies are those which, when installed simultaneously, interact to affect fuel economy. A vehicle with synergistic technologies will not experience the change in fuel economy predicted by adding the impact of each technology separately. Conceptually such interactions could yield either greater or lower fuel economy; however, in all cases observed in FEM the actual fuel economy is lower than expected. For example, Variable Valve Timing I is synergistic with 4-speed automatic transmissions. If both are present on a vehicle then the actual fuel economy improvement is 2 percent below what would be expected if the technologies were simply added together with no regard for their interaction.

Synergy adjustments are made once all other engineering notes have been applied. For each synergistic pair of technologies the fuel economy is adjusted as follows:

$$\begin{aligned}
 FE_{YEAR} = FE_{YEAR} + & \left( MKT\$PEN_{itc1,YEAR} - MKT\$PEN_{itc1,YEAR-1} \right) \\
 & * \left( MKT\$PEN_{itc2,YEAR} - MKT\$PEN_{itc2,YEAR-1} \right) * SYN\$DEL_{itc1,itc2}
 \end{aligned}
 \tag{28}$$

where:

FE = Fuel economy, by size class and group, initialized to the previous year's value and subsequently modified with each iteration of the model.  
*itc1* = First synergistic technology  
*itc2* = Second synergistic technology  
 SYN\$DEL = The synergistic effect of the two technologies on fuel economy

### **C: Calculate Net Impact of Technology Change**

The net impact of changes in technology market shares is first calculated for fuel economy, weight

and price. Horsepower is dependant on these results and must be calculated subsequently. For a given technology  $itc$ , the change in market share since the last period (DELTA\$MKT) is calculated as follows:

$$DELTA\$MKT_{itc} = MKT\$PEN_{itc,YEAR} - MKT\$PEN_{itc,YEAR-1} \quad (29)$$

DELTA\$MKT<sub>itc</sub> is used to calculate the incremental changes in fuel economy, vehicle weight, and price due to the implementation of the considered technology.

### Fuel Economy

Current fuel economy for a vehicle class is calculated as the previously adjusted fuel economy plus the sum of incremental changes due to newly adopted technologies:

$$FE_{YEAR} = FE_{YEAR} + \sum_{itc=1}^{NUMTECH} FE_{YEAR-1} * DELTA\$MKT_{itc} * DEL\$FE_{itc} \quad (30)$$

where:

NUMTECH = Number of newly adopted technologies

### Vehicle Weight

Current weight for a vehicle class is calculated as the current weight plus the sum of incremental changes due to newly adopted technologies. As with the technology cost equation, the weight equation has both absolute and variable components. Most technologies add a fixed number of pounds to the weight of a vehicle. With material substitution technologies the weight change depends upon how much new material is used, which is a function of the original weight of the vehicle. The weight equation includes both absolute and weight dependant terms in the summation expression. For any given technology, one term or the other will be zero.

$$WEIGHT_{YEAR} = WEIGHT_{YEAR} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * [DEL\$WGTAbs_{itc} + (WEIGHT_{BASEYR} * DEL\$WGTWGT_{itc})] \quad (31)$$

where:

DEL\$WGTAbs = The change in weight (lbs) associated with technology  $itc$

DEL\$WGTWGT = The fractional change in vehicle weight due to technology *itc*

WEIGHT = Vehicle weight, by size class and group, initialized to the previous year's value and subsequently modified with each iteration of the model.

### Vehicle Price

Current price for a vehicle class is calculated as the current price plus the sum of incremental changes due to newly adopted technologies. As with the weight equation, the price equation has both absolute and variable components. Most technologies add a fixed cost to the price of a vehicle. For the material substitution technologies, cost depends on the amount of new material used, which is in turn dependent on the original weight of the vehicle. The price equation includes both absolute and weight dependant terms in the summation expression. For any given technology, one term or the other will be zero.

$$PRICE_{YEAR} = PRICE_{YEAR} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * [DEL\$COSTABS_{itc} + (WEIGHT_{YEAR} - WEIGHT_{BASEYR}) * DEL\$COSTWGT_{itc}] \quad (32)$$

where:

DEL\$COSTABS = The cost of technology *itc*

DEL\$COSTWGT = The weight-based change in cost of technology *itc* (\$/lb)

PRICE = Vehicle price, by size class and group, initialized to the previous year's value and subsequently modified with each iteration of the model.

The characteristics of electric and fuel cell vehicles, including weight, battery cost, and fuel economy must then be calculated in separate subroutines prior to the estimation of market shares.

## **D: Estimate EV and Fuel Cell Characteristics**

### Electric Vehicles

This set of calculations, contained within the subroutine EVCALC estimates battery cost, vehicle price (low and high volume sales), weight and fuel economy for electric vehicles. Fuel economy is in kilowatt-hours/mile (wall plug.)

The first step in EVCALC is determination of the battery weight and cost for both lead acid and Nickel Metal Hydride (Ni-MH) batteries. The numerical constants in the equations represent the result of exogenous analysis and professional judgement on the part of the model developers.

#### 1) Weight and cost of a lead acid battery

$$BATTERY1\$WT = 0.60 * WEIGHT_{Year,Gasoline}$$

*and*

**(33)**

$$BATTERY1\$COST = BATTERY1\$WT * 2.30 * 1.75 + 1500$$

where:

- BATTERY1\$WT = Weight of a lead acid battery large enough to provide adequate range and performance
- BATTERY1\$COST = Cost of a lead acid battery
- 0.60 = Fraction of vehicle weight accounted for by the battery system
- \$2.30 = Cost/pound of a lead acid battery
- 1.75 = Cost multiplier to determine retail price
- \$1,500 = Fixed cost amortization per unit EV

## 2) Weight and cost of a nickel metal hydride battery

$$BATTERY2\$WT = 0.203 * WEIGHT_{Year,Gasoline}$$

*and*

**(34)**

$$BATTERY2\$COST = BATTERY2\$WT * 8.20 * 1.75 + 1500$$

where:

- BATTERY2\$WT = Weight of a Ni-MH battery large enough to provide adequate range and performance
- BATTERY2\$COST = Cost of a Ni-MH battery
- \$8.20 = Cost/pound of a Ni-MH battery
- 1.75 = Cost multiplier to determine retail price
- \$1,500 = Fixed cost amortization per unit EV

The next step is to apply a learning curve adjustment to the cost of the battery. It is assumed that there is a twenty-five (25) percent cost reduction/decade for both lead acid and Nickel Metal Hydride batteries. The learning curves have been pre-calculated and are initialized in BLOCK DATA. The lead acid curve begins immediately, while the Nickel Metal Hydride battery costs do not begin to go down until after 2003.

## 3) Learning curve adjustment for battery costs

$$BATTERY1\$COST = BATTERY1\$COST * LEADACID\$COST_{Year}$$

*and*

**(35)**

$$BATTERY2\$COST = BATTERY2\$COST * NIMHY\$COST_{Year}$$

where:

LEADACID\$COST = Cost reduction learning curve for a lead acid battery

NIMHY\$COST = cost reduction learning curve for a Ni-MH battery

Next, the average price of an electric vehicle battery is determined based on the expected market shares of lead acid and Nickel Metal Hydride batteries:

4) Average price of an electric vehicle battery

$$\begin{aligned} BATTERY_{Year,ElectricVehicle} &= BATTERY1\$COST * (1 - NIMHY\$MKTSH_{Year}) \\ &+ BATTERY2\$COST * NIMHY\$MKTSH_{Year} \end{aligned} \quad (36)$$

where:

BATTERY = Average price of an electric vehicle battery

NIMHY\$MKTSH = Expected market share of Ni-MH batteries

Finally, Price, Weight and Fuel Economy are calculated:

5) Electric Vehicle Price

$$PRICE_{Year,ElectricVehicle} = PRICE_{Year,ElectricVehicle} + BATTERY_{Year,ElectricVehicle} \quad (37)$$

Since PRICEHI (high production AFV) uses the same equation as PRICE (with the substitution of PRICEHI for PRICE on both sides on the equation), it is not shown separately.

6) Electric Vehicle Weight

$$\begin{aligned} WEIGHT_{Year,ElectricVehicle} &= \frac{BATTERY1\$WT}{0.33} * (1 - NIMHY\$MKTSH_{Year}) \\ &+ \frac{BATTERY2\$WT}{0.22} * NIMHY\$MKTSH_{Year} \end{aligned} \quad (38)$$

7) Fuel Economy (miles/Kilowatt-hour wall plug)

$$FE_{Year,Electric\ Vehicle} = \left[ \frac{0.8 \cdot (2,200)}{0.16 \cdot WEIGHT_{Year,Electric\ Vehicle}} \right] \quad (39)$$

### Fuel Cell Vehicles

The subroutines FCMCALC and FCHCALC calculate fuel cell cost, vehicle price (low and high volume sales), and fuel economy for methanol and hydrogen fuel cell vehicles, respectively. Note that although values for fuel cell vehicles are calculated for the early years, it is not likely that there will actually be any on the road until at least 2010. Hydrogen supply is expected to be a major problem for the corresponding vehicles. In the following equations the *FC* subscript refers to Fuel Cell.

#### 1) Fuel Cell Cost

$$FUELCELL_{Year,FC} = 30 * \frac{WEIGHT_{Year,Gasoline}}{2200} * FUELCELL\$COST_{Year,FC} \quad (40)$$

where:

FUELCELL = Cost of the fuel cell.

FUELCELL\$COST = Cost of the fuel cell in \$/kw

#### 2) Battery Power Required to start vehicle

$$BATTERY\$POWER = 20 * \frac{WEIGHT_{Year,Gasoline}}{2200} \quad (41)$$

where:

BATTERY\$POWER = Required battery power in Kw

#### 3) Weight of Battery

$$BATTERY\$WT = 2.2 * \frac{BATTERY\$POWER}{0.5} \quad (42)$$

where:

BATTERY\$WT = Weight of battery



4) Cost of Battery

$$BATTERY_{Year,FC} = 2.30 * BATTERY\$WT * LEADACID\$COST_{Year} \quad (43)$$

where:

BATTERY = Cost of the lead acid battery

\$2.30 = Initial cost per pound for the battery

LEADACID\\$COST<sub>Year</sub> = Cost reduction learning curve for a lead acid battery

5) Add Battery to cost of fuel cell and calculate retail price

$$FUELCELL_{Year,FC} = (FUELCELL_{Year,FC} + BATTERY_{Year,FC} + HTANK_{FC}) * 1.75 + 150 \quad (44)$$

where:

HTANK = Cost of the hydrogen storage tank: \$0 for Methanol FC, \$3000 for Hydrogen FC.

1.75 = Cost multiplier to determine retail price

\$1,500 = Fixed cost amortization per unit fuel cell vehicle

6) Fuel Cell Vehicle Price

$$PRICE_{Year,FC} = PRICE_{Year,FC} + FUELCELL_{Year,FC} \quad (45)$$

7) Fuel Cell Fuel Economy (gasoline equivalent mpg)

$$FE_{Year,FC} = \frac{1}{0.00625 * \frac{WEIGHT_{Year,Gasoline}}{1000}} \quad (46)$$

**E: Adjust Horsepower**

Calculating the net impact of changes in technology share on vehicle horsepower is a two step

process. First, horsepower is calculated on the basis of weight; this step assumes no change in performance. This initial estimate simply maintains the weight to horsepower ratio observed in the base year:

### Unadjusted Horsepower

Assuming a constant weight/horsepower ratio:

$$HP_{YEAR} = HP_{BASEYR} * \frac{WEIGHT_{YEAR}}{WEIGHT_{BASEYR}} \quad (47)$$

where:

HP = Vehicle horsepower  
WEIGHT = Vehicle weight

### Adjustment Factor

The second step adjusts horsepower for changes in performance. This calculation is based on household income, vehicle price, fuel economy, fuel cost, and the perceived desire for performance (PERFFACT):

$$ADJHP = PERFFACT * \left[ \left( \frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} \right)^{0.9} * \left( \frac{PRICE_{YEAR-1}}{PRICE_{YEAR}} \right)^{0.9} * \left( \frac{FE_{YEAR}}{FE_{YEAR-1}} \right)^{0.2} * \left( \frac{FUELCOST_{YEAR-1}}{FUELCOST_{YEAR}} \right)^{0.2} - 1 \right] \quad (48)$$

where:

ADJHP = Vehicle horsepower adjustment factor

Note that if income, vehicle price, fuel economy and fuel cost remain the same, the expression in parentheses resolves to:  $(1*1*1*1 - 1) = 0$ . Thus, unless there is some change in the economics, there will be no change in horsepower due to a desire for more performance. In an economic status quo, the only changes in horsepower will be those required to maintain the base year weight-to-horsepower ratio calculated above.

### Adjusted Horsepower

The current year horsepower is then calculated as follows:

$$HP_{YEAR} = HP_{YEAR} * \left( 1 + \sum_{1990}^{YEAR} ADJHP \right) \quad (49)$$

Note that this equation uses the sum of horsepower adjustments to date. This is necessary because the first step of the adjustment ignores the previous period result ( $HP_{YEAR-1}$ ) and calculates current horsepower using the base year weight-to-horsepower ratio. The summation term incorporates all horsepower adjustments due to economic changes which occur in the intervening forecast periods. The final HP estimate is then checked to see if it meets the minimum driveability criterion which are set at  $WT/HP = 30$  for all cars except sports and luxury for which the criterion is  $WT/HP = 25$ . These minima are derived from the experience of the early 1980's.

### ***F: Readjust Fuel Economy and Price***

Once the horsepower adjustment has been determined, the final fuel economy for the vehicle must be calculated.

#### *Fuel Economy Adjustment Factor*

The fractional change in fuel economy based on the fractional change in horsepower is first calculated (ADJFE). This is an engineering relationship expressed by the following equation:

$$ADJFE = -0.22 * ADJHP - 0.560 * ADJHP^2 \quad (50)$$

#### *Adjusted Fuel Economy*

The final vehicle fuel economy is then determined as follows:

$$FE = FE * (1 + ADJFE) \quad (51)$$

#### *Adjusted Vehicle Price*

Vehicle price is finally estimated:

$$PRICE = PRICE + ADJHP * VALUEPERF \quad (52)$$

Note that as these are final adjustments, the results do not feed back into the horsepower adjustment equation.

The above equations result in an estimate of the market shares of the considered technologies within each class of vehicle. The effective range for each vehicle class is then calculated.

### **G: Estimate Vehicle Range**

For most vehicles, range is a function of tank size and fuel economy as shown in below:

#### 1) Vehicle Range Calculation

$$RANGE_{Year, FuelType} = TANKSIZE * FE_{Year} * (1 + AFVADJRN_{FuelType}) \quad (53)$$

where:

RANGE = Vehicle range

TANKSIZE = Tanksizes for a gasoline vehicle of the same size class

AFVADJRN = Range adjustment, relative to gasoline, for an AFV (exogenous, from Block Data)

The range adjustment factor (AFADJRN) is derived through engineering judgment and is based on current gasoline vehicle tank sizes, likely relative fuel capacity for alternative vehicles and the actual base year relative fuel economies of gasoline and alternative fuel vehicles. Of necessity, the range estimate is less accurate than the AFV fuel economy projections.

Range for Electric Battery vehicles is set to 80 miles. This is an engineering judgment of the best performance likely to be obtained from a production electric powered vehicle in the foreseeable future. The next step is to calculate the market shares of each vehicle class within each CAFE group.

### **III. CALCULATE CLASS MARKET SHARES**

This routine calculates vehicle class market shares within each "corporate" average fuel economy group (i.e. Domestic Cars, Import Cars, Domestic Trucks and Import Trucks.) Market shares for each class are derived by calculating an increment from the base year (1990) market share. The market share increment (or decrement) is determined by one of the following equations (depending on vehicle class):

#### All Vehicle Classes Except Luxury Cars.<sup>3</sup>

---

<sup>3</sup> Note: Market shares for Mini and Sub-Compact cars are solved jointly using equation 24. The resulting combined market share is allocated between the two classes based on the original 1990 allocation. Special treatment of these two classes was made necessary by the small sample size in the analysis data sets.

$$\ln \left( \frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i} \right)_{YEAR} - \ln \left( \frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i} \right)_{1990} = A * \ln \left( \frac{YEAR}{1990} \right) + B * \ln \left( \frac{FUELCOST_{YEAR}}{FUELCOST_{1990}} \right) + C * \ln \left( \frac{INCOME_{YEAR} - \$13,000}{INCOME_{1990} - \$13,000} \right) \quad (54)$$

where CLASS\$SHARE<sub>i</sub> is the market share of the i<sup>th</sup> market class, and the values of the coefficients A, B, and C are tabulated in Table E-1 of Appendix E.

### Luxury Cars:

The calculated increment is added to the base year market share to obtain a current year value. After market shares are derived for all vehicle classes, the results are normalized so that market shares sum to 100% within each CAFE group.

$$\ln \left( \frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i} \right)_{YEAR} - \ln \left( \frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i} \right)_{1990} = A * \ln \left( \frac{YEAR}{1990} \right) + B * \ln \left( \frac{FUELCOST_{YEAR}}{FUELCOST_{1990}} \right) + C * \ln \left( \frac{INCOME_{YEAR}}{INCOME_{1990}} \right) \quad (55)$$

## **CALCULATE CORPORATE AVERAGE FUEL ECONOMY**

This routine calculates the "corporate" average fuel economy for each of the four groups:

- 1) Domestic Cars
- 2) Import Cars
- 3) Domestic Trucks
- 4) Import Trucks

For each vehicle group the CAFE calculation proceeds as follows:

$$CAFE_{i,k, YEAR} = \frac{\sum_{i=1}^7 CLASS\$SHARE_{i,k, YEAR}}{\sum_{i=1}^7 \frac{CLASS\$SHARE_{i,k, YEAR}}{FE_{i,k, YEAR}}} \quad (56)$$

where:

i = Vehicle Class  
k = CAFE Group

This CAFE estimate is then compared with the legislative standard for the manufacturer group and year. If the forecast CAFE is less than the standard, a second iteration of the model is performed after resetting the regulatory cost (REGCOST). If the recalculated CAFE is still below the standard, no further iteration occurs, as the manufacturer is then assumed to pay the fine.

#### IV. COMBINE RESULTS OF DOMESTIC AND IMPORTED VEHICLES

In subsequent components of the transportation model, domestic and imported vehicles are not treated separately. It is therefore necessary to construct an aggregate estimate of fuel economy for each class of car and light truck. Aggregate fuel economy is determined by weighting each vehicle class by their relative share of the market. These figures are assumed to be constant across classes and time, and have been obtained from Oak Ridge estimates of the domestic and imported market shares:<sup>4</sup>

For Cars (except mini-compacts):

$$FE_{CLASS} = \left[ \frac{.742}{FE_{CLASS,Domestic}} + \frac{.258}{FE_{CLASS,Import}} \right]^{-1} \quad (57)$$

For Light Trucks (except standard pickups, standard vans, and standard utility vehicles):

$$FE_{CLASS} = \left[ \frac{.868}{FE_{CLASS,Domestic}} + \frac{.132}{FE_{CLASS,Import}} \right]^{-1} \quad (58)$$

All mini-compact cars are imported, and all standard pickups, standard vans, and standard utility vehicles are produced domestically.

The fuel economies of the seven size classes described above are subsequently collapsed into six size classes considered by the remainder of the Transportation Model, and benchmarked to correspond

---

<sup>4</sup> Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 12*, ORNL-6710, 3/92.  
For Cars: Table 3.9, 1990 data. For Light Trucks: Table 3.16, 1990 data.

to 1992 NHTSA estimates of fuel economy for each size class. These numbers are then passed to the Alternative Fuel Vehicle (AFV) Model, and the overall fleet stock model to produce estimates of fleet efficiencies.

### **3A-3. AFV Model**

The Alternative Fuel Vehicle (AFV) Model is a forecasting tool designed to support the Light Duty Vehicle (LDV) Module of the NEMS Transportation Sector Model. This model uses estimates of new car fuel efficiency obtained from the Fuel Economy Model (FEM) subcomponent of the LDV Module, and fuel price estimates generated by NEMS to generate market shares of each considered technology. The model is useful both to assess the penetration of alternative-fuel vehicles and to allow analysis of policies that might impact this penetration.

#### **RATIONALE**

The objective of the AFV model is to estimate the market penetration (market shares) of alternative-fuel vehicles during the period 1990-2030. The model provides market shares for fourteen alternative-fuel technologies in addition to the conventional gasoline and diesel technologies. The shares are projected in three stages. In the first stage the two conventional technologies are allowed to compete with a single representative alternative-fuel vehicle technology. In the second stage the overall alternative-fuel vehicle share is disaggregated among eleven competitive alternative-fuel technologies. In the third stage the electric vehicle (EV) share is distributed among four EV and hybrid technologies. Forecasts of vehicle-technology shares are developed for each of the nine U.S. Census regions.

The AFV model is an improvement over the predecessor model used in the AEO 93, which assigned market shares to four basic alternative technologies based on legislative mandates. That model left no room for consideration of technological or market-driven limitations on the penetration of AFV's, thereby limiting its usefulness in evaluating the impacts of alternative policies.

#### **ALTERNATIVE SPECIFICATIONS**

There are very few current models which attempt to estimate the market penetration of alternative fuel vehicles. The methodology used in the AFV module is based on attribute-based discrete choice techniques and logit-type choice functions described in previous reports.<sup>5</sup> The attribute coefficients used in the module are derived from a logit discrete-choice consumer preference model commissioned

---

<sup>5</sup> See Fulton, L., *New Technology Vehicle Penetration: A Proposal for an Analytical Framework*, Submitted to EIA, Office of Energy markets and End Use, March 17, 1991.



by the state of California.<sup>6</sup> The methodology consists of the estimation of a demand function for vehicle sales in the U.S. market and the derivation of coefficients for the vehicle and fuel attributes which portrays consumer demand. Once the demand function has been determined, projections of the changes in vehicle and fuel attributes for the considered technologies are multiplied by the corresponding attribute coefficients to produce the market share penetration for the various technologies.

An important limitation in estimating market share penetration of alternative fuel technologies is the lack of experience in consumer use of alternative technologies. Only a limited number of alternative-fuel technologies are commercially available at the present time and the vehicle options which are available are still in experimental stages of development resulting in significantly high vehicle prices. Lack of data on previous consumer purchases of alternative fuel vehicles poses a significant obstacle in estimating an equation to forecast future market share penetration. A stated preference survey performed for the California Energy Commission (CAC) which asked consumers their vehicle choice preference in reference to hypothetical scenarios is used in the AFV module. The demand function for personal vehicle choice determined from this survey is used as the source for the attribute coefficients for the AFV module.<sup>7</sup>

The demand estimation incorporates a logit discrete choice model to calculate consumer vehicle preference in relation to vehicle and fuel attributes. A survey was conducted in which respondents were asked to express their preferences for vehicles based on vehicle and fuel attributes. The stated preference survey consisted of a sample size of 692 respondents yielding 3460 observations. Based on the stated preference surveys a mathematical model was estimated to account for consumer preferences in vehicle choice.

The demand function is a logit discrete choice model that can be represented as follows:

$$\log \frac{\hat{P}_i}{1 - \hat{P}_i} = \beta_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_i X_i + \epsilon_i$$

where  $P_i$  is the probability of a consumer choosing vehicle  $i$ ,  $\beta_1$  is the constant,  $\beta_i$  are the coefficients

---

<sup>6</sup> The coefficients of the vehicle attributes derived from the Logit discrete choice model are taken from Bunch, D.S.; Bradley, M.; Golob, T.F.; Kitamura, R.; Occhiuzzo, G.P., *Demand For Clean Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Survey*, CAC, Dec. 1991.

<sup>7</sup> For a detailed explanation of the demand function estimation, see Bunch, D.S.; Bradley, M.; Bolob, T.F.; Kitamura, R. and Occhiuzzo, G.P., *Demand for Clean-Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Survey*, California Energy Commission, December 1991.

of vehicle and fuel attributes and  $X_i$  are vehicle and fuel attributes.

The resulting specifications of the nested multinomial logit discrete choice model for estimating market share penetration of alternative fuel technologies from the stated preference survey are presented in Table E-2 of Appendix E. The independent variables, coefficients, t-statistics, sample size, and log-likelihood calculations are listed. The coefficient signs of the five fundamental independent variables correspond with *a priori* expectations for consumer preference and all the fundamental independent variables are significant in the model.<sup>8</sup>

The basic structure of the forecast component of the market share estimation for alternative fuel vehicle sales is a three-dimensional matrix format. The matrix consists of  $I$  vehicle technology types,  $K$  attributes for each technology, and  $T$  number of years for the analysis. Each cell  $C_{ikt}$  in the  $C$  matrix contains a coefficient reflecting the value of attribute  $k$  of vehicle technology  $i$  for the given year  $t$ .<sup>9</sup>

The calculation of the market share penetration of alternative fuel vehicle sales is expressed in the following equation:

$$S_{it} = P_{it} = \sum_{n=1}^N \frac{P_{itn}}{N}, \quad P_{itn} = \frac{e^{V_{itn}}}{\sum_{i=1}^I e^{V_{itn}}}$$

where:

- $S_{it}$  = market share sales of vehicle type  $i$  in year  $t$ ,
- $P_{it}$  = aggregate probability over population  $N$  of choosing type  $i$  in year  $t$ ,
- $n$  = individual  $n$  from population  $N$ ,
- $P_{itn}$  = probability of individual  $n$  choosing type  $i$  in year  $t$ ,
- $V_{itn}$  = a function of the  $K$  elements of the vector of attributes ( $A$ ) and coefficients ( $B$ ), generally linear in parameters, i.e.:

$$V = \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k$$

and  $V$  is specific to vehicle  $i$ , year  $t$ , and individual  $n$ .

---

<sup>8</sup> Several variations for the discrete-choice stated preference model for alternative fuel vehicle choice were presented in the California Energy Commission report; however, the nested multinomial logit model presented in Table 2 is the preferred model to use in the AFV module.

<sup>9</sup> The forecasting methodology is based on the methodology defined in the Decision Analysis Corporation of Virginia Report, *Alternative Vehicle Sales Module: Design of the Modeling Framework and Prototype Module Description*, for Energy Information Administration, Task 91-137, September 30, 1991.

The above equation asserts that the share of each technology is equivalent to the aggregate probability over the population of choosing that technology, which is produced by summing the individual probability functions. The individual probabilities are a function of the ratio of the  $V$ 's (taken as an exponential). The market share of each vehicle type is ultimately determined by its attributes relative to the attributes of all competing vehicles.

The  $C$  matrix represented below is a simple illustration of the matrix format used in the market share calculation. For simplicity, a 4 by 4 matrix of four vehicle types ( $i = 4$ ) and four attributes ( $k = 4$ ), for individual  $n$  in year  $t$ , has been chosen.

	$C_{ik} = (\beta_{ik} X_{ik})$	$k=1$	$k=2$	$k=3$	$k=4$
$V_1 = \sum C_{1k}$	$i=1$	$C_{11}$	$C_{12}$	$C_{13}$	$C_{14}$
$V_2 = \sum C_{2k}$	$i=2$	$C_{21}$	$C_{22}$	$C_{23}$	$C_{24}$
$V_3 = \sum C_{3k}$	$i=3$	$C_{31}$	$C_{32}$	$C_{33}$	$C_{34}$
$V_4 = \sum C_{4k}$	$i=4$	$C_{41}$	$C_{42}$	$C_{43}$	$C_{44}$

The factor  $C_{ik}$  represents the product of the coefficient  $\beta_{ik}$  derived from the demand function and the attribute value  $X_{ik}$  for vehicle type  $i$  and attribute  $k$ .

The coefficients of the vehicle attributes in the AFV module are assumed to remain constant over time. This enables the calculation of the  $C$  matrix to be less cumbersome; however, the methodology can utilize either changing or constant coefficient values for the vehicle attributes. The  $C$  matrix is replicated for each year of the analysis and for each target group incorporated in the study. The scope of the AFV module covers a 40 year time period with 9 regional target groups, three size classes and three scenarios. A  $V$  value is produced for each of the vehicle technologies, and for each of the target regions, size and scenario during each year of the study.

A separate  $IKT$  matrix must be calculated for each individual in the population, or at least for each group of similar individuals. It is necessary to calculate  $P_{in}$  separately for each group and average to obtain an aggregate probability and market share for each vehicle type. However, a single  $IKT$  matrix can be calculated by taking one additional step. An aggregate  $IKT$  matrix which approximates

the results obtained by taking an average probability can be calculated over the individual matrices. This is dependent on the condition that the average probability function over the population equals each group probability function, not just the average of all functions. Demographic variables can be used to subdivide the population into similar groups in order to approximate this condition. These variables can be incorporated into the  $V_{it}$  expression as dummy variables, which produce separate coefficients for each population group. An example of demographic variables which subdivide the population could be family size or income level. A separate dummy variable would be used for each family size category or income level category found in the population<sup>10</sup>.

The following equation illustrates how including demographic variables, the aggregate probability function approximates each individual probability function.

$$P_{it} \approx P_{in} \text{ for all } n \quad \therefore \quad P_{it} \approx \frac{e^{V_{it}}}{\sum_{i=1}^I e^{V_{it}}}$$

Where  $V_{it}$  is a function of the K-size attribute vector containing elements taken as averages over segments of the population N, with these segments defined by dummy variables.

This allows estimation of the model using a single *IKT* matrix over the population.

### MODEL STRUCTURE

The AFV module operates in three stages, using a bottom-up approach to determine the eventual market shares of conventional and alternative vehicles. Results from the lower stages are passed to the next higher stage in the sequence. At this stage of the LDV Model, vehicle sales and characteristics are mapped from the seven or six size classes considered in previous sections to three aggregate size classes. As the prices of alternative fuel vehicles are functions of sales volume (estimated in the FEM Model), the AFV Model goes through two iterations; first, estimating sales volume using the previous year's volume-dependent prices, then re-estimating prices and consequent sales. The first step in the calculation involves the evaluation of Stage 3, in which market shares of one type of alternative vehicle, Electric Vehicles and associated hybrids, are determined. These results are then passed to Stage 2, in which market shares for all alternative vehicles are estimated.

---

<sup>10</sup> The number of dummy variables required in subdividing the population is one less than the number of groups so that if 5 family size groups were included in the module 4 dummy variables would be required.

The average characteristics of alternative vehicles are subsequently passed to Stage 1, where the final

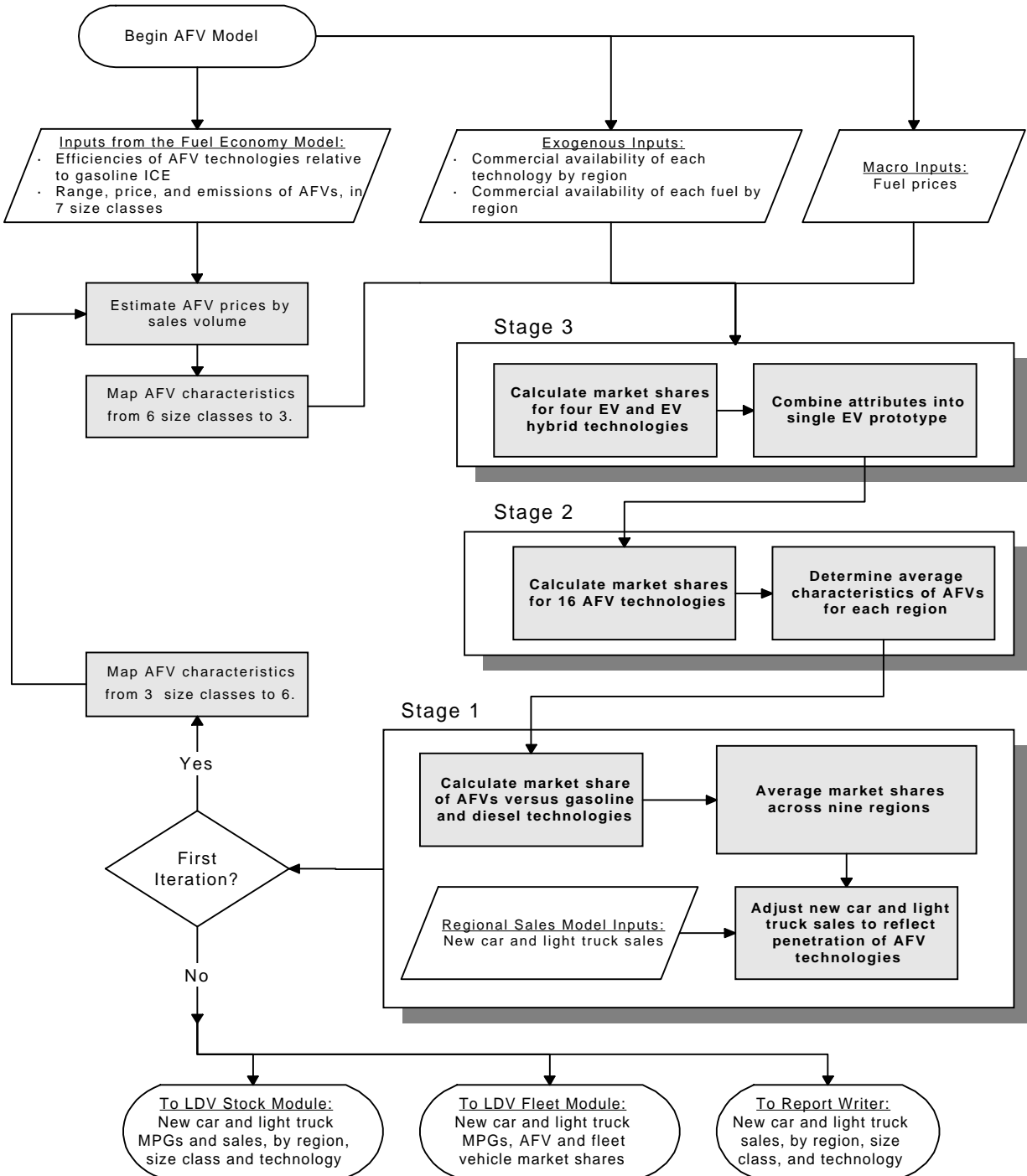


Figure 3A-3. Alternative Vehicle Model

mix of alternative and conventional vehicles is calculated.

An additional constraint is included at each stage of the market share calculation which incorporates commercial availability of the alternative-fuel technology. The aggregate probability function assumes that all technologies are fully developed and available to the consumer at the present time. This assumption does not hold true for most of the alternative-fuel technologies, which at the present time still remain in development stages. Therefore, an upper limit constraint is placed on the market share penetration of alternative vehicle sales corresponding to the expected development and commercial availability of alternative fuel vehicles. This constraint applies to the early years and is gradually reduced through the forecasting period, via a logistic curve for each technology. The equations associated with each stage of the model are presented below, in order of execution.

The Alternative Fuel Vehicle Model flowchart is presented in Figure 3A-3 below. More detailed sketches of AFV calculations are presented at the end of Section 3A.

### **STAGE 3**

Stage 3 of the AFV module determines the market share of each of the four EV technologies considered in the model. These market shares are used to characterize a prototypic EV when all alternative vehicles are considered in Stage 2. The steps involved in Stage 3 are described below.

1) Map vehicle range and price for cars and light trucks from six to three size classes, combining domestic and imported vehicles. For each AFV technology:

$$LDVRANGE_{ISC} = \frac{\sum_{OSC} \sum_{K=1}^2 [FEMRNG_{K,OSC} \cdot LDVSHRR_{OSC}]}{2 \cdot \sum_{OSC} LDVSHRR_{OSC}}$$

and

$$LDVPRICE_{ISC} = \frac{\sum_{OSC} \sum_{K=1}^2 [FEMPRI_{K,OSC} \cdot LDVSHRR_{OSC}]}{2 \cdot \sum_{OSC} LDVSHRR_{OSC}}$$

(59)

where:

LDVRANGE = Aggregate vehicle range for reduced size class *ISC*, for each technology

LDVPRICE = Aggregate vehicle price for reduced size class *ISC*, for each technology

FEMRNG = Vehicle range, from the FEM Model, by size class, *OSC*, and origin, *K*

FEMPRI = Vehicle price, from the FEM Model, by size class, *OSC*, and origin, *K*

LDVSHRR = Vehicle sales shares, by size class, represented in the code by PASSHRR for cars, and LTSHRR for light trucks

$K$  = Index indicating 1) domestic, or 2) import

$OSC, ISC$  = Index indicating expanded or corresponding reduced size class:

For cars:  $ISC = 1, OSC = 1, 2, 3, 6; ISC = 2, OSC = 4; ISC = 3, OSC = 5$

For light trucks:  $ISC = 1, OSC = 1, 3; ISC = 2, OSC = 2, 5; ISC = 3, OSC = 4, 6$

The factor of 2 in the denominator reflects the fact that sales shares are counted twice for each size class: once for domestic and once for imported vehicles.

2) Map vehicle fuel economy for cars and light trucks from six to three size classes, combining domestic and imported vehicles. For each AFV technology:

$$LDVMMPG_{ISC} = \left[ \frac{\sum_{OSC} \sum_{K=1}^2 \left( \frac{LDVSHRR_{OSC}}{FEMMPG_{K,OSC}} \right)}{2 \cdot \sum_{OSC} LDVSHRR_{OSC}} \right]^{-1} \quad (60)$$

where:

LDVMMPG = Aggregate vehicle fuel economy for reduced size class  $ISC$ , for each technology, represented in the code as CARMPG for cars, and TRKMMPG for light trucks

FEMMPG = Vehicle fuel economy, from the FEM Model, by size class,  $OSC$ , and origin,  $K$

3) Calculate the weighted average fuel price for each EV technology, by region.

$$AFCOST_{EVTECH,REG} = \frac{\sum_{FUEL} (RFP_{FUEL,REG} \cdot FAVAIL_{FUEL,REG})}{\sum_{FUEL} FAVAIL_{FUEL,REG}} \quad (61)$$

where:

AFCOST = Electric vehicle fuel price, in 1990\$ / MMBTU

RFP = Price of each fuel used by the corresponding EV technology

FAVAIL = Relative availability of the corresponding fuel

EVTECH = Index referring the electric vehicle technology

FUEL = Index referring to fuel used by technology EVTECH

4) Calculate EV operating costs, by region.

$$COPCOST_{EVTECH,ISC,REG} = \frac{AFCOST_{EVTECH,REG}}{LDVMPG_{EVTECH,ISC}} \quad (62)$$

where:

COPCOST = Fuel operating costs for each technology, in 1990 cents per mile

5) Determine fuel availability relative to gasoline,  $FAVAIL_{EVTECH,REG}$ , using the highest value associated with any of the fuels used in electric hybrids.

$$FAVAIL_{EVTECH,REG} = MAX ( FAVAIL_{FUEL,REG} ) \quad (63)$$

6) Calculate the logit function inputs from the attributes and coefficients, by region.

$$\begin{aligned} ETECT_{EVTECH,REG} = EXP [ & BETACONST_{EVTECH} + \beta_1 VPRICE_{EVTECH} + \beta_2 COPCOST_{EVTECH,REG} \\ & + \beta_3 VRANGE_{EVTECH} + \beta_4 VRANGE_{EVTECH}^2 + \beta_5 VEMISS_{EVTECH} \quad (64) \\ & + \beta_6 VEMISS_{EVTECH}^2 + \beta_7 FAVAIL_{EVTECH,REG} + \beta_8 FAVAIL_{EVTECH,REG}^2 ] \end{aligned}$$

where:

BETACONST = Constant associated with each EV technology

VPRICE = Price of each EV technology in 1990\$

VRANGE = Vehicle range of the considered technology

VEMISS = Emissions levels relative to gasoline ICE's: In the current model, emissions are not considered significant inputs.  $\beta_5$  and  $\beta_6$  are therefore set to zero.

7) Calculate EV market shares, by region.

$$APSHR33_{EVTECH,REG} = \frac{ETECT_{EVTECH,REG} \cdot COMAVAIL_{EVTECH}}{\sum_{EVTECH=1}^4 ( ETECT_{EVTECH,REG} \cdot COMAVAIL_{EVTECH} )} \quad (65)$$

where:

APSHR33 = Relative market shares of each EV technology

COMAVAIL = Commercial availability of each technology

8) Calculate average market shares across Census regions:

$$APSHR33_{EVTECH} = \frac{1}{9} \sum_{REG=1}^9 APSHR33_{EVTECH,REG} \quad (66)$$



9) Determine the characteristics of a prototypical EV technology by weighting the individual technologies' characteristics by their respective market shares.

$$\Psi_{EV} = \sum_{EVTECH=1}^4 \Psi_{EVTECH} \cdot APSHR33_{EVTECH} \quad (67)$$

where  $\Psi_{EV}$  denotes the average attributes of the EV technologies: vehicle price, efficiency, relative emissions, range, commercial availability, and alternative-specific constant. A similar procedure is used to characterize regional attributes such as fuel price and availability, and operating costs. These attributes are used as inputs in the Stage 2 subroutine.

## STAGE 2

Stage 2 determines the relative market shares among the set of alternative vehicles. The result of this step is a prototypic AFV whose characteristics are determined by the market share-weighted attributes of all 11 alternative vehicle types. The sequence of calculations replicates those conducted in Stage 3, and is presented below.

10) Calculate the weighted average fuel price for each AFV technology, by region.

$$AFCOST_{AFVTECH,REG} = \frac{\sum_{FUEL} (RFP_{FUEL,REG} \cdot FAVAIL_{FUEL,REG})}{\sum_{FUEL} FAVAIL_{FUEL,REG}} \quad (68)$$

where:

AFCOST = Alternative vehicle fuel price, in 1990\$ / MMBTU  
 AFVTECH = Index referring to AFV technology

11) Calculate AFV operating costs, by region.

$$COPCOST_{AFVTECH,REG,OSC} = \frac{AFCOST_{AFVTECH,REG}}{LDVMPG_{AFVTECH,OSC}} \quad (69)$$

where:

COPCOST = Fuel operating costs for each technology, in 1990\$ per mile

12) Determine fuel availability relative to gasoline,  $FAVAIL_{AFVTECH,REG}$ , which is set to the highest value associated with the group of fuels used in multi-fuel vehicles.

$$FAVAIL_{AFVTECH,REG} = MAX ( FAVAIL_{FUEL,REG} ) \quad (70)$$

13) Calculate the logit function inputs from the attributes and coefficients, by region.

$$\begin{aligned} FVECT_{AFVTECH,REG} = EXP [ & BETACONST_{AFVTECH} + \beta_1 VPRICE_{AFVTECH} + \beta_2 COPCOST_{AFVTECH,R} \\ & + \beta_3 VRANGE_{AFVTECH} + \beta_4 VRANGE_{AFVTECH}^2 + \beta_5 VEMISS_{AFVTECH} \\ & + \beta_6 VEMISS_{AFVTECH}^2 + \beta_7 FAVAIL_{AFVTECH,REG} + \beta_8 FAVAIL_{AFVTECH,REG}^2 \end{aligned} \quad (71)$$

where:

BETACONST = Constant associated with each AFV technology  
VPRICE = Price of each AFV technology in 1990\$  
VRANGE = Vehicle range of the considered technology  
VEMISS = Emissions levels relative to gasoline ICE's

14) Calculate AFV market shares, by region.

$$APSHR22_{AFVTECH,REG} = \frac{AFVECT_{AFVTECH,REG} \cdot COMAVAIL_{AFVTECH}}{\sum_{AFVTECH=1}^{11} (AFVECT_{AFVTECH,REG} \cdot COMAVAIL_{AFVTECH})} \quad (72)$$

where:

APSHR22 = Relative market shares of each AFV technology  
COMAVAIL = Commercial availability of each technology

15) Determine average characteristics of AFV's for each region, for use in Stage 1.

$$\Psi_{AFV,REG} = \sum_{AFVTECH=1}^{11} \Psi_{AFVTECH,REG} \cdot AFVMSH_{AFVTECH,REG} \quad (73)$$

## STAGE 1

Stage 1 determines the final mix of conventional and alternative technologies, using the share-weighted average characteristics of AFV's determined in Stage 2. Three technologies are considered in this stage: gasoline, diesel, and alternatives.

16) Calculate the logit function inputs from the attributes and coefficients, by region.

$$\begin{aligned}
 VECT_{TECH,REG} = EXP [ & BETACONST_{TECH} + \beta_1 VPRICE_{TECH} + \beta_2 COPCOST_{TECH,REG} \\
 & + \beta_3 VRANGE_{TECH} + \beta_4 VRANGE_{TECH}^2 + \beta_5 VEMISS_{TECH} \\
 & + \beta_6 VEMISS_{TECH}^2 + \beta_7 FAVAIL_{TECH,REG} + \beta_8 FAVAIL_{TECH,REG}^2 ] \quad (74)
 \end{aligned}$$

where:

BETACONST = Constant associated with each technology

VPRICE = Price of each technology in 1990\$

VRANGE = Vehicle range of the considered technology

VEMISS = Emissions levels relative to gasoline ICE's

TECH = Index referring to the three major vehicle technologies: gasoline, diesel & alternative

17) Calculate market shares, by region.

$$APShr11_{TECH,REG} = \frac{VECT_{TECH,REG} \cdot COMAVAIL_{TECH}}{\sum_{TECH} (VECT_{TECH,REG} \cdot COMAVAIL_{TECH})} \quad (75)$$

where:

APShr11 = Relative market shares of each technology

COMAVAIL = Commercial availability of each technology

The final step is to combine the market shares of the preceding three stages to produce absolute market shares of each of the sixteen technologies addressed in this model. The absolute regional market shares of gasoline and diesel vehicles remain unchanged from those calculated in Stage 1, the AFV market shares from Stage 2 are adjusted by the total alternative market share from Stage 1, and the EV market shares from Stage 3 are modified by the adjusted electric vehicle market share. These values are placed in  $APShr44_{IT,REG}$ , where  $IT$  represents the expanded sixteen technologies.

For gasoline and diesel vehicles (TECH = 1,2):

$$APShr44_{IT,REG} = APShr33_{TECH,REG} \quad (76)$$

For non-electric AFV's (TECH = 3, AFVTECH ≠ 9):

$$APSHR44_{IT,REG} = APSHR33_{AFV} * APSHR22_{AFVTECH} \quad (77)$$

For electric AFV's (TECH = 3, AFVTECH = 9):

$$APSHR44_{IT,REG} = APSHR33_{AFV} * APSHR22_{EV} * APSHR11_{EVTECH} \quad (78)$$

Regional sales of new cars and light trucks may then be calculated, disaggregated by six size classes and by technology:

$$NCSTECH_{IT,REG,SC} = APSHR_{IT,REG,SC} * NCS_{REG,SC} \quad (79)$$

and:

$$NLTECH_{IT,REG,SC} = APSHR_{IT,REG,SC} * NLTS_{REG,SC} \quad (80)$$

where:

NCSTECH = Regional new car sales, by size class and technology

NLTECH = Regional new light truck sales, by size class and technology

APSHR = Absolute regional market shares of each vehicle technology

NCS = Regional new car sales, from the Regional Sales Model

NLTS = Regional new light truck sales, from the Regional Sales Model

On the first iteration of this model, the vehicle sales by technology type are passed back to the FEM Model to re-estimate the sales-dependent vehicle prices, and the revised prices are passed back to the AFV Model. Following the second iteration, these values are passed to the LDV Stock Module, in which the average attributes of the fleet of private light-duty vehicles are determined.

### **3C. LDV Fleet Module**

The Light Duty Vehicle Fleet Module generates estimates of the stock of cars and trucks used in business, government, and utility fleets. The model also estimates travel demand, fuel efficiency, and energy consumption by these fleet vehicles prior to their transition to the private sector at predetermined vintages.

#### **RATIONALE**

Fleet Vehicles are treated separately in TRAN because of the special characteristics of fleet light duty vehicles. The LDV Fleet Module generates estimates of the stock of cars and light trucks which are used in three different types of fleets, as well as VMT, fuel efficiency and energy consumption estimates which are distinct from those generated for personal light duty vehicles in the LDV and LDV Stock Modules. The primary purpose for this is not only to simulate as accurately as possible the very different sets of characteristics one would expect to see in fleet as opposed to personal vehicles but also to allow for the greater opportunity for regulation and policy-making that fleet purchases represent. Legislative mandates for AFV purchases, fleet fuel efficiencies, etc. can be incorporated through the subroutine TLEGIS, which has been set up specifically for this purpose.

#### **ALTERNATIVE SPECIFICATIONS**

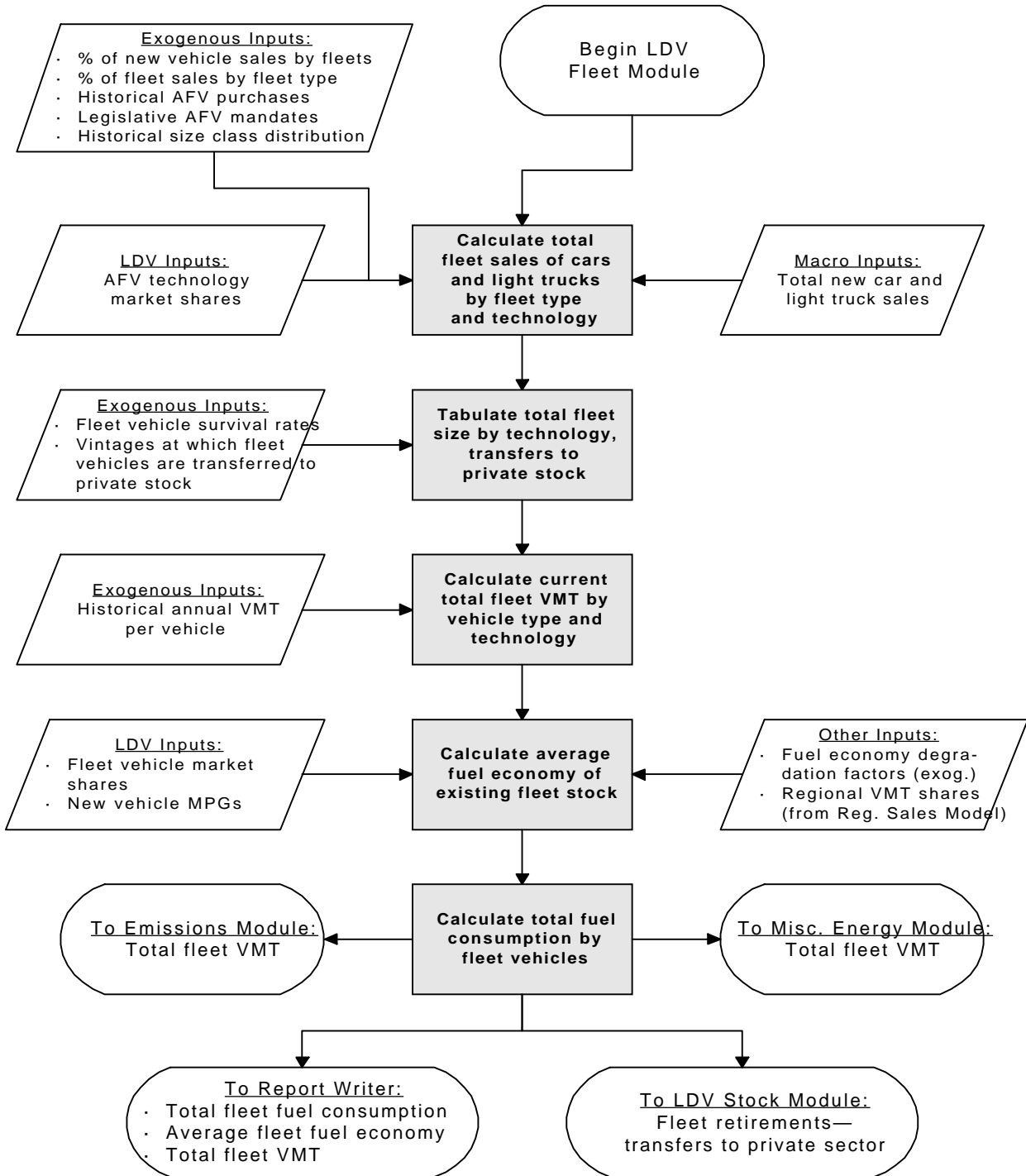
No alternative specifications were considered.

#### **MODEL STRUCTURE**

In a departure from the conventions of other modules, this model uses the same variable names for cars and light trucks; they are distinguished by the value of an index designating vehicle type. Vehicles are also distinguished by the type of fleet to which they are assigned; business, government, and utility fleets are assumed to have different operating characteristics and retirement rates. This model consists of three stages: determine total vehicle purchases, surviving fleet stocks and travel demand, calculate the fuel efficiency of fleet vehicles, and estimate the consequent fuel consumption.

The flowchart for the Light Duty Vehicle Fleet Module is presented below in Figure 3C-1. Additional flowcharts outlining major LDV Fleet calculations in more detail are presented at the end of this section.

**Figure 3C-1. Light Duty Vehicle Fleet Module**



## Calculate Fleet Stocks and VMT

Calculate fleet acquisitions of cars and light trucks:

$$FLTSAL_{IT=1,ITY,T} = FLTCRAT * SQTRCARS_T * FLTCSHR_{ITY}$$

and: (81)

$$FLTSAL_{IT=2,ITY,T} = FLTTRAT * SQDTRUCKSL_T * FLTTSHR_{ITY}$$

where:

- FLTSAL = Sales to fleets by vehicle and fleet type
- FLTCRAT = Fraction of total car sales attributed to fleets
- FLTTRAT = Fraction of total truck sales attributed to fleets
- SQTRCARS = Total automobile sales in a given year
- SQDTRUCKSL = Total light truck sales in a given year
- FLTCSHR = Fraction of fleet cars purchased by a given fleet type
- FLTTSHR = Fraction of fleet trucks purchased by a given fleet type
- IT = Index of vehicle type: 1 = cars, 2 = light trucks
- ITY = Index of fleet type: 1 = business, 2 = government, 3 = utility

For cars only: separate the business fleet sales into "covered" and "uncovered" strata, reflecting the fact that EPACT regulations do not extend to privately owned or leased fleet vehicles. This separation is based on an extrapolation of historical trends in business fleets, using an assumed upper limit. Details on this, and other derivations are provided in the Appendix.

$$LTFRAC_{T-1971} = BFLTFRAC_{MIN} + (BFLTFRAC_{MAX} - BFLTFRAC_{MIN}) \cdot EXP^{(K_2(T-1971))} \quad (82)$$

and:

$$BUSCOV_T = FLTSAL_{IT=1,ITY=1,T} \cdot BFLTFRAC_T \quad (83)$$

where:

- BUSCOV = Business fleet acquisitions covered by EPACT provisions
- BFLTFRAC = Fraction of business fleet purchases covered by EPACT provisions in year T

Calculate the percentage of fleet vehicle sales which go to fleets of 50 or more vehicles:

For cars:

$$FLTPCT_{VT=1,ITY=1,3,IFS=3} = k_3 \left[ \frac{1}{Ln(50)} \right] \quad (84)$$

For light trucks:

$$FLTPCT_{VT=2,ITY=1,3,IFS=3} = (50)^{k_{2,ITY}} \quad (85)$$

where:

$k_3$  = Normalized proportionality constant for automobile fleets, estimated to be 1.386.  
 $k_{2,ITY}$  = Proportionality constant for business and utility fleets, -0.747 and -0.111, respectively.

Calculate the number of fleet vehicles covered by the provisions of EPACT, taking into consideration the geographic and central-refuelling constraints. These constraints are constant, and are tabulated below.

For cars:

$$LTSALX_{IT=1,ITY=1,T} = BUSCOV_T \cdot FLTPCT_{IT,ITY,T} \cdot CTLREFUEL_{ITY} \cdot MSA_{ITY} \cdot FLT20_{IT}$$

and

$$(86)$$

$$FLTSALX_{IT=1,ITY=1,T} = FLTSAL_{IT,ITY,T} \cdot CTLREFUEL_{ITY} \cdot MSA_{ITY} \cdot FLT20_{ITY}$$

For light trucks:

$$SALX_{IT=2,ITY=1,3,T} = FLTSAL_{IT,ITY,T} \cdot FLTPCT_{IT,ITY,T} \cdot CTLREFUEL_{ITY} \cdot MSA_{ITY} \cdot FLT20_{ITY}$$

and

$$(87)$$

$$FLTSALX_{IT=2,ITY=2,T} = FLTSAL_{IT,ITY,T} \cdot CTLREFUEL_{ITY} \cdot MSA_{ITY} \cdot FLT20_{ITY}$$

where:

FLTSALX = The number of vehicles of each vehicle and fleet type subject to EPACT requirements.  
 CTLREFUEL = The percentage of fleet vehicles which are capable of being centrally refuelled.  
 MSA = The percentage of fleets which have 20 or more vehicles located within urban areas.



FLT20 = The percentage of fleet vehicles actually located within urban areas.

<b>Geographic Constraints, by Fleet Type</b>			
	<b>Business (ITY = 1)</b>	<b>Government (ITY = 2)</b>	<b>Utility (ITY = 3)</b>
<b>CTLREFUEL</b>	50%	100%	100%
<b>MSA</b>	90%	63%	90%
<b>FLT20</b>	75%	90%	90%

The number of alternative-fuel vehicles sold for each fleet and vehicle type under EPACT mandates is then estimated:

$$FLTALTE_{IT,ITY,T} = FLTSALX_{IT,ITY,T} \cdot EPACT3_{ITY,T} \quad (88)$$

where:

- FLTALTE = AFV sales to fleets under EPACT mandates
- EPACT3 = Sales-weighted aggregation of EPACT purchase requirements, reflecting impacts on three fleet types. See the Appendix for further details.

The number of alternative-fuel vehicles which would result from a continuation of historical purchase patterns is also calculated, representing a minimum acquisition level:

$$FLTALTH_{IT,ITY,T} = FLTSAL_{IT,ITY,T} \cdot FLTAPSHR1_{ITY} \quad (89)$$

where:

- FLTALTH = Fleet AFV purchases, using constant historical shares.
- FLTAPSHR1 = Fleet percentage of AFV's, by fleet type.

Determine total alternative fuel fleet vehicle sales, using the maximum of the market-driven and legislatively mandated values :

$$FLTALT_{IT,ITY,T} = MAX \left[ FLTALTE_{IT,ITY,T} , FLTALTH_{IT,ITY,T} \right] \quad (90)$$

where:

FLTALT = Number of AFV's purchased by each fleet type in a given year  
 FLTAPSHR1 = Fraction of each fleets' purchases which are AFV's, from historical data  
 EPACT = Legislative mandates for AFV purchases, by fleet type

The difference between total and AFV sales represents conventional sales:

$$FLTCONV_{IT,ITY,T} = FLTSAL_{IT,ITY,T} - FLTALT_{IT,ITY,T} \quad (91)$$

where:

FLTCONV = Fleet purchases of conventional vehicles  
 FLTSAL = Sales to fleets by vehicle and fleet type  
 FLTALT = Number of AFV's purchased by each fleet type in a given year

Fleet purchases are subsequently divided by size class:

$$FLTSLSCA_{IT,ITY,IS,T} = FLTALT_{IT,ITY,T} * FLTSSHR_{IT,ITY,IS}$$

and:

$$FLTSLSCC_{IT,ITY,IS,T} = FLTCONV_{IT,ITY,T} * FLTSSHR_{IT,ITY,IS}$$

where:

FLTSLSCA = Fleet purchases of AFV's, by size class  
 FLTSLSCC = Fleet purchases of conventional vehicles, by size class  
 FLTSSHR = Percentage of fleet vehicles in each size class, from historical data  
 IS = Index of size classes: 1 = small, 2 = medium, 3 = large

A new variable is then established, disaggregating AFV sales by engine technology:

$$FLTECHSAL_{IT,ITY=1,IS,ITECH} = FLTSLSCA_{IT,ITY=1,IS} * APSHRFLTB_{IT,ITECH,ITY=1}$$

$$FLTECHSAL_{IT,ITY \neq 1,IS,ITECH} = FLTSLSCA_{IT,ITY \neq 1,IS} * FLTECHSHR_{ITECH,ITY} \quad (93)$$

and:

$$FLTECHSAL_{IT,ITY,IS,ITECH=6} = FLTSLSCC_{IT,ITY,IS}$$

where:

FLTECHSAL = Fleet sales by size, technology, and fleet type  
 APSHRFLTB = Alternative technology shares for the business fleet  
 FLTECHSHR = Alternative technology shares for the government and utility fleets

*ITECH* = Index of engine technologies: 1-5 = alternative fuels (neat), 6 = gasoline

Sales are then summed across size classes:

$$FLTECH_{IT,ITY,ITECH} = \sum_{IS=1}^3 FLTECHSAL_{IT,ITY,IS,ITECH} \quad (94)$$

where:

FLTECH = Vehicle purchases by fleet type and technology

The next step is to modify the array of surviving fleet stocks from previous years, and to add these new acquisitions. This is done by applying the appropriate survival factors to the current vintages and inserting FLTECH into the most recent vintage:

$$FLSTKVN_{IT,ITY,ITECH,IVINT,T} = FLSTKVN_{IT,ITY,ITECH,IVINT-1,T-1} * SURVFLTT_{VT,IVINT-1}$$

and: (95)

$$FLTSTKVN_{IT,ITY,ITECH,IVINT,T} = FLTECH_{IT,ITY,ITECH,T}$$

where:

FLTSTKVN = Fleet stock by fleet type, technology, and vintage

SURVFLTT = Survival rate of a given vintage

IVINT = Index referring to vintage of fleet vehicles

The stocks of fleet vehicles of a given vintage are then identified, assigned to another variable, and removed from the fleet:

$$OLDFSTK_{IT,ITY,ITECH,IVINT,T} = FLTSTKVN_{IT,ITY,ITECH,IVINT,T} \quad (96)$$

where:

OLDFSTK = Old fleet stocks of given types and vintages, transferred to the private sector

The variable OLDFSTK is subsequently sent to the LDV Stock Model to augment the fleet of private vehicles. The vintages at which these transitions are made are dependent on the type of vehicle and the type of fleet, as shown below.

Vehicle Type (VT)	Fleet Type (ITY)	Transfer Vintage (IVINT)
Automobile (VT = 1)	Business (ITY = 1)	5 Years

Automobile	Government (ITY = 2)	6
Automobile	Utility (ITY = 3)	7
Light Truck (VT = 2)	Business	6
Light Truck	Government	7
Light Truck	Utility	6

Total surviving vehicles are then summed across vintages:

$$TFLTECHSTK_{IT,ITY,ITECH,T} = \sum_{IVIN=1}^6 FLTSTKVN_{IT,ITY,ITECH,IVIN,T} \quad (97)$$

where:

TFLTECHSTK = Total stock within each technology and fleet type

The percentage of total fleet stock represented by each of the vehicle types and technologies is determined as follows:

$$VFSTKPF_{IT,ITY,ITECH,T} = \frac{TFLTECHSTK_{IT,ITY,ITECH,T}}{\sum_{IT=1}^2 \sum_{ITY=1}^3 \sum_{ITECH=1}^6 TFLTECHSTK_{IT,ITY,ITECH,T}} \quad (98)$$

where:

VFSTKPF = Share of fleet stock by vehicle type and technology

Historical data on the amount of travel by fleet vehicles is now used to estimate total fleet VMT:

$$FLTVMT_T = \sum_{IT=1}^2 \sum_{ITY=1}^3 \sum_{ITECH=1}^6 (TFLTECHSTK_{IT,ITY,ITECH,T} * FLTVMTYR_{IT,ITY,T}) \quad (99)$$

where:

FLTVMT = Total VMT driven by fleet vehicles

FLTVMTYR = Annual miles of travel per vehicle, by vehicle and fleet type

Total VMT is then disaggregated by vehicle type and technology:

$$FLVMTECH_{IT,ITY,ITECH,T} = FLVMT_T * VFSTKPF_{IT,ITY,ITECH,T} \quad (100)$$

where:

FLVMTECH = Fleet VMT by technology, vehicle type, and fleet type

## Calculate Fleet Stock MPG

The average efficiencies of the five non-gasoline technologies are calculated as follows:

$$FLTMPG_{IT=1,ITY,ITECH} = \left[ \sum_{ASC=1}^3 \frac{FMSHC_{ITY,ITECH,ASC}}{NAMPG_{ITS,ASC}} \right]^{-1}$$

and: (101)

$$FLTMPG_{IT=2,ITY,ITECH} = \left[ \sum_{ASC=1}^3 \frac{FMSHLT_{ITY,ITECH,ASC}}{NAMPG_{ITS,ASC} * RATIO_{ASC}} \right]^{-1}$$

where:

- FLTMPG = New fleet vehicle fuel efficiency, by fleet type and engine technology
- FMSHC = The market share of fleet cars, from the AFV model
- FMSHLT = The market share of fleet light trucks, from the AFV model
- NAMPG = New AFV fuel efficiency, from the AFV model
- ITS = Index which matches technologies in the AFV model to corresponding ITECH

For conventional technologies, when ITECH refers to gasoline ICE's, the calculation is similar. FEM estimates of fuel economy for the six vehicle size classes are averaged into three classes to correspond to the output of the fleet model, and new fleet vehicle fuel economy is calculated as follows:

$$FLTMPG_{IT=1,ITY,ITECH} = \left[ \sum_{ASC=1}^3 \frac{FMSHC_{ITY,ITECH,ASC}}{FEC3SC_{ASC}} \right]^{-1}$$

and: (102)

$$FLTMPG_{IT=2,ITY,ITECH} = \left[ \sum_{ASC=1}^3 \frac{FMSHLT_{ITY,ITECH,ASC}}{FET3SC_{ASC}} \right]^{-1}$$

where:

- FEC3SC = New car MPG, in three size classes, from the FEM model
- FET3SC = New light truck MPG, in three size classes, from the FEM model

The fuel efficiency of new vehicles is then added to an array of fleet stock efficiencies by vintage, which is adjusted to reflect the passage of time:

$$MPGFSTK_{IT,ITY,ITECH,IVIN,T} = MPGFSTK_{IT,ITY,ITECH,IVIN-1,T-1}$$

and: (103)

$$MPGFSTK_{IT,ITY,ITECH,IVIN=1,T} = FLTMPG_{IT,ITY,ITECH,T}$$

where:

MPGFSTK = Fleet MPG by vehicle and fleet type, technology, and vintage

Average fuel efficiency by vehicle and fleet type is then calculated:

$$MPGFLTSTK_{IT,ITY,ITECH} = \left[ \sum_{IVINT=1}^{MAXVINT} \left( \frac{FLTSKTVN_{IT,ITY,ITECH,IVINT}}{MPGFSTK_{IT,ITY,ITECH,IVINT} * VDF_{VT}} \right) \right]^{-1} \quad (104)$$

where:

MPGFLTSTK = Fleet MPG by vehicle and fleet type, and technology, across vintages

MAXVINT = Maximum IVIN index associated with a given vehicle and fleet type

The overall fleet average MPG is finally calculated for cars and light trucks:

$$FLTOTMPG_{IT,T} = \left[ \sum_{ITY=1}^3 \sum_{ITECH=1}^6 \frac{VFSTKPF_{IT,ITY,ITECH,T}}{MPGFLTSTK_{IT,ITY,ITECH,T}} \right]^{-1} \quad (105)$$

where:

FLTOTMPG = Fleet vehicle average fuel efficiency for cars and light trucks

### Calculate Fuel Consumption by Fleet Vehicles

Fuel consumption is simply the quotient of fleet travel demand and fuel efficiency, which have been addressed above:

$$FLILDVC_{IT,ITY,ITECH,T} = \frac{FLVMTECH_{IT,ITY,ITECH,T}}{MPGFLTSTK_{IT,ITY,ITECH,T}} \quad (106)$$

where:

FLILDVC = Fuel consumption by technology, vehicle and fleet type

Consumption is then summed across fleet types, and converted to Btu values:

$$FLTFCBTU_{IT,ITECH,T} = \sum_{ITY=1}^3 FLTLDVC_{IT,ITY,ITECH,T} * QBTU_{ITECH} \quad (107)$$

where:

FLTFCBTU = Fuel consumption, in Btu, by vehicle type and technology

QBTU = Energy content, in Btu/Gal, of the fuel associated with each technology

Consumption by trucks and cars are added, and total consumption is subsequently divided among regions:

$$FLTFCBTUR_{IR,ITECH,T} = \sum_{IT=1}^2 FLTFCBTU_{IT,ITECH,T} * RSHR_{IR,T} \quad (108)$$

where:

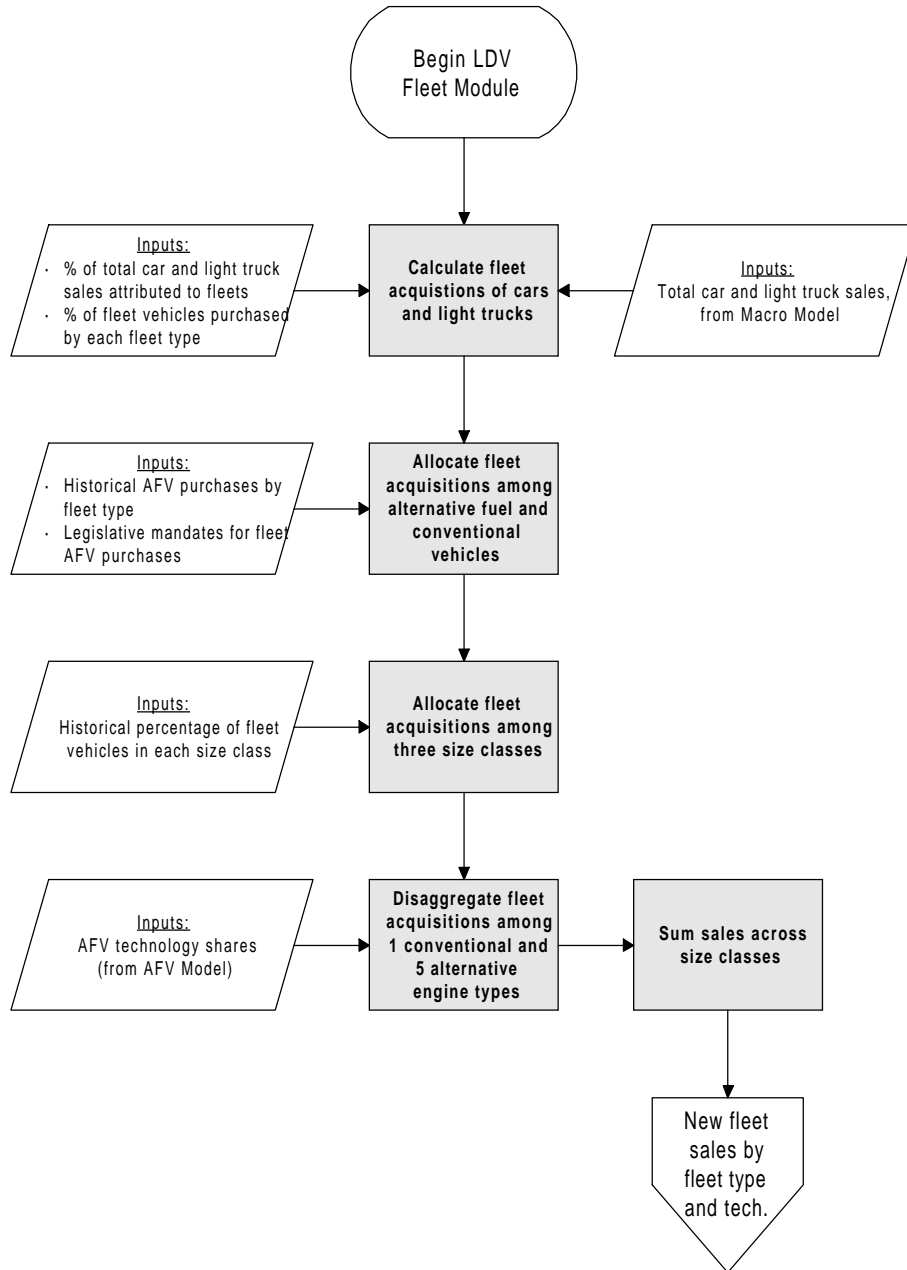
FLTFCBTUR = Regional fuel consumption by fleet vehicles, by technology

RSHR = Regional VMT shares, from the Regional Sales Model

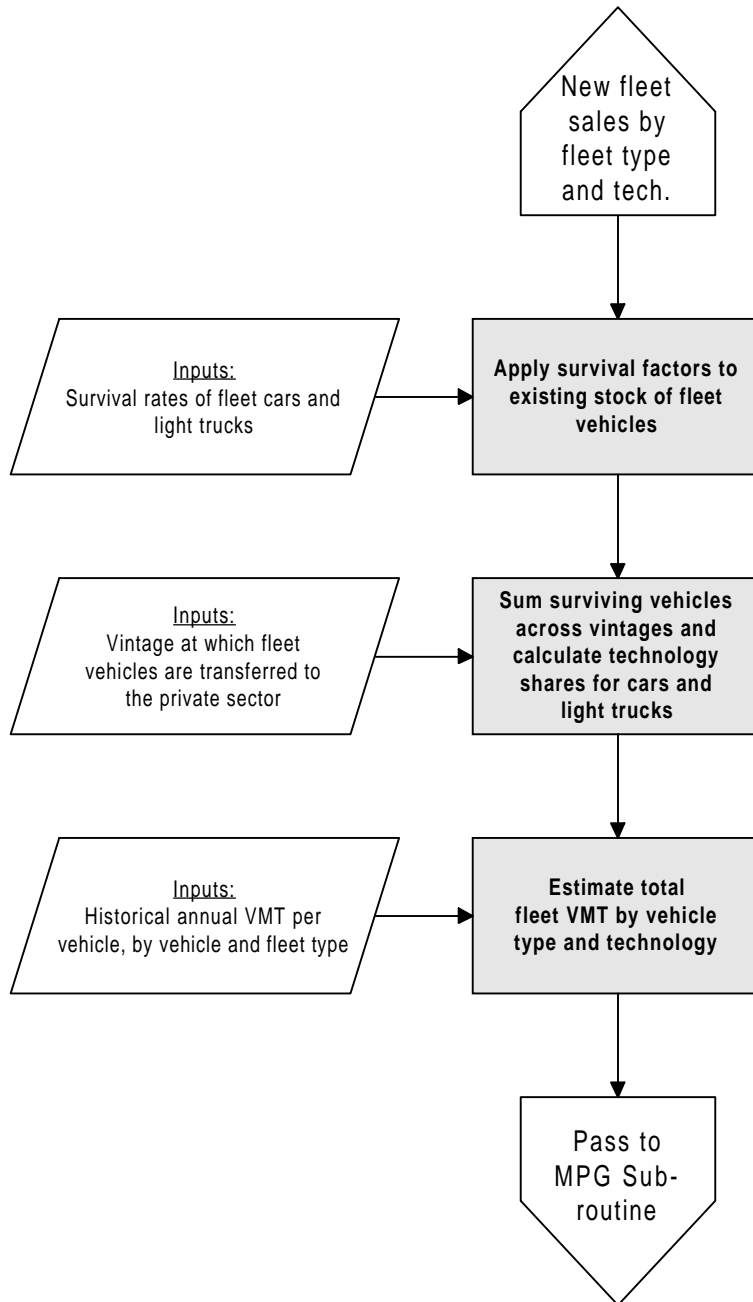
IR = Index of regions



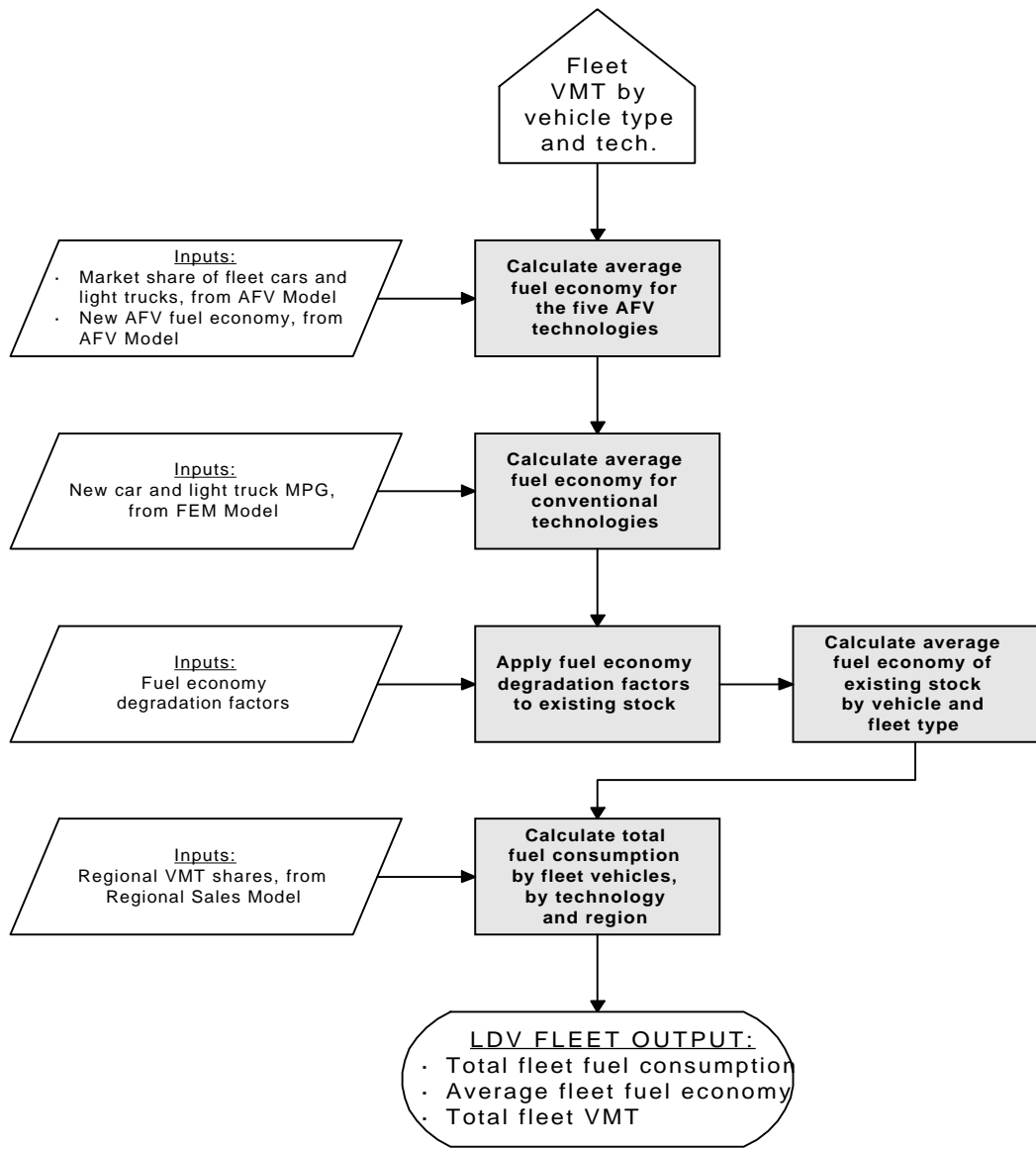
**Figure 3C-2: LDV Fleet Module 1: Process New Fleet Acquisitions**



**Figure 3C-3. LDV Fleet Module 2: Determine Characteristics of Existing Fleets**



**Figure 3C-4. LDV Fleet Module 3: Determine Fleet Fuel Economy and Consumption**



## 3E-1. Freight Truck Stock Adjustment Model

### Introduction

This document describes the methodology of the freight truck stock model which has been integrated into the Transportation Demand Sector Model of the National Energy Modeling System. The newly revised Freight Truck Stock Adjustment Model (FTSAM) improves upon previous EIA freight transport models in that the stock of freight trucks is taken into consideration for the first time. This allows for greater manipulation of a number of important parameters, including the market penetration of existing and future fuel-saving technologies as well as alternatively-fueled heavy-duty vehicles. The Freight Truck Stock Adjustment Model uses NEMS forecasts of real fuel prices and selected industries' output from the Macroeconomic Model to estimate freight truck travel demand, purchases and retirements of freight trucks, important truck stock characteristics such as fuel technology market share and fuel economy, and fuel consumption.

### Alternative Specifications

Current NEMS Model: The freight model currently used for the AEO is an aggregate version of the Argonne National Laboratory freight model, FRATE. Forecasts are made for three modes of freight transport: trucks, rail, and ships. In each case, travel forecasts are based on the industrial production of specific industries, travel growth in most cases being directly proportional to increases in value added. This is then converted to energy demand using the average energy intensity for the mode in question. Total energy demand is subsequently shared out to the various types of fuel used for freight transport. The proposed version of the Freight Truck Stock Adjustment Model will replace the average energy intensity with vintage, size class, sector and fuel technology-specific freight truck fuel economies.

Argonne National Laboratory—Transportation Energy and Emissions Modeling System: Argonne National Laboratory's Transportation Energy and Emissions Modeling System (TEEMS) links several disaggregate models to produce a forecast of transportation activity, energy use, and emissions. The freight sector model estimates future-year activity (in vehicle-miles) and energy consumption by sector. Indices of sectoral output are supplied by a macroeconomic model. A mode choice model then computes ton-miles traveled by truck, rail, water, and air for 24 commodity sectors based on commodity characteristics, changes in fuel price, energy intensities, and modal operating characteristics. The FRATE model is highly disaggregate, incorporating a variety of commodity and mode-dependent characteristics used by a shipper to maximize utility. Forecasts are dependent on base year (1985) freight movement data, which have been obtained from several

sources. Truck vehicle-miles and ton-miles of travel are estimated using the Truck Inventory and Use Survey, and growth indices of sectoral economic output are obtained from Data Resource Inc.'s macroeconomic model. Vehicle miles are assigned to truck size groups based on commodity-specific allocation factors. Four size classes are defined by average laden weight. Fuel types are limited to gasoline and diesel. Energy requirements are computed using exogenous fuel economy baselines in combination with market penetration of fuel-saving technologies. Truck stocks within each size and fuel combination are computed on the basis of historical and projected vehicle utilization rates.

DRI/McGraw-Hill—Energy Review: Demand for motor fuels in the transportation sector is based on a vintage capital analysis of on-road vehicles. Consumers are assumed to determine the composition of the capital stock--in terms of both volume and technological characteristics--through their vehicle purchase decisions. The demand for travel, in conjunction with the number and type of vehicles in the stock, then determines the level of fuel consumption. Motor vehicles are divided into cars, light trucks, medium trucks (10,000-33,000 lbs. gross) and heavy trucks. The allocation of trucks among weight classes was changed for the 1994 version. FHWA's *Highway Statistics* categorizes trucks in three size classes: "two axle, four tire"; "other single unit"; and "combination trucks". DRI assumes that all two-axle, four-tire trucks belong in the light-duty truck category and all combination trucks belong in the heavy-duty category. However, the more than 4 million vehicles registered in the "other single unit" category include some light trucks and potentially some heavy trucks as well.

## **Model Structure**

The Freight Truck Stock Adjustment Model forecasts the consumption of diesel fuel, motor gasoline, liquefied petroleum gas (LPG) and compressed natural gas (CNG) accounted for by freight trucks in each of twelve industrial sectors. Eleven truck vintages, two truck size classes and two fleet types are tracked throughout the model, each having its own average fuel economy and average number of miles driven per year. This section presents and describes the methodology used by the model to forecast each of these important variables.

There are six main procedures which are executed during each year of the model run in order to produce estimates of fuel consumption. In the first, fuel economies of the incoming class of new trucks are estimated through market penetration of existing and future fuel-saving technologies. Relative fuel economies are used in the second routine to determine the market share of each fuel technology in the current year's truck purchases. The third routine determines the composition of the existing truck population, utilizing the characteristics of the current year's class of new trucks along with exogenously estimated vehicle scrappage and fleet transfer rates. Actual and perceived sectoral demand for freight travel in the form of vehicle-miles traveled (VMT) is then estimated and

used to determine truck purchases in the fourth routine. In the fifth routine, actual VMT demand is allocated among truck types and divided by fuel economy to determine fuel consumption. Finally, the truck stocks are rolled over into the next vintage, and the model is prepared for the next year's run.

## **1. Estimate New Truck Fuel Economies**

The first step in the FTSAM is to determine the characteristics the incoming class of truck purchases. Estimates of new medium and heavy truck fuel economies are generated endogenously and depend on the market penetration of specific fuel-saving technologies. Currently existing fuel-saving technologies are based on the *1992 Truck Inventory and Use Survey*<sup>11</sup> and include aerodynamic features, radial tires, “axle or drive ratio to maximize fuel economy”, “fuel economy engine”, and variable fan drives. Currently existing technologies gain market share via time-dependent exponential decay functions with exogenously determined maxima and minima, based on historical trends.

Future technologies are adapted from Argonne National Laboratory's *Transportation Energy Use Through the Year 2010*,<sup>12</sup> and include improved tires & lubricants, electronic engine controls, electronic transmission controls, advanced drag reduction, turbocompound diesel engines, and “heat engines/LE-55”, a DOE/EERE technology. Placeholders allow for the introduction of five additional technologies. Future technologies enter the market at various times throughout the model run depending on the year in which they become commercially available and on the level of fuel prices relative to a “trigger price” at which the technology becomes economically viable. Because prices vary by fuel type, the market shares of fuel-saving technologies are specified separately for diesel, gasoline, LPG and CNG trucks.

Characterizations of existing and future fuel-saving technologies are documented in an earlier report.<sup>13</sup> Because future technologies are speculative, future technology characterizations can be modified by the user. However, existing characterizations are derived from historical data and should not be altered.

---

<sup>11</sup>*1992 Census of Transportation: Truck Inventory and Use Survey*, U.S. Department of Commerce, Bureau of the Census, TC92-T-52, May 1995.

<sup>12</sup>*Forecast of Transportation Energy Demand Through the Year 2010*, Argonne National Laboratory, energy Systems Division, ANL/ESD-9, April, 1991.

<sup>13</sup>*NEMS Transportation Sector Model: Freight Truck Stock Adjustment Model Update*, Decision Analysis Corporation of Virginia, Task 95-101, Subtask 1-3, Appendix A, November 30, 1995.

The first step the model executes in each year is to calculate the average fuel price over the previous three years:

$$AVGPRC_{T,FUEL} = \frac{(PRICE_{T,FUEL} + PRICE_{T-1,FUEL} + PRICE_{T-2,FUEL})}{3} \quad (109)$$

where:

- $T$  = Index referring to model run year; where  $T = 0, \dots, 23$
- $FUEL$  = Index referring to fuel type, where  $FUEL = 1$  refers to diesel,  $FUEL = 2$  refers to gasoline,  $FUEL = 3$  refers to LPG and  $FUEL = 4$  refers to CNG
- AVGPRC = Average price of fuel  $FUEL$  over three year period, in \$ per MBtu
- PRICE = Price of each fuel, in \$ per MBtu

Whether a future technology enters the market during a particular year depends on the trigger price of that technology relative to the average price of each fuel over the past three years. If the technology has not yet entered market and the average price is greater than the technology's trigger price, the technology enters the market during the current year:

$$\begin{aligned} & \text{For } TECH = 6, \dots, 16 \\ & \text{If } AVGPRC_{T,FUEL} \geq TRIGPRC_{SC,FUEL,TECH} \\ & INITYR_{SC,FUEL,TECH} = T \end{aligned} \quad (110)$$

where:

- $TECH$  = Index referring to fuel-saving technologies, where  $TECH = 1, \dots, 5$  refers to currently available technologies and  $TECH = 6, \dots, 16$  refers to future technologies
- $SC$  = Index referring to truck size class, where  $SC = 2$  refers to medium trucks and  $SC = 3$  refers to heavy trucks
- INITYR = Year in which technology  $TECH$  enters market
- TRIGPRC = Exogenously determined fuel price at which technology  $TECH$  becomes economically viable

If a future technology enters market in the current year, coefficients for the logistic market penetration curve are determined:

$$COEFT_{SC,FUEL,TECH} = \frac{\ln(0.01)}{\left[ \frac{CYCLE_{SC,FUEL,TECH}}{2} \right]}$$

*and*

**(111)**

$$MIDYR_{SC,FUEL,TECH} = INITYR_{SC,FUEL,TECH} + \left[ \frac{CYCLE_{SC,FUEL,TECH}}{2} \right]$$

where:

COEFT = Endogenously determined logistic market penetration curve parameter

CYCLE = Exogenously determined logistic market penetration curve parameter representing number of years until 99 percent of maximum market penetration

MIDYR = Endogenously determined logistic market penetration curve parameter

These coefficients are then used during the remainder of the forecast period to determine that technology's market share. Technology market penetration depends on the level of fuel prices relative to the technology's trigger price. For each technology which has entered the market, and for existing technologies, the effect of fuel prices on market penetration is determined for the current year:

$$PREFF_{T,SC,FUEL,TECH} = 1 + PRCVAR_{SC,FUEL,TECH} \cdot \left[ \frac{AVGPRC_{T,FUEL}}{TRIGPRC_{SC,FUEL,TECH}} - 1 \right] \quad \mathbf{(112)}$$

where:

PREFF = Effect of fuel price on market penetration rates for six fuel-saving technologies

PRCVAR = Exogenously determined fuel price sensitivity parameter for each technology, representing percent increase in technology market share if fuel price exceeds trigger price by 100%

For each available technology, including existing technologies, the model determines its share of the available market in the current year:



$$\begin{aligned}
& \text{For } TECH = 1, \dots, 5 \\
TECH_{T, SC, FUEL, TECH} &= \min \left\{ PREFF_{T, SC, FUEL, TECH} \cdot [ BSHRT_{SC, TECH} \right. \\
& \left. + (ESHRT_{SC, FUEL, TECH} - BSHRT_{SC, TECH}) \cdot (1 - e^{CONST_{SC, TECH} + COEFT_{SC, TECH} \cdot T})], 1 \right\}
\end{aligned} \tag{113}$$

$$\begin{aligned}
& \text{For } TECH = 6, \dots, 16 \\
TECHSHR_{T, SC, FUEL, TECH} &= \min \left\{ PREFF_{T, SC, FUEL, TECH} \cdot \frac{ESHRT_{SC, FUEL, TECH}}{1 + e^{COEFT_{SC, FUEL, TECH} \cdot (T - MDYR_{SC, FUEL, TECH})}}, 1 \right\}
\end{aligned}$$

where:

- TECHSHR = Market share of fuel-saving technology *TECH* for size class *SC* and fuel type *FUEL*
- CONST = Exogenously determined market penetration curve parameter for existing technologies
- COEFT = Market penetration curve parameter; exogenous for existing technologies, endogenous for future technologies
- BSHRT = Exogenously determined market penetration curve parameter representing market share of existing technology *TECH* in 1992
- ESHRT = Exogenously determined market penetration curve parameter representing final market share of technology *TECH* if fuel price were always equal to trigger price

If a technology A is superseded by another mutually exclusive technology B at any time during the model run, technology A's market share must be adjusted to reflect the smaller pool of vehicles in its base market:

$$TECHSHR_{T, SC, FUEL, TECH} = (1 - SPRSDEFF_{T, SC, FUEL, TECH}) \cdot TECHSHR_{T, SC, FUEL, TECH} \tag{114}$$

where:

- SPRSDEFF = Superseding effect, equal to the market share of the superseding technology

Once the market shares in a given year are established, the effects of the technologies on the base fuel price are tallied and combined to form a vector of "MPG Effects", which are used to augment the base fuel economy of new trucks of each size class and fuel type:

$$MPGEFF_{T, SC, FUEL} = \prod_{TECH=1}^{16} (1 + MPGINCR_{SC, FUEL, TECH} \cdot TECHSHR_{T, SC, FUEL, TECH}) \tag{115}$$

where:

- MPGEFF = Total effect of all fuel-saving technologies on new truck fuel economy in year *T*
- MPGINCR = Exogenous factor representing percent improvement in fuel economy due to each technology

Fuel economy of new medium and heavy trucks can finally be determined:

$$MPG_{T,SC,AGE=0,FUEL} = BASEMPG_{SC,FUEL} \cdot MPGEFF_{T,SC,FUEL} \quad (116)$$

where:

BASEMPG = Fuel economy of new medium and heavy trucks with no fuel-saving technologies

## 2. Determine the Share of Each Fuel Type in Current Year's Class of New Trucks

Another major characteristic of the current year's class of new trucks, the market share of each fuel type, is calculated in the second FTSAM routine. Market penetration of alternative fuel freight trucks is more likely to be driven by legislative and/or regulatory action than by strict economics. For this reason, separate trends are incorporated for "fleet" vehicles, which are assumed to be more likely targets of future legislation, and "non-fleet" vehicles. The fuel technology routine described below is intended to simulate economic competition among fuel technologies after the "creation" of a market for alternative fuel trucks by government action. The user specifies the market share alternative fuel trucks are likely to achieve if they have no cost advantage over conventional technologies. The inherent sensitivity of each fuel technology to the cost of driving is also specified exogenously. The latter parameter represents the commercial potential of each fuel technology over and above what is mandated by government, and serves to modify the exogenous trend based on relative fuel prices and fuel economies. Additional user-specified parameters include the year in which the market penetration curves are initiated and the length of the market penetration cycle.

The first step in this process is to calculate the fuel cost per mile for trucks of each size class and fuel type:

$$FCOST_{T,SC,FUEL} = \frac{AVGPRC_{T,FUEL}}{MPG_{T,SC,FUEL}} \cdot HTRATE \quad (117)$$

where:

FCOST = Fuel cost of driving a truck of fuel type *FUEL*, in dollars per mile

HTRATE = Heat rate of gasoline, in million Btu per gallon

The fuel cost of driving diesel trucks relative to AFVs is then calculated:

$$RCOST_{T,SC,FUEL} = 1 - \left[ \frac{FCOST_{T,SC,FUEL}}{FCOST_{T,SC,FUEL=1}} - 1 \right] \cdot PRCDIFFVAR_{SC,FUEL} \quad (118)$$

where:

- RCOST = Fuel cost per mile of diesel relative to LPG and CNG  
 PRCDIFFVAR = Exogenously determined parameter representing inherent variation in AFV market share due to difference in fuel prices

The market penetration curve parameters are determined during a user-specified trigger year:

$$COEFAFV_{SC,FUEL,FLT} = \frac{\ln(0.01)}{\left[ \frac{CYCAFV_{SC,FUEL,FLT}}{2} \right]}$$

and

**(119)**

$$MYRAFV_{SC,FUEL,FLT} = TRYRAFV_{SC,FUEL,FLT} + \frac{CYCAFV_{SC,FUEL,FLT}}{2}$$

where:

- FLT* = Index referring to fleet type, where *FLT* = 1 refers to trucks in fleets of nine or less and *FLT* = 2 refers to trucks in fleets of ten or more  
 COEFAFV = Endogenously determined logistic market penetration curve parameter  
 CYCAFV = Exogenously determined logistic market penetration curve parameter representing number of years until maximum market penetration  
 MYRAFV = Logistic market penetration curve parameter representing “halfway point” to maximum market penetration  
 TRYRAFV = Exogenously determined year in which each alternative fuel begins to increase in market share, due to EPACT or other factors

After the market penetration of alternative fuel trucks has been triggered, the AFV market trend is determined through a logistic function:

$$H_{T,SC,FUEL,FLT} = RCOST_{T,SC,FUEL} \cdot \left[ BSHRF_{SC,FUEL,FLT} + \frac{ESHRF_{SC,FUEL,FLT} - BSHRF_{SC,FUEL,FLT}}{1 + e^{COEFAFV_{SC,FUEL,FLT} \cdot (T - MYRAFV_{SC,FUEL,FLT})}} \right] \quad (120)$$

where:

- BSHRF = Base year (1992) market share of each fuel type  
 ESHRF = Exogenously determined final market share of each fuel type

The share of diesel in conventional truck sales is forecast through a time-dependent exponential decay function based on historical data:

$$MPATH_{T,SC,FUEL=1,FLT} = BSHRF_{SC,FUEL,FLT} + \left[ ESHRF_{SC,FUEL,FLT} - BSHRF_{SC,FUEL,FLT} \right] \cdot \left( 1 - e^{CONSD_{SC,FLT} + COEFT_{SC,FLT} \cdot T} \right) \quad (121)$$

where:

- CONSD = Exogenously determined market penetration curve parameter for diesel trucks  
 COEFD = Exogenously determined market penetration curve parameter for diesel trucks

LPG and CNG trucks are already prominent in some sectors of the economy, most notably in the petroleum products sector. The market share of alternative fuel trucks is assumed never to dip below the historical level in each sector. The actual AFV market share is thus calculated as the maximum of historical and forecast shares:

$$FSHR_{T,SEC,SC,FUEL=3,4,FLT} = \max \left[ BSEC_{SEC,SC,FUEL,FLT}, MPATH_{T,SC,FUEL,FLT} \right] \quad (122)$$

where:

- BSEC = Exogenously determined base year (1992) share of alternative fuels in truck purchases

Because of the potential for any fuel type to exceed the user-specified “maximum” due to cost advantages over other technologies, market penetration must be capped at one hundred percent. Diesel market share is calculated as the forecast share of diesel in conventional truck sales multiplied by the share occupied by conventional trucks:

$$FSHR_{T,SEC,SC,FUEL=1,FLT} = \left( 1 - \sum_{FUEL=3}^4 FSHR_{T,SEC,SC,FUEL,FLT} \right) \cdot \left( \min \left[ MPATH_{T,SC,FUEL,FLT} \cdot BSECD_{SEC,SC,FLT}, 1 \right] \right) \quad (123)$$

where:

- BSECD = Exogenously determined parameter representing tendency of each sector to purchase diesel trucks

The remainder of truck purchases are assumed to be gasoline:

$$FSHR_{T,SEC,SC,FUEL=2,FLT} = 1 - \sum_{FUEL=1,3,4} FSHR_{T,SEC,SC,FUEL,FLT} \quad (124)$$

### 3. Determine Composition of Existing Truck Stock

Once the characteristics of the incoming class of new trucks are determined, the next step is to determine the composition of the stock of existing trucks. Scrapage rates are applied to the current truck population:

$$TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} = TRKSTK_{T-1,SEC,SC,AGE-1,FUEL,FLT} \cdot (1 - SCRAP_{SC,AGE-1}) \quad (125)$$

where:

TRKSTK = Stock of trucks in year  $T$

SCRAP = Exogenously determined factor which consists of the percentage of trucks of each age which are scrapped each year

A number of trucks are transferred in each year from fleets of ten or more to fleets of nine or less. Transfers of conventional trucks are based on exogenously determined transfer rates:

$$TRF1_{T,SEC,SC,AGE,FUEL} = TRFRATE_{SC,AGE} \cdot TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} \quad (126)$$

where:

TRF1 = Number of trucks transferred from fleet to non-fleet populations, if no restrictions are placed on the transfer of alternative-fuel trucks

TRFRATE = Exogenously determined parameter representing the percentage of trucks of each vintage to be transferred from fleets to non-fleets in each year

The transfer of alternative fuel trucks is somewhat more complicated. Alternative fuel trucks purchased by centrally refueled fleets might not be as easy to resell as conventional trucks, especially if LPG and CNG are not widely available at filling stations. For this reason, an additional routine is incorporated which, at the user's option, restricts the transfer of alternative fuel trucks from fleets to non-fleets. If this option is chosen, the share of LPG and CNG trucks in fleet transfers in each vintage cannot be greater than the share of each fuel in non-fleet purchases in each sector. In other words, if two percent of non-fleet trucks sold to Sector 3 in year  $T$  are fueled with LPG, no more than two percent of each vintage of fleet transfers can be LPG-fueled. Restricted AFV transfers are calculated as follows:

$$F2_{T,SEC,SC,AGE,FUEL=3,4} = FSHR_{T,SEC,SC,FUEL,FLT=1} \cdot TRFRATE_{SC,AGE} \cdot \sum_{FUEL=1}^4 TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} \quad (127)$$

where:

TRF2 = Number of trucks transferred from fleet to non-fleet populations, if the fuel mix of fleet transfers is exactly the same as the fuel mix of new non-fleet purchases

Actual fleet transfers are then defined as the unrestricted fleet transfers as calculated in  $TRF1$  for conventional trucks, and the minimum of unrestricted and restricted transfers for AFVs:

$$TRF_{T,SEC,SC,AGE,FUEL=1,2} = TRF1_{T,SEC,SC,AGE,FUEL}$$

and

$$(128)$$

$$TRF_{T,SEC,SC,AGE,FUEL=3,4} = \min \left[ TRF1_{T,SEC,SC,AGE,FUEL}, TRF2_{T,SEC,SC,AGE,FUEL} \right]$$

where:

TRF = Total number of trucks transferred from fleet to non-fleet populations

Fleet transfers do not automatically go to non-fleets in the same sector, but are allocated based on each sector's share of the total non-fleet truck population of each vintage of trucks:

$$TRFSHR_{T,SC,SEC} = \frac{\sum_{FUEL=1}^4 \sum_{AGE=1}^{11} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1}}{\sum_{FUEL=1}^4 \sum_{AGE=1}^{11} \sum_{SEC=1}^{12} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1}}$$

(129)

where:

TRFSHR = Share of fleet transfers which goes to each sector

The new existing population of trucks is simply the existing population (after scrappage) modified by fleet transfers:

$$TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} - TRF_{T,SEC,SC,AGE,FUEL}$$

and

$$(130)$$

$$STK_{T,SEC,SC,AGE,FUEL,FLT=1} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1} + TRFSHR_{T,SEC,SC} \cdot \sum_{SEC=1}^{12} TRF_{T,SEC,SC,AGE,}$$

#### 4. Calculate Purchases of New Trucks

Truck purchases are based on the operating characteristics of new and existing trucks, primarily the average annual vehicle mileage per truck, and on the demand for freight travel in the current year.

Annual vehicle mileage determines the ability of the existing stock to meet the VMT demand. VMT per truck has increased steadily since the early 1970s, and is forecast as an index in which 1992 is equal to one. The index is defined as a time-dependent exponential decay function for each size class with exogenously determined parameters:

$$VMTTREND_{T,SC} = \frac{BSHRV_{SC} + (ESHRV_{SC} - BSHRV_{SC}) \cdot (1 - e^{CONSV_{SC} + COEFV_{SC} \cdot T})}{BSHRV_{SC} + (ESHRV_{SC} - BSHRV_{SC}) \cdot (1 - e^{CONSV_{SC} + COEFV_{SC} \cdot 1992})} \quad (131)$$

where:

- VMTTREND = Index of average annual VMT per truck, where 1992 = 1
- BSHRV = Exogenously determined VMT per vehicle increase factor representing minimum annual vehicle mileage
- ESHRV = Exogenously determined VMT per vehicle increase factor representing maximum annual vehicle mileage
- CONSV = Exogenously determined exponential VMT per vehicle increase factor
- COEFV = Exogenously determined exponential VMT per vehicle increase factor

This index is multiplied by base year annual VMT to calculate VMT per truck in each year:

$$ANNVMT_{T,SEC,SC,AGE,FUEL} = ANNVMTBASE_{SEC,SC,AGE,FUEL} \cdot VMTTREND_{T,SC} \quad (132)$$

where:

- ANNVMT = Average annual VMT per vehicle by sector, size class, truck age and fuel type
- ANNVMTBASE = Base year average annual VMT per vehicle by sector, size class, truck age and fuel type

Annual VMT per truck varies by sector, size class, truck age and fuel type, and is multiplied by the array of existing trucks to determine the VMT which can be provided by the current population of trucks in each sector:

$$VMTOLD_{T,SEC} = \sum_{FLT=1}^2 \sum_{FUEL=1}^{16} \sum_{AGE=1}^{11} \sum_{SC=1}^3 TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} \cdot ANNVMT_{SEC,SC,AGE} \quad (133)$$

where:

- VMTOLD = VMT which can be provided by existing stock of trucks in each sector, after scrappage

The next step is to calculate the demand for freight travel in each sector. Demand for freight travel is expressed in vehicle-miles traveled (assuming that load factors remain constant throughout the forecast period), and is calculated based on “freight adjustment coefficients”, or FACs. FACs are

intended to capture the relationship between growth in industrial output and demand for freight travel in each industrial sector. In keeping with the approach taken elsewhere in the NEMS Transportation Demand Sector Model, historical trends are moderated over time by means of a time-dependent exponential decay function. The current year FAC is calculated as follows:

$$COEFFAC = \ln \left[ \frac{9}{T90 - T50} \right]$$

*and*

**(134)**

$$FACTR_{T,SEC} = FACBASE_{SEC} + \frac{1 - FACBASE_{SEC}}{1 + e^{COEFFAC \cdot (T50 - T)}}$$

where:

COEFFAC = FAC decay parameter

T90 = User-specified year by which 90% of FAC decay is experienced

T50 = User-specified year by which 50% of FAC decay is experienced

FACTR = “Freight Adjustment Coefficient”: factor relating growth in value added of sector *SEC* to growth in demand for freight truck VMT

FACBASE = Base year Freight Adjustment Coefficient

Freight adjustment coefficients, and the user-specified decay parameters, have a substantial impact on total truck VMT and hence on fuel consumption. The fifty and ninety percent years are currently set to 2002 and 2007, respectively; these can be easily modified by the user to reflect differing assumptions about the relationship between economic growth and truck VMT over time.

FACs are then used to calculate the actual VMT demand in each sector. The VMT demand in each year affects both the size of the truck stock and the number of miles driven by each truck in that year, and is calculated as follows:

*For T = 0*

$$VMTDMD_{T,SEC} = VMTDMD_{BASE,SEC} \cdot FACTR_{SEC} \cdot \frac{OUTPUT_{T,SEC}}{OUTPUT_{T-1,SEC}}$$

**(135)**

*For T = 1-22*

$$VMTDMD_{T,SEC} = VMTDMD_{T-1,SEC} \cdot FACTR_{SEC} \cdot \frac{OUTPUT_{T,SEC}}{OUTPUT_{T-1,SEC}}$$

where:



VMTDMD = Demand for freight travel by sector *SEC*, in year *T*  
 VMTDMDBASE = Demand for freight travel by sector *SEC*, in year 0  
 FACTR = "Freight Adjustment Coefficient": exogenously determined factor relating growth in value added of sector *SEC* to growth in demand for freight truck VMT

Truck purchases are based not on the actual VMT demand for a given year, for this cannot be known in advance by the decision-makers, but on the level of demand which is expected to occur at the time the trucks are delivered. Since industry practice is to order trucks six months in advance<sup>14</sup>, the purchasing period for trucks delivered in year *T* extends from July 1 of year *T-1* to June 30 of year *T*. Purchase orders are placed based on the expected freight shipping orders six months later. Expected shipping orders are based on two factors: the level of demand currently being experienced, or the perceived baseline demand, and the expected growth rate of VMT demand over the next six months.

The predicted growth in VMT demand can be defined as the growth experienced during the previous six months. On July 1 of year *T-1*, the predicted growth rate is simply the growth rate for year *T-1*, while on June 30 of year *T*, the predicted growth rate is the growth rate for year *T*. Assuming that truck ordering takes place continuously throughout the year, the predicted growth rate can be calculated as follows:

$${}^p\text{VMTGROWTH}_{T,SEC} = 0.5 \cdot \left[ \frac{\text{OUTPUT}_{T,SEC}}{\text{OUTPUT}_{T-1,SEC}} - 1 \right] + 0.5 \cdot \left[ \frac{\text{OUTPUT}_{T-1,SEC}}{\text{OUTPUT}_{T-2,SEC}} - 1 \right] \quad (136)$$

where:

${}^p\text{VMTGROWTH}$  = Growth rate with which perceived demand for freight travel in year *T* is forecast by freight companies

The perceived baseline demand is defined to be the level of VMT demand which has been experienced in the year prior to the purchasing period, and is estimated as follows:

---

<sup>14</sup> Personal conversation with Donnie Hatcher of McClendon Trucking, Lafayette, Alabama.

For  $T = 0$

$$PVMTBASE_{T,SEC} = 0.5 \cdot VMTDMDBASE_{SEC} \quad (137)$$

For  $T = 1-22$

$$PVMTBASE_{T,SEC} = 0.5 \cdot VMTDMD_{T,SEC} + 0.25 \cdot VMTDMD_{T-1,SEC}$$

where:

PVMTBASE = Baseline from which perceived demand for freight travel in year T is calculated.

Assuming that only the perceived baseline demand from previous needs to be “brought forward” into the current year, the VMT demand perceived by freight companies can be estimated as follows:

$$PVMTBASE_{T,SEC} = 0.5 \cdot VMTDMT_{T-1,SEC} + 0.25 \cdot VMTDMD_{T-2,SEC} \quad (138)$$

and

$$PVMTDMD_{T,SEC} = 0.25 \cdot VMTDMD_{T,SEC} + PVMTBASE_{T,SEC} \cdot (1 + PVMTGROWTH_{T,SEC}) \cdot FACTR_{SEC}$$

where:

PVMTBASE = Baseline from which perceived demand for freight travel in year T is forecast by freight companies

PVMTDMD = Perceived demand for freight travel in year T

The difference between perceived VMT demand and VMT provided by the surviving stock of trucks constitutes the perceived unmet VMT demand, which is provided by purchasing new trucks:

$$PVMTUNMET_{T,SEC} = PVMTDMT_{T,SEC} - VMTOLD_{T,SEC} \quad (139)$$

where:

PVMTUNMET = Difference between perceived VMT demand and demand which can be met by existing stock of trucks

Unmet VMT demand is next allocated among size classes and fleet types by means of constant size class and fleet type allocation factors. Size class allocation factors determine truck purchases by size class, while fleet allocation factors represent the share of new trucks accounted for by fleets in each

sector. The calculation is as follows:

$$\begin{aligned} \Gamma_{T,SEC,SC,FLT=1} &= MAX \left[ PVMTUNMET_{T,SEC} \cdot VMTSCFAC_{SEC,SC} \cdot (1 - FLTSHR_{SEC,SC}) \right. \\ &\quad \left. and \right. \\ \Gamma_{T,SEC,SC,FLT=2} &= MAX \left[ PVMTUNMET_{T,SEC} \cdot VMTSCFAC_{SEC,SC} \cdot FLTSHR_{SEC,SC} \right. \end{aligned} \quad (140)$$

where:

- PVMT = Perceived demand for freight travel by new trucks of size class *SC* and fleet type *FLT* in sector *SEC*
- VMTSCFAC = Exogenously determined parameter representing percentage of new truck sales which go to each size class *SC* in sector *SEC*
- FLTSHR = Exogenous parameter representing percentage of new truck sales of each size class *SC* which go to fleets of ten or more in sector *SEC*

Market shares and VMT per vehicle for trucks of each fuel technology have been calculated above; these are used to calculate a fuel technology-weighted average annual VMT per vehicle of the current year's class of new fleet and non-fleet trucks:

$$PVN_{T,SEC,SC,FLT} = \sum_{FUEL=1}^4 FSHR_{T,SEC,SC,FUEL,FLT} \cdot ANNVMT_{T,SEC,SC,AGE=0,FUEL} \quad (141)$$

where:

- AGE* = 0 refers to new trucks
- PVN = Annual VMT per vehicle for new trucks in year *T*

Truck purchases are finally calculated as the perceived unmet VMT demand divided by VMT per truck, weighted by fuel type:

$$TRKSTK_{T,SEC,SC,AGE=0,FUEL,FLT} = \left[ \frac{PVMT_{T,SEC,SC,FLT}}{PVN_{T,SEC,SC,FLT}} \right] \cdot FSHR_{T,SEC,SC,FUEL,FLT} \quad (142)$$

## 5. Calculate Fuel Consumption

The next stage of the model takes the total miles driven by trucks of each size class, fuel type and age in each NEMS Industrial Sector and divides by fuel economy to determine fuel consumption. Since truck purchases are based on the perceived unmet VMT, and not actual VMT demand, there may be excess VMT demand which is not currently being met by the existing or new trucks (there may also be a surplus of trucks in comparison to the actual VMT demand in a given year). Actual VMT demand must therefore be allocated among truck types:

$$VMT_{T,SEC,SC,AGE,FUEL,FLT} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} \cdot ANNVMT_{T,SEC,SC,AGE,FUEL} \cdot \left[ \frac{\sum_{SEC=1}^{12} VMTDMD_{T,SEC}}{\sum_{SEC=1}^{12} PVMTDMD_{T,SEC}} \right] \quad (143)$$

where:

$$VMT = \text{Actual VMT by trucks of each type in year } T$$

Freight truck fuel economy is dependent on the “fuel economy degradation factor”, which converts EPA-rated fuel economy into on-road values, accounting for increased traffic congestion and other factors. The fuel economy degradation factor is calculated in the LDV Module and modified by the FTSAM based on the simplifying assumption that all of the fuel economy degradation occurs because of worsening driving conditions in congested urban areas. The light-duty vehicle degradation calculated in FEM is thus reduced to reflect the higher percentage of highway miles driven by freight trucks:

$$MPGDEGFAC_{T,SC} = \frac{1 - \left[ \left( 1 - MPGDEGFAC_{T,LDV} \right) \cdot \frac{URBANSHR_{SC}}{URBSHRLDV} \right]}{1 - \left[ \left( 1 - MPGDEGFAC_{T=0,LDV} \right) \cdot \frac{URBANSHR_{SC}}{URBSHRLDV} \right]} \quad (144)$$

where:

$MPGDEGFAC_{LDV}$  = Fuel economy degradation factor, from LDV Module

$MPGDEGFAC$  = Fuel economy degradation factor for freight trucks

$URBANSHR$  = % of miles driven in urban areas by trucks of each size class in base year (1992)

$URBSHRLDV$  = % of miles driven in urban areas by LDVs in base year (1992)

EPA does not rate heavy-duty trucks for fuel economy. Because historical values for medium and heavy trucks reflect on-road fuel economies, the fuel economy degradation factor must be indexed so that the value in 1992 is equal to one.

Fuel consumption, in gallons of gasoline equivalent, is finally calculated by dividing VMT by on-road

fuel economy:

$$FUEL_{T,SEC,SC,AGE,FUEL,FLT} = \frac{VMT_{T,SEC,SC,AGE,FUEL,FLT}}{MPG_{T,SEC,SC,AGE,FUEL} \cdot MPGDEGFAC_{T,SC}} \quad (145)$$

where:

FUEL = Total freight truck fuel consumption by sector, size class and fuel type in year  $T$ , in gallons of gasoline equivalent

MPGDEGFAC<sub>T,SC</sub> = Fuel economy degradation factor, overwritten in the code by 0.99.

Converting from gasoline equivalent to trillion Btu is a trivial application of the heat rate of gasoline:

$$TRIL_{T,SEC,SC,FUEL,FLT} = \sum_{AGE=0}^{11} FUEL_{T,SEC,SC,AGE,FUEL,FLT} \cdot HTRATE \cdot 10^{-6} \quad (146)$$

where:

TRIL = Total fleet truck fuel consumption by sector, size class and fuel type in year  $T$ , in trillion Btu

## 6. Roll Truck Population and Fuel Economy

The final stage prepares the model for the next year by calculating new fuel economies of trucks which are ten years old or older:

$$MPG_{T+1,SC,SGE=10,FUEL} = \frac{\sum_{FLT=1}^2 \sum_{AGE=10}^{11} \sum_{SEC=1}^{12} VMT_{T,SEC,SC,AGE,FUEL,FLT}}{\sum_{FLT=1}^2 \sum_{AGE=10}^{11} \sum_{SEC=1}^{12} FUEL_{T,SEC,SC,AGE,FUEL,FLT}} \quad (147)$$

where:

AGE = 10 refers to trucks in the tenth vintage, i.e., trucks which are ten years old during model run year  $t$

AGE = 11 refers to trucks in the eleventh vintage, i.e., trucks which are eleven years old or older during model run year  $t$

$T+1$  = refers to the next model run year

The last two vintages of trucks are finally collapsed into one:

$$TRKSTK_{T,SEC,SC,AGE=10,FUEL,FLT} = TRKSTK_{T,SEC,SC,AGE=10,FUEL,FLT} + TRKSTK_{T,SEC,SC,AGE=11,FUEL,FLT} \quad (148)$$

## **Conclusion**

This model is a disaggregate, policy-sensitive approach to the forecasting of freight truck energy demand. It represents a substantial improvement over the current model for a number of reasons, the foremost being that vehicle stock and purchases are considered for the first time. This allows the user to test policies which might affect the penetration of alternative fuels or future fuel-saving technologies into the heavy-duty vehicle market. Additional factors considered for the first time include the number and composition of trucks in fleets of ten or more, historical and future market trends of existing fuel-saving technologies, historical trends toward higher vehicle utilization rates, and the effect on truck fuel economy of worsening driving conditions.

## APPENDIX A: TECHNOLOGY IMPROVEMENTS FOR AUTOMOBILES

The characteristics of the automotive technologies considered in the LDV module have been developed by Energy and Environmental Analysis, Inc. of Arlington Virginia, and are tabulated on the following pages in Tables A.2 to A.5.<sup>15</sup> Much of this research has been derived from an earlier study of technological change and its potential application to fuel economy improvements.<sup>16</sup> In this study, numerous automotive technologies have been evaluated in regard to both their estimated impacts on vehicle performance and their cost-effectiveness from a producer's standpoint. Individual technologies or groups of technologies have been assigned to one of three "certainty levels", defined below, which indicates the likelihood of their incorporation in the near-term.

The Standard Technology Matrices for cars and light trucks (Tables A.2 and A.3) represent a relatively conservative estimation of technology cost, availability, and impact over the course of the forecast. The corresponding High Technology Matrices (Tables A.4 and A.5) reflect a more optimistic assessment of the potentials of selected technologies. In order to permit a ready comparison of technology characteristics, those elements in the High Technology Matrices which differ from their Standard Technology counterparts are shaded.

Level	Technology Characteristics
1	Technologies currently in production in at least one mass market vehicle worldwide and which have no technical risk in the sense that they are fully demonstrated and are available to all manufacturers through either direct production or licensing. Level 1 improvements are therefore available for production use within one product cycle.
2	Technologies ready for commercialization and for which there are no engineering constraints (such as emissions control considerations) which would inhibit their use in production vehicles. Technologies assessed at Level 2 are considered to have low technical risk in the sense that some "debugging" effort may be required because of a lack of on-road experience
3	Technologies in advanced stages of development but which may face some technical constraints before they can be used in production vehicles. Because Level 3 technologies bear some uncertainty as to when they will be fully available for use in production, it is not possible to presently establish with certainty that they are available for incorporation into new vehicles over the course of a complete product cycle.

---

<sup>15</sup>*NEMS Fuel Economy Model: LDV High Technology Update*, Decision Analysis Corporation of Virginia, DE-AC01-92EI21946, Task 95124, Subtask 9-2, 6/17/96.

<sup>16</sup>DeCicco, J., and Ross, M., *An Updated Assessment of the Near-Term Potential for Improving Automotive Fuel Economy*, American Council for an Energy-Efficient Economy, Washington DC, 11/93.

<sup>17</sup>*Ibid.* p. 12.

**Table A.2: Standard Technology Matrix For Cars**

	<b>Fractional Fuel Efficiency Change</b>	<b>Incremental Cost (1990 \$)</b>	<b>Incremental Cost (\$/Unit Wt.)</b>	<b>Incremental Weight (Lbs.)</b>	<b>Incremental Weight (Lbs./Unit Wt.)</b>	<b>First Year Introduced</b>	<b>Fractional Horsepower Change</b>
<b>Front Wheel Drive</b>	0.060	160	0.00	0	-0.08	1980	0
<b>Unit Body</b>	0.040	80	0.00	0	-0.05	1980	0
<b>Material Substitution II</b>	0.033	0	0.60	0	-0.05	1987	0
<b>Material Substitution III</b>	0.066	0	0.80	0	-0.10	1997	0
<b>Material Substitution IV</b>	0.099	0	1.00	0	-0.15	2007	0
<b>Material Substitution V</b>	0.132	0	1.50	0	-0.20	2017	0
<b>Drag Reduction II</b>	0.023	32	0.00	0	0.00	1985	0
<b>Drag Reduction III</b>	0.046	64	0.00	0	0.05	1991	0
<b>Drag Reduction IV</b>	0.069	112	0.00	0	0.01	2004	0
<b>Drag Reduction V</b>	0.092	176	0.00	0	0.02	2014	0
<b>TCLU</b>	0.030	40	0.00	0	0.00	1980	0
<b>4-Speed Automatic</b>	0.045	225	0.00	30	0.00	1980	0.05
<b>5-Speed Automatic</b>	0.065	325	0.00	40	0.00	1995	0.07
<b>CVT</b>	0.100	250	0.00	20	0.00	1995	0.07
<b>6-Speed Manual</b>	0.020	100	0.00	30	0.00	1991	0.05
<b>Electronic Transmission I</b>	0.005	20	0.00	5	0.00	1988	0
<b>Electronic Transmission II</b>	0.015	40	0.00	5	0.00	1998	0
<b>Roller Cam</b>	0.020	16	0.00	0	0.00	1987	0
<b>OHC 4</b>	0.030	100	0.00	0	0.00	1980	0.2
<b>OHC 6</b>	0.030	140	0.00	0	0.00	1980	0.2
<b>OHC 8</b>	0.030	170	0.00	0	0.00	1980	0.2
<b>4C/4V</b>	0.080	240	0.00	30	0.00	1988	0.45
<b>6C/4V</b>	0.080	320	0.00	45	0.00	1991	0.45
<b>8C/4V</b>	0.080	400	0.00	60	0.00	1991	0.45
<b>Cylinder Reduction</b>	0.030	-100	0.00	-150	0.00	1988	-0.1
<b>4C/5V</b>	0.100	300	0.00	45	0.00	1998	0.55
<b>Turbo</b>	0.050	800	0.00	80	0.00	1980	0.45
<b>Engine Friction Reduction I</b>	0.020	20	0.00	0	0.00	1987	0
<b>Engine Friction Reduction II</b>	0.035	50	0.00	0	0.00	1996	0
<b>Engine Friction Reduction III</b>	0.050	90	0.00	0	0.00	2006	0
<b>Engine Friction Reduction IV</b>	0.065	140	0.00	0	0.00	2016	0
<b>VVT I</b>	0.080	140	0.00	40	0.00	1998	0.1
<b>VVT II</b>	0.100	180	0.00	40	0.00	2008	0.15
<b>Lean Burn</b>	0.100	150	0.00	0	0.00	2012	0
<b>Two Stroke</b>	0.150	150	0.00	-150	0.00	2004	0
<b>TBI</b>	0.020	40	0.00	0	0.00	1982	0.05
<b>MPI</b>	0.035	80	0.00	0	0.00	1987	0.1
<b>Air Pump</b>	0.010	0	0.00	-10	0.00	1982	0
<b>DFS</b>	0.015	15	0.00	0	0.00	1987	0.1
<b>Oil 5W-30</b>	0.005	2	0.00	0	0.00	1987	0
<b>Oil Synthetic</b>	0.015	5	0.00	0	0.00	1997	0
<b>Tires I</b>	0.010	16	0.00	0	0.00	1992	0
<b>Tires II</b>	0.020	32	0.00	0	0.00	2002	0
<b>Tires III</b>	0.030	48	0.00	0	0.00	2012	0
<b>Tires IV</b>	0.040	64	0.00	0	0.00	2018	0
<b>ACC I</b>	0.005	15	0.00	0	0.00	1992	0
<b>ACC II</b>	0.010	30	0.00	0	0.00	1997	0
<b>EPS</b>	0.015	40	0.00	0	0.00	2002	0
<b>4WD Improvements</b>	0.030	100	0.00	0	-0.05	2002	0
<b>Air Bags</b>	-0.010	300	0.00	35	0.00	1987	0
<b>Emissions Tier I</b>	-0.010	150	0.00	10	0.00	1994	0
<b>Emissions Tier II</b>	-0.010	300	0.00	20	0.00	2003	0
<b>ABS</b>	-0.005	300	0.00	10	0.00	1987	0
<b>Side Impact</b>	-0.005	100	0.00	20	0.00	1996	0
<b>Roof Crush</b>	-0.003	100	0.00	5	0.00	2001	0
<b>Increased Size/Wt.</b>	-0.033	0	0.00	0	0.05	1991	0
<b>Compression Ratio Increase</b>	n/a	n/a	n/a	n/a	n/a	n/a	n/a
<b>Idle Off</b>	n/a	n/a	n/a	n/a	n/a	n/a	n/a
<b>Optimized Manual Transmission</b>	n/a	n/a	n/a	n/a	n/a	n/a	n/a
<b>Variable Displacement</b>	n/a	n/a	n/a	n/a	n/a	n/a	n/a
<b>Electric Hybrid</b>	n/a	n/a	n/a	n/a	n/a	n/a	n/a





**Table A.4: High Technology Matrix For Cars**

	Fractional Fuel Efficiency Change	Incremental Cost (1990 \$)	Incremental Cost (\$/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.060	160	0.00	0	-0.08	1980	0
Unit Body	0.040	80	0.00	0	-0.05	1980	0
Material Substitution II	0.033	0	0.30	0	-0.05	1987	0
Material Substitution III	0.066	0	0.40	0	-0.10	1997	0
Material Substitution IV	0.099	0	0.50	0	-0.15	2003	0
Material Substitution V	0.132	0	0.75	0	-0.20	2007	0
Drag Reduction II	0.023	32	0.00	0	0.00	1985	0
Drag Reduction III	0.046	64	0.00	0	0.05	1991	0
Drag Reduction IV	0.069	112	0.00	0	0.01	1997	0
Drag Reduction V	0.092	176	0.00	0	0.02	2003	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	1995	0.07
CVT	0.100	250	0.00	20	0.00	1995	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	1991	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	1988	0
Electronic Transmission II	0.090	60	0.00	5	0.00	1998	0
Roller Cam	0.020	16	0.00	0	0.00	1987	0
OHC 4	0.030	45	0.00	0	0.00	1980	0.2
OHC 6	0.030	55	0.00	0	0.00	1980	0.2
OHC 8	0.030	65	0.00	0	0.00	1980	0.2
4C/4V	0.080	125	0.00	30	0.00	1988	0.45
6C/4V	0.080	165	0.00	45	0.00	1991	0.45
8C/4V	0.080	205	0.00	60	0.00	1991	0.45
Cylinder Reduction	0.030	-100	0.00	-150	0.00	1988	-0.1
4C/5V	0.100	300	0.00	45	0.00	1998	0.55
Turbo	0.080	300	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	1987	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	1996	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	2006	0
Engine Friction Reduction IV	0.065	120	0.00	0	0.00	2016	0
VVT I	0.080	100	0.00	40	0.00	1998	0.1
VVT II	0.100	130	0.00	40	0.00	2008	0.15
Lean Burn	0.120	75	0.00	0	0.00	2012	0
Two Stroke	0.150	0	0.00	-150	0.00	2004	0
TBI	0.020	40	0.00	0	0.00	1982	0.05
MPI	0.035	80	0.00	0	0.00	1987	0.1
Air Pump	0.010	0	0.00	-10	0.00	1982	0
DFS	0.015	15	0.00	0	0.00	1987	0.1
Oil %w-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	5	0.00	0	0.00	1992	0
Tires II	0.033	10	0.00	0	0.00	2002	0
Tires III	0.048	15	0.00	0	0.00	2012	0
Tires IV	0.053	20	0.00	0	0.00	2018	0
ACC I	0.010	5	0.00	0	0.00	1992	0
ACC II	0.017	13	0.00	0	0.00	1997	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	1987	0
Emissions Tier I	-0.010	150	0.00	10	0.00	1994	0
Emissions Tier II	-0.010	300	0.00	20	0.00	2003	0
ABS	-0.005	300	0.00	10	0.00	1987	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	0.010	0	0.00	0	0.00	1995	0.02
Idle Off	0.110	260	0.00	0	0.00	1997	0
Optimized Manual Transmission	0.120	60	0.00	0	0.00	1997	0
Variable Displacement	0.030	65	0.00	0	0.00	1999	0
Electric Hybrid	0.660	1785	0.00	0	0.00	2001	0

**Table A.5: High Technology Matrix For Trucks**

	Fractional Fuel Efficiency Change	Incremental Cost (1990 \$)	Incremental Cost (\$/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.020	160	0.00	0	-0.08	1985	0
Unit Body	0.060	80	0.00	0	-0.05	1995	0
Material Substitution II	0.033	0	0.30	0	-0.05	1987	0
Material Substitution III	0.066	0	0.40	0	-0.10	1997	0
Material Substitution IV	0.099	0	0.50	0	-0.15	2003	0
Material Substitution V	0.132	0	0.75	0	-0.20	2007	0
Drag Reduction II	0.023	32	0.00	0	0.00	1985	0
Drag Reduction III	0.046	64	0.00	0	0.05	1991	0
Drag Reduction IV	0.069	112	0.00	0	0.01	1997	0
Drag Reduction V	0.092	176	0.00	0	0.02	2003	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	1995	0.07
CVT	0.100	250	0.00	20	0.00	1995	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	1991	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	1988	0
Electronic Transmission II	0.090	60	0.00	5	0.00	1998	0
Roller Cam	0.020	16	0.00	0	0.00	1987	0
OHC 4	0.030	45	0.00	0	0.00	1980	0.2
OHC 6	0.030	55	0.00	0	0.00	1980	0.2
OHC 8	0.030	65	0.00	0	0.00	1980	0.2
4C/4V	0.080	125	0.00	30	0.00	1988	0.45
6C/4V	0.080	165	0.00	45	0.00	1991	0.45
8C/4V	0.080	205	0.00	60	0.00	1991	0.45
Cylinder Reduction	0.030	-100	0.00	-150	0.00	1988	-0.1
4C/5V	0.100	300	0.00	45	0.00	1998	0.55
Turbo	0.080	300	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	1987	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	1996	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	2006	0
Engine Friction Reduction IV	0.065	120	0.00	0	0.00	2016	0
VVT I	0.080	100	0.00	40	0.00	1998	0.1
VVT II	0.120	130	0.00	40	0.00	2008	0.15
Lean Burn	0.100	75	0.00	0	0.00	2012	0
Two Stroke	0.150	0	0.00	-150	0.00	2004	0
TBI	0.020	40	0.00	0	0.00	1982	0.05
MPI	0.035	80	0.00	0	0.00	1987	0.1
Air Pump	0.010	0	0.00	-10	0.00	1982	0
DFS	0.015	15	0.00	0	0.00	1987	0.1
Oil 5W-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	5	0.00	0	0.00	1992	0
Tires II	0.033	10	0.00	0	0.00	2002	0
Tires III	0.048	15	0.00	0	0.00	2012	0
Tires IV	0.053	20	0.00	0	0.00	2018	0
ACC I	0.040	5	0.00	0	0.00	1992	0
ACC II	0.017	13	0.00	0	0.00	1997	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	1987	0
Emissions Tier I	-0.010	150	0.00	10	0.00	1994	0
Emissions Tier II	-0.010	300	0.00	20	0.00	2003	0
ABS	-0.005	300	0.00	10	0.00	1987	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	0.010	0	0.00	0	0.00	1995	0.02
Idle Off	0.110	260	0.00	0	0.00	1997	0
Optimized Manual Transmission	0.120	60	0.00	0	0.00	1997	0
Variable Displacement	0.030	65	0.00	0	0.00	1999	0
Electric Hybrid	0.660	1785	0.00	0	0.00	2001	0

## APPENDIX B: CHARACTERISTICS OF ALTERNATIVE FUEL VEHICLES

This appendix provides a documentation of the updated Fuel Economy Model that also forecasts attributes of Alternative Fuel Vehicles (AFVs) for incorporation into the NEMS transportation model. The NEMS model requires a forecast of vehicle attributes consistent with those provided for conventional gasoline powered vehicles. The existing AFV module considers only three size classes, and requires five attributes by size class, which includes vehicle price and fuel efficiency as well as range, fuel availability and an estimate of emissions relative to gasoline. In general, fuel availability is specified exogenously, while the Fuel Economy Model (FEM) is expected to supply other attributes. The updated FEM provides attributes for AFVs in up to 12 market classes and five fuel types.

Other than gasoline and diesel powered vehicles, the model considers a variety of alternative fuel vehicles that are of both the dedicated and bi-fuel (alternative fuel/gasoline) type. The fuels considered include methanol, ethanol, electricity, compressed natural gas and liquified petroleum gas for a matrix of 10 alternative fuel vehicle types. The existing AFV module contains two other AFV types that are engine technology based classifications (assuming that the 10 described above use piston i.c. engine based technology). The two others are turbine powered using gasoline or CNG, and fuel cell powered using methanol or pure hydrogen, for an additional four AFV classes.

Available data for the manufacturers suggest that turbine powered vehicles are most unlikely to be produced as they have significantly higher costs and lower fuel economy than i.c. engines of equal power. Fuel cell powered vehicles using either methanol or pure hydrogen are unlikely to see commercial production before 2010. Attributes of all other vehicle types are summarized in this report, and a preliminary estimate of fuel cell vehicle attributes is also provided. Most of the data provided are drawn from ongoing work by EEA for the DOE's Alternative Fuel Transition Model, or from a recently completed EEA analysis for the Office of Technology Assessment.

The specification of AFV attributes requires a series of supply side issues to be resolved largely based on the judgement of EEA. Essentially, manufacturers can choose to tradeoff first cost against vehicle range, performance and even emissions. The choice of such parameters should ideally be made by the demand forecasting model, but such capabilities are not yet available in demand forecasting models.

The first consideration in forecasting AFV demand is that all fuels are not well suited to all vehicle size classes. For example, the size and weight of CNG tanks make it a poor choice for small cars.

Based on engineering considerations, EEA has estimated the likely combinations of fuel types and vehicle types that will be available in cars and light trucks. These combinations are shown in Table B.1 and B.2 respectively. It should be noted that there are no technical barriers to any particular combination of fuel type and size class, and these favored combinations are based on EEA's judgement about market acceptability and economic barriers facing AFVs in each class.

A second and more important consideration is that vehicle price is a strong function of sales volume. There are significant fixed costs associated with the design, tooling and certification of an AFV model, and if a model has a sales volume of only a few hundred units per year, the fixed costs allocations to each unit are quite large. A typical (non-luxury) gasoline car model is produced at annual volumes of 100,000 to 200,000 units, while most current AFV model sales are only in the range of a few tens to hundreds of units per year. Since the supply and demand models are not interactive, the pre-specification of vehicle price involves estimating sales volumes. Other analysis by EEA suggests that economies of scale result in similar percentage price reduction for every order of magnitude increase in production volume. In this analysis, EEA has assumed that AFV's will be derived from gasoline vehicles and sales volume per model will be in the 2,000 to 3,000 range so that modest economy of scale is achieved, but the full extent is not, for the near term. Pricing at volumes of 20,000 to 30,000 units per year is also considered. Based on other analysis for DOE, EEA recommends that prices at intermediate volumes be scaled in proportion to the logarithm of sales.

EEA analysis for the DOE indicates that auto-manufacturers must anticipate a sales volume of about 2500 units per year of a given AFV model in order to enter the market. At much lower sales volumes in the range of a few tens of vehicles to a few hundred vehicles per year, automanufacturers have typically subcontracted the work to small conversion shops, or else these AFVs have been aftermarket conversions of existing gasoline vehicles. In general, manufacturers believe that most aftermarket conversions are not well engineered in terms of emissions, fuel economy, and safety, and often have poor performance at high or low ambient temperatures. However, these conversions are much cheaper than automanufacturer designed products at the same sales volume, so that an aftermarket conversion is usually sold at 250 units/yr at the same price as an OEM conversion sold at 2500 units/year. The poor quality is a deterrent to consumer purchase.

<b>Table B.1: Alternative Fuel Type Potential Application by Size Class (Cars)</b>						
	<u>Mini/Sub Compact</u>	<u>Compact</u>	<u>Midsize</u>	<u>Large</u>	<u>Luxury</u>	<u>Sport</u>
<b>Alcohol Flex<sup>18</sup></b>	X	X	X	X	X	X
<b>Methanol Neat</b>	X	X	X	X		X
<b>Ethanol Neat</b>		X	X	X		
<b>CNG Dedicated</b>				X		
<b>CNG Bifuel</b>				X		
<b>LPG Dedicated</b>			X	X		
<b>LPG Bifuel</b>			X	X		
<b>Electric</b>	X	X				
<b>EV/Hybrid</b>		X	X			
<b>Fuel Cell Methanol</b>			X	X		
<b>Fuel Cell Hydrogen</b>			X	X		

The following sections summarize the changes required to develop each particular AFV type from a gasoline based car, which EEA believes will serve as the base design, since developing a unique "ground up" AFV design is not likely as long as AFV sales volumes per model are less than 10 percent of similar gasoline engine model sales. Manufacturer's may contemplate offering a unique "ground up" design only for EVs, if a specific model can be sold in volumes of 50,000 units per year or more, which appears unlikely to this time. In addition, only OEM products are considered so that quality issues do not influence purchase considerations.

As a result, future model specific improvements for all AFV types will follow those for gasoline vehicles, except for inapplicable technologies for a specific AFV type. These inapplicable technologies are recognized in the descriptions that follow. In addition, it should be emphasized that there is a sales volume based price affect, but there is no "learning curve" effect for all engine technologies that are very similar to gasoline engine technologies, namely engines for alcohol fuels, CNG and LPG. Learning curve effects for EVs and hybrid vehicles are primarily associated with future cost reductions in energy storage media, either batteries or ultracapacitors, and in power electronics. Learning curves also exist for CNG fuel tanks, but the cost reductions will be less dramatic than for EVs and hybrids.

---

<sup>18</sup> Includes methanol/ethanol.

<b>Table B.2: Alternative Fuel Type Potential Application by Size Class (Light Trucks)</b>							
	<b>Mini-Utility</b>	<b>Compact Pickup</b>	<b>Compact Van</b>	<b>Compact Utility</b>	<b>Standard Pickup</b>	<b>Standard Van</b>	<b>Standard Utility</b>
<b>Alcohol Flex<sup>19</sup></b>	X	X	X	X	X	X	X
<b>Methanol Neat</b>		X	X				
<b>Ethanol Neat</b>			X				
<b>CNG Dedicated</b>		X			X	X	
<b>CNG Bifuel</b>			X		X	X	
<b>LPG Dedicated</b>		X	X		X	X	
<b>LPG Bifuel</b>		X	X		X	X	
<b>Electric</b>		X	X				
<b>EV/Hybrid</b>			X	X			X
<b>Fuel Cell Methanol</b>		X				X	
<b>Fuel Cell Hydrogen</b>			?			?	

Each AFV type will require additional or specialized parts that result in variable cost increases, as well as fixed costs associated with:

- engineering
- tooling
- certification
- marketing

To the extent possible, total incremental AFV fixed costs per model have been identified. Table B.3 shows how the variable and fixed costs can be translated into a incremental retail price equivalent (IRPE) given a certain anticipated sales (or production) volume per model. These formulas have been used to develop retail price estimates. Ideally, the NEMS model should assume low sales volume prices, compute the actual sales, and iteratively check if the sales volumes predicted are in line with pricing assumptions.

---

<sup>19</sup> Includes ethanol/methanol.

<b>Table B.3: Conversion of Variable and Fixed Costs to IRPE</b>	
<b>Supplier costs to manufacturer</b>	A
<b>Total manufacturer investments</b>	B
<b>Unit cost of investment, C per production volume V</b>	$\frac{B \times 1.358}{V \times 4.487}$
<b>Automanufacturer Cost</b>	$A \times 1.4 + C = D$
<b>IRPE</b>	$D \times 1.25$

### **FLEXIBLE FUEL AND DEDICATED ALCOHOL VEHICLES**

These vehicles closely resemble the gasoline engine powered vehicle, and the modifications of a conventional vehicle to be either a flexible fuel vehicle (FFV) or dedicated alcohol fuel vehicle are relatively minor. At present, all alcohol vehicles are OEM products and no aftermarket conversions are expected. The most significant modifications are:

- Upgrade of the fuel tank and fuel lines materials to be corrosion resistant to alcohol
- New high flow fuel pump that can provide up to twice the flow rate of conventional pumps
- Modified fuel injectors and a new fuel/spark calibration for alcohol fuel
- Modifications to the evaporative emission control system to handle alcohol gasoline blends (FFV only)

The FFV also has a unique component, the fuel alcohol sensor that signals the engine electronic control system on the alcohol gasoline blend being used. The variable cost of all of the above parts is typically about \$300 to \$500 at low sales volume, with much of the cost associated with the fuel pump and fuel sensor. The high end of the range of costs is associated with converting a vehicle whose current fuel system requires significant materials changes, whereas the lower end would be for a vehicle whose current fuel system is corrosion resistant to alcohol.

Dedicated alcohol vehicles require similar changes but do not need the fuel sensor. If the engine is optimized for alcohol, it needs a new high compression ratio cylinder head, which partly offsets the cost of the sensor. Dedicated alcohol vehicle will have a simpler evaporative emission control system, although cost savings here are expected to be small. The net variable cost of a dedicated alcohol vehicle will be only slightly lower than that of an FFV and is estimated at \$250 to 350 at low sales volume. Variable costs (which include supplier fixed costs) are expected to be reduced to half the low volume levels, i.e. \$150 to 250, due to reduced per unit supplier costs, if volumes increase to 25,000 units/year.



Fixed costs for the automanufacturer are estimated at \$7 to \$8 million per model line, based on input from the manufacturers, for an assumed sales volume of 2500 units/year. However, significantly higher sales volume does not require much higher investment, and it is estimated that 25,000 units/year sales capability would require only an additional \$2 million more to expand assembly capacity and enhance the marketing network.

Attributes of flexible fuel and dedicated vehicles are shown in Table B.4, relative to gasoline vehicle attributes. Prices are shown as if manufactures are pricing these vehicles as a standard product, (which they are clearly not) and EIA may wish to modify the prices to reflect current pricing. All of the improvements possible for conventional vehicles are applicable to FFV's and dedicated alcohol vehicles. At present, EEA believes that dedicated vehicles and FFVs operated on alcohol fuel may have small benefits in reactivity adjusted HC emissions (in the range of -10 to -20 percent) relative to an equal technology gasoline vehicle, but other emission benefits are negligible. In general, the range of prices shown at each sales volume are associated with vehicle size changes, with smaller cars at the low end of the price range, large trucks at the high end of the range, and mid-sized/large cars and compact trucks at the middle of the range.

<b>Table B.4: Characteristics of Alcohol Fuel Vehicles Relative to Gasoline ICE's</b>				
	<b>Methanol FFV</b>	<b>Ethanol FFV</b>	<b>Methanol Dedicated</b>	<b>Ethanol Dedicated</b>
<b>Horsepower</b>	+4	+3	+8	+6
<b>Range on M85/E85</b>	-43	-27	-37	-24
<b>Fuel Economy</b>	+2	+1	+8	+4
<b>Incremental Price (\$) <sup>20</sup></b>				
<b>@ 2,500 units/yr</b>	1650-2000	1650-2000	1560-1820	1560-1820
<b>@ 25,000 units/yr</b>	410-500	410-500	370-425	370-425

### **CNG/LPG VEHICLES**

CNG/LPG vehicles are the next step in complexity from an alcohol fueled vehicle for conversion from a conventional gasoline vehicle. The major difference is that the fuel tanks are more complex, heavy and expensive, especially for CNG. Currently, most CNG and LPG vehicles are aftermarket conversions, but the OEMs have recently entered this market with a range of new products.

---

<sup>20</sup> Assumes manufacturer makes normal return on investment.

Outside of the fuel tanks, engine and fuel conversion costs are quite similar to these for a dedicated alcohol fuel vehicle. These include more expensive fuel lines, new fuel injectors and more expensive fuel injector drivers. The pump in an alcohol fuel vehicle is replaced by a pressure regulator, which can be a relatively expensive piece of equipment for a CNG vehicle that is certified to a stringent emission standard. Low pressure LPG pressure regulators are less expensive, but some manufacturers are experimenting with liquid LPG injection for optimal emission control. Engine improvements for both CNG and LPG systems are also similar, requiring revisions to the valve seats, pistons and rings and head gasket.

For dedicated systems, increases to the engine compression ratio (CR) by 0.5 to 1 point for LPG and 1.5 to 2 points for CNG are optimal. Such increases may, in turn, lead to revisions to the cooling system and air intake system. The increases in CR lead to a fuel economy benefit of and 4 and 8 percent for LPG and CNG, respectively.

Engine components and costs for a dual fuel system of high quality that is emission certified is estimated at \$350 to 450. Engine improvements for dedicated CNG/LPG engines that are optimized will increase these costs to \$500 to \$600. However, there will be a cost savings of \$350 associated with the elimination of the gasoline fuel system and evaporative system, for a net cost of \$150 to 250. The costs are for volumes of 2,500 units/year and could decrease by 50 percent at 25,000 units/year, based on interviews with CNG system manufacturers.

Costs of fuel tanks are significant. For CNG, the incremental costs of tanks are estimated at \$100-125 per gasoline equivalent gallon, and a typical tank for cars is about 9 gallons, while one for trucks is 12 gallons. Hence, CNG tank costs are \$900 to 1125 for cars, and \$1200 to 1500 for trucks at low volume. The tanks add about 150 lbs weight for cars and 200 lbs for trucks. LPG tanks cost approximately one-third as much as CNG tanks. One significant uncertainty is how much the cost of CNG/LPG tanks can decline as a function of volume. It has been estimated that costs will decline by 33% as sales volume increases from 2500 units/year to 25,000 units/year, but this figure may indicate benefits from "learning" as well.

Engineering and tooling costs for CNG and LPG vehicles are significantly higher than for alcohol fueled vehicles, because of the need to modify the body and chassis to accommodate the tanks, and the need to upgrade suspension tires and brakes to accommodate the increased weight. In addition, the vehicle will have to be crash tested due to the extensive changes to the fuel system, to verify system integrity. At low volume it has been estimated that engineering, tooling and certification costs per model for dual fuel vehicle are about \$15 million. Additional engine engineering costs for a dedicated CNG/LPG vehicle are estimated at \$3 million. Expansion of special assembly facilities

to accommodate a volume of 25,000 units per year is estimated to cost an additional \$5 million for facilities.

Costs and vehicle attributes for CNG/LPG vehicles are shown in Table B.5. In addition, it is assumed that future CNG/LPG vehicles will be certified as ILEVs for emissions to meet Clean Fleet and California requirements. As before, the range of costs span the size range of vehicles from small cars to large trucks. At sales volumes of a few hundred units per year, only aftermarket conversions are expected to be available at approximately the same price as OEM products at a sales volume of 2500 units/year.

Future improvements to CNG/LPG vehicles will not differ from those for gasoline vehicles, with the sole exception of VVT (Variable Valve Timing). Pumping losses in CNG/LPG engines are lower because of the air displacement effect of gaseous fuels. EEA estimates that VVT benefits will be reduced to half its gasoline benefit when used in conjunction with these fuels.

## **ELECTRIC, FUEL CELL AND HYBRID VEHICLES**

These vehicles are a significant departure from conventional vehicles in that their drivetrain and fuel system is very different from a gasoline engine and its fuel tank/fuel system. The pricing analysis of these vehicles reflects the fact that there are no electric vehicles (EVs) or Hybrid Electric Vehicles (HEVs) in production and that data must be extrapolated from current prototypes and pre-production vehicle models. Fuel cell powered vehicles are still at least a decade or two away from commercialization.

### **Electric Vehicles**

In the electric vehicle, the engine is replaced by an electric motor and controller, while the gasoline tank is replaced by a battery. EEA analysis for the OTA for an EV with a production volume of 25,000 units/yr revealed a range of attributes that depend on battery technology. Table B.6 provides the data for four vehicle classes for several different batteries for the year 2005, which is believed to be the earliest point where relatively high EV production volume can be realized. However, the table assumes that a relatively high technology body would be used.

<b>Table B.5: Attributes of CNG/LPG Vehicles Relative to Gasoline Vehicles</b>				
	<b>CNG Bi-fuel</b>	<b>LPG Bi-fuel</b>	<b>CNG Dedicated</b>	<b>LPG Dedicated</b>
<b>Horsepower</b>	-15	-8	-5	0
<b>Range</b>	-50	-20	-40	-15

<b>Fuel Economy (BTU equivalent)</b>	-0	-0	+8	+4
<b>Incremental Price<sup>21</sup></b>				
<b>@ 2,500 units/yr</b>	4750/5350	3550/3950	4840/5440	3670/3860
<b>@ 25,000 units/yr</b>	1825/2225	1085/1175	1695/2100	920/985

Note that range is based on an assumed tank size that holds approximately half the gasoline energy equivalent for CNG vehicles and 80 percent of the gasoline energy equivalent for LPG. Other tank sizes could be incorporated at different costs.

EEA believes that the Lead Acid battery is potentially the only viable near term solution. Some analysts claim that the Nickel Metal Hydride battery (Ni-MH) can become cost competitive at \$200/kwh relative to a lead-acid battery at \$125/kwh by the year 2002, but others believe that the Ni-MH batteries are more likely to cost \$400/kwh initially. A range of 80 to 100 miles is the best that can be considered in the entire time frame to 2015, given the steep increase in costs to obtain a 200 mile range. Beyond 2005, the Ni-MH battery could be dominant, although it is very speculative to make such a prediction. Of course, all EVs are zero emission vehicles.

Electric vehicles can be conversions of existing gasoline vehicles, but the conversion is rather extensive. Essentially, the entire drivetrain must be replaced, necessitating removal of the gasoline engine and transmission. In addition, the fuel tank must be removed, and the vehicle equipped with batteries. The EV motor/controllers and batteries have very different characteristics of weight and size relative to the components displaced in a conventional gasoline car, so that the repackaging of these components, especially the battery, requires significant engineering and design effort. The conversion process typically utilizes a vehicle built without any of the gasoline vehicle's drivetrain and fuel systems, and such vehicles are referred to as gliders.

<b>Table B.6: EV Characteristics in 2005</b>					
<b>Battery (Scenario)</b>	<b>Range</b>	<b>Battery Weight (kg)</b>	<b>Total Weight (kg)</b>	<b>Energy Eff. (kwh/km)</b>	<b>Incr. Price (1994)</b>

<sup>21</sup> Cars/Light Trucks.

<b>Subcompact</b>					
Lead Acid (m)	80	612	1540	0.190	8,030
Ni-MH (m)	100	283	1010	0.116	13,575 (6631)*
Ni-MH (o)	200	823	1850	0.201	42,500
Na-S (o)	200	263	943	0.106	27,050
<b>Intermediate</b>					
Lead Acid (m)	80	830	2,031	0.250	10,900
Ni-MH (m)	100	370	1,335	0.153	17,900 (8835) <sup>22</sup>
Ni-MH (o)	200	1,075	2,430	0.265	55,675
Na-S (o)	200	343	1,250	0.141	35,500
<b>Compact Van</b>					
Lead Acid (m)	80	918	2,336	0.288	12,700
Ni-MH (m)	100	425	1,540	0.177	21,000 (10,600)*
Ni-MH (o)	200	1,234	2,800	0.305	64,400
Na-S (o)	200	394	1,440	0.162	41,220
<b>Standard Pickup</b>					
Lead Acid (m)	80	1,186	2,918	0.360	16,760
Ni-MH (m)	100	550	1,887	0.217	27,520 (14,070)*
Ni-MH (o)	200	1,598	3,527	0.384	83,820
Na-S (o)	200	510	1,764	0.199	53,800

Energy Efficiency is based on electrical consumption at wall plug. Price increment is relative to advanced conventional vehicle for the same scenario.

Purpose designed EVs have been displayed by some automanufacturers such as GM and BMW, but most industry analysts doubt that such vehicles will be produced at a production capacity level of less than 100,000 units/year because of the very high investment in the design, tooling and certification for a unique design. Indeed, GM officials have stated that they can never recover the \$260 million invested in the design and engineering for the purpose-built "Impact" EV. Even at 100,000 units/year, media reports suggest that a purpose built EV would require investments similar to that for a conventional car (about \$1 billion per model) but the incremental investment for a glider derived EV would be about one-tenth that amount.

For electric vehicles derived from a glider, investment costs have had to estimated since none of the manufacturers provided this information. Approximate estimates from published magazine articles and other anecdotal information support an estimate of \$50 million in engineering, tooling,

---

<sup>22</sup> Price if Ni-mH battery can be manufactured at \$200/kwh.

certification and launch cost for a production capacity of 2,500 units per year. This investment increases to \$80 million for 25,000 units per year and \$100 million for 100,000 units/year, based on the media reports discussed, as well as anecdotal information from the automanufacturers. However, the major capital expense is the construction of a battery plant, which is not treated here, since the battery is a "variable cost" to the automanufacturer. In addition, the same battery type or model can be used across different vehicle series and different automanufacturers.

In the near term (certainly to 2000 and perhaps to 2005), EEA believes that the only realistic battery option is the Advanced Lead Acid Battery. EEA interviewed the only manufacturer (Horizon) of such a battery that is nearing commercial production, and obtained costs at low volume production (of approximately 5000 vehicle battery packs per year) and at high volume (50,000 per year). Horizon's estimates for the high volume production rate battery was for a future unspecified date and may involve economies of both scale and learning, since such a battery has never been produced before.

The post-2002 estimate assumes emergence of the Nickel Metal Hydride battery, and its attributes have been estimated from current prototype performance. Although there is considerable uncertainty about its costs, it is assumed that the resulting EV will be cost competitive with a 2010 lead-acid battery powered EV, given a learning cost reduction schedule for the lead-acid battery. Although it is not necessary to specify the battery under this assumption to derive IRPE, it is necessary to do so to derive the characteristics of the EV in terms of weight, size and performance. EVs will also benefit from future improvements to weight, drag and rolling resistance.

For the computer model, it is assumed that all EV production will be based on a "glider" derived from a conventional gasoline car. The weight of the glider with no electrical components is estimated at 54 percent of the weight of the gasoline car. For an EV with performance levels equivalent to a gasoline car, battery weight ( $W_{Batt}$ ) is given by:

$$W_{Batt} = \left[ \frac{0.1 \frac{R}{S_3}}{0.9 - 0.15 \frac{R}{S_E}} \right] \cdot W_{Glider}$$

where  $R$  is the EV range (in km),  $S_E$  is the battery specific energy in watt hours per kilogram, and  $W_{GLIDER}$  is glider weight in kg. An advanced lead acid battery has a specific energy of 40 wh/kg, while the Nickel Metal Hydride battery has an  $S_E$  of 72. These equations are used to estimate battery weight.

The IRPE of the EV at 25,000 units/year is estimated based on the assumption that the cost of the electric motor and electronic controller will offset the cost of the gasoline engine, fuel system and emission control system while the cost of the battery will be the most significant cost increment to the EV. In volume production, Lead Acid batteries are expected to cost (the automanufacturer) \$125 per kwh or \$5 per kg. The Nickel Metal Hydride battery is initially expected to cost \$400 per kwh or \$28.80 per kg. These costs apply in 1998, but Ni-MH batteries in 2002 should decrease to about \$250 per kwh.

Costs are expected to go down significantly with experience, but the "learning curve" is difficult to quantify objectively. Costs are expected to decline by 25 percent per decade based on interviews with battery manufacturers so that, for example, lead-acid batteries will sell for \$94 per kwh in 2008. The IRPE calculation amortizes the \$80 million in fixed costs as per the formula in Table B.3. Costs at low sales volumes of 2,500 units/year have been calculated externally, and in general, it has been found that an offset of \$10,000 in IRPE provides a reasonable representation of the low volume sales price relative to the calculated high volume sales price.

### **Fuel-Cell Vehicles**

In a full cell vehicle, the fuel cell is similar to the EV battery in that it supplies motive power to the motors. The sizing of the fuel cell is based on the continuous power requirement of the vehicle, but all other factors will be quite similar to those for an EV. However, the present state of development of fuel cells is in its infancy, and considerable development is required before the fuel cell can be commercialized. Fuel cell powered vehicles are also zero emission vehicles.

PEM Fuel cells can use only hydrogen as fuel, and hence, hydrogen must be either carried on board in liquid form in a cryogenic tank, or manufactured on board with a methanol reformer. The DOE

is researching the PEM fuel cell and reformer, and the costs and weights of these components are based on very aggressive targets set by DOE, not on current costs which are two orders of magnitude above the targets. The DOE targets may be appropriate for fuel cells in the 2020 time frame.

Calculations by EEA for OTA, based on DOE cost and performance targets, indicate that fuel cell vehicles of either type will have weights approximately similar to these of conventional gasoline vehicles, so that the FEM utilizes a short-cut approach to fuel cell IRPE determination. It starts with the finding that weights are similar to derive the required power output of a fuel cell, which is 30 kw per ton of vehicle weight. Peak output requirements are assumed to be met by a high power lead acid battery with peak power capacity of 2/3 of the fuel cell output, and a specific power capability of 500 w/kg.

Costs are based on these power output estimates and it is assumed that fuel cells will be initially available at the cost of \$450 per kw with a methanol reformer costing an additional \$200 per kw in 2003. The costs are one order of magnitude higher than DOE targets but may be representative of prices that can be achieved in the short-term. The cost of a cryogenic hydrogen tank is estimated at about \$3000, with only a weak dependence on size, at a sales volume of 25,000 unit/year. Costs of batteries are computed using the same methodology used to calculate EV battery costs.

Fixed cost amortization and low volume cost increases are assumed to be identical to those derived for EVs. However, the learning curve is expected to be very steep so that fuel cell/reformer costs decline 14 percent per year, to reach DOE targets by 2020. Fuel economy calculations are based on the details developed the OTA report, and are simply weight based for the purposes of the FEM.



## **Electric Hybrid Vehicles**

Electric Hybrid Vehicles feature both an engine and an electric motor as part of the drivetrain, but there can be a wide variety of designs that allow for large variations in the relative sizes of the electric motor, i.e. engine, and electric storage capacity. Hybrids are often classified as series or parallel, and also as charge depleting or charge sustaining. Even within these four categories, manufacturers disagree about the optimal relative size of the engine versus the electric motor. Due to these uncertainties, EEA has selected one promising approach which is a series, charge sustaining hybrid, with an engine sized to be able to produce the continuous power requirement of 30 kilowatts per ton of loaded vehicle weight, as an example for determining the IRPE.

Since the calculations to derive hybrid vehicle characteristics are relatively complex, a reduced form based on EEA's work for OTA has been used. Most of the costs of the vehicles scale in approximate proportion to vehicle weight, so that the gasoline vehicle weight is used as an indicator, and the calculated midsize hybrid vehicle costs and fuel economy are used as a reference point for scaling. The IRPE of hybrid vehicles are scaled based on an expected midsize vehicle IRPE of \$4400 in 2002 under a production rate of 25,000 units/year. A learning curve reduces these costs at 25 percent per decade, while low volume production at 2,500 units/year imposes an IRPE penalty of \$10,000.

Series hybrid vehicles are expected to have 30 percent better composite fuel economy than current conventional gasoline cars. However, future engine improvements to reduce pumping loss and drivetrain improvements are not applicable to such vehicles, due to the electric drivetrain used. Emissions of these vehicles are expected to conform to California ULEV regulations, much like CNG vehicle emissions.

## APPENDIX C: CHARACTERISTICS OF FLEET VEHICLES

### Aggregation of EPACT Requirements

Under the provisions of EPACT, purchases of vehicles by fleets meeting certain criteria are affected by the requirement that a proportion be alternatively fueled. The specific conditions under which these provisions are in effect, and the fleet sizes which are affected are not static, but are subject to revision. The impact of the current legislation on different fleet types is tabulated below.<sup>23</sup>

<b>Table C.1: Federal Mandates for Alternative-Fueled Vehicles</b>					
Year	Percent of Total Light Duty Vehicle Acquisitions				
	Federal	State	Fuel Providers	Electric Utilities	Municipal & Private
1996	25	10	30	---	---
1997	33	15	50	---	---
1998	50	25	70	30	---
1999	75	50	90	50	20
2000	75	75	90	70	20
2001	75	75	90	90	20
2002	75	75	90	90	30
2003	75	75	90	90	40
2004	75	75	90	90	50
2005	75	75	90	90	60
Thereafter	75	75	90	90	70

Affected fleets are also distinguished by geographical location: fleets of 50 or more of which 20 or more are located in metropolitan areas with a population over 250,000 with the capability of central refueling.<sup>24</sup> Federal mandates for the three fleet types considered by the model are estimated using a stock-weighted average of the relevant categories above, and identified as EPACT3<sub>ITY,T</sub> in the code. Business fleets are directly mapped to the "Municipal and Private" column above, government fleets combine "Federal" and "State" requirements, and Utility fleets combine the "Fuel Providers" and "Electric Utilities" mandates. Weighting factors are derived from recent stock estimates, and

<sup>23</sup>The table has been reproduced from *Alternatives To Traditional Transportation Fuels 1994, Volume 1*, U.S. Department of Energy, Energy Information Administration, DOE/EIA-0585(94)1, February 1996, Table 1.

<sup>24</sup>PL 102-486 §301(5)(A)&(B), and §301(9), 10 CFR 106 STAT. 2866, et. seq.

are subject to periodic revision.

### Business Fleet Stratification for Automobiles

Vehicles which are categorized under the somewhat broad definition of business fleets include automobiles used for daily rental and long term leasing--vehicles not intended to be covered under the alternative fuel provisions of EPACT. As the AEO95 model was structured, all business fleet vehicles were considered to be covered by the legislation, resulting in an elevated estimate of the consequent sales of alternative fuel vehicles. A time series of the number of automobiles in each category is tabulated in the table below. The fraction of business fleet vehicles which would be subject to EPACT shows a distinct downward trend over the past twenty years, as depicted below, reaching approximately 50 percent in 1990.

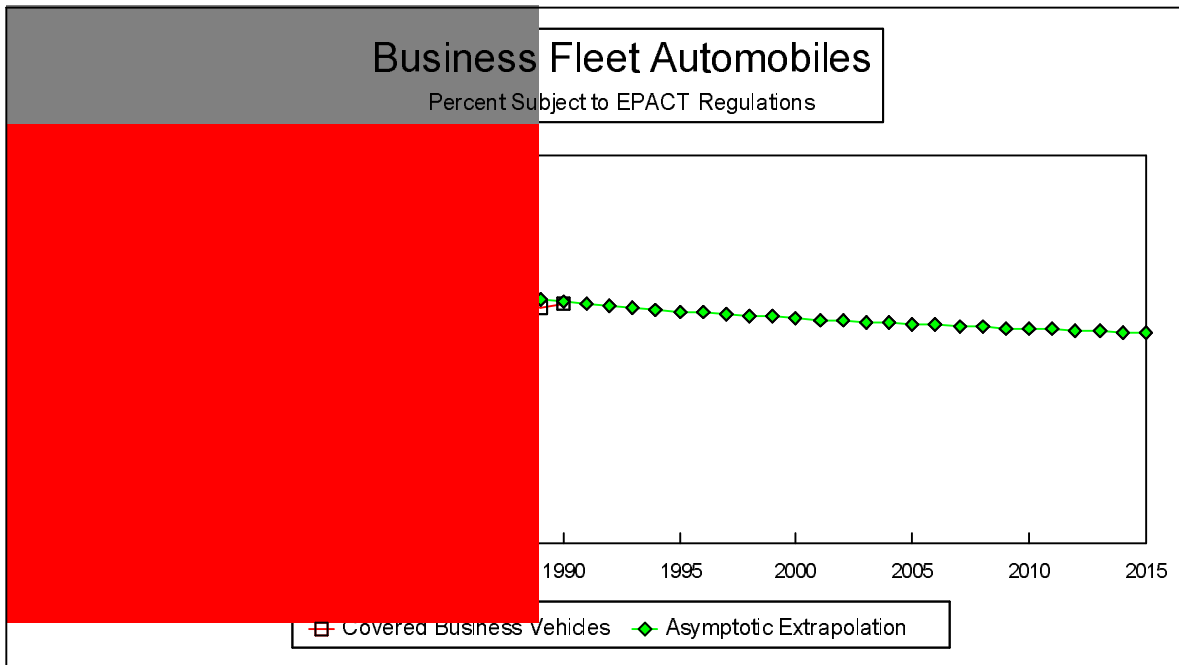
<b>Table C.3: Business Fleet Distribution of Vehicles</b>				
	<b>Business Fleets</b>			<b>Percent Covered</b>
	<b>Total</b>	<b>Covered</b>	<b>Uncovered</b>	
1971	3,900	2,336	1,564	59.90%
1972	4,107	2,449	1,658	59.63%
1973	4,430	2,691	1,739	60.74%
1974	4,482	2,740	1,742	61.13%
1975	4,553	2,763	1,790	60.69%
1976	4,858	2,911	1,947	59.92%
1977	5,075	2,952	2,123	58.17%
1978	5,411	3,003	2,408	55.50%
1979	5,554	3,054	2,500	54.99%
1980	5,692	3,139	2,553	55.15%
1981	5,679	3,163	2,516	55.70%
1982	5,567	3,125	2,442	56.13%
1983	5,641	3,182	2,459	56.41%
1984	5,972	3,216	2,756	53.85%
1985	6,184	3,276	2,908	52.98%
1986	6,438	3,163	3,275	49.13%
1987	6,606	3,298	3,308	49.92%
1988	6,869	3,414	3,455	49.70%
1989	6,978	3,413	3,565	48.91%
1990	6,974	3,455	3,519	49.54%

A new variable, BFLTFRAC, has been established to further stratify the stock of business fleet cars, with only the "covered" vehicles being used to estimate AFV purchases under EPACT. This variable is estimated using an asymptotic extrapolation of the historical trend, using an assumed lower limit of 40 percent, and a functional form as follows:

$$BFLTFRAC_{T-1971} = BFLTFRAC_{MIN} + (BFLTFRAC_{MAX} - BFLTFRAC_{MIN}) \cdot EXP^{(K_2 \cdot (T-1971))}$$

The input assumptions, estimated coefficients, and extrapolated values of BFLTFRAC are provided below.

<b>Covered Business Fleet Extrapolation</b>	
<b>Input Assumptions</b>	
BFLTFRAC <sub>MIN</sub>	40%
BFLTFRAC <sub>MAX</sub>	61.2%
Base Year	1971
<b>Regression Output</b>	
k <sub>2</sub>	-0.0404
R <sup>2</sup>	0.839



**Figure 7**

**Distribution of Fleet Light Trucks**

As noted in the amended documentation, the Light Duty Vehicle Fleet Module first estimates the sales of light trucks to fleets as follows:

$$FLTSAL_{VT=2,ITY,T} = FLTTRAT \cdot SQDTRUCKSL_T \cdot FLTSHR_{ITY}$$

where:

- FLTSAL = Sales to fleets by vehicle and fleet type
- FLTTRAT = Fraction of total truck sales attributed to fleets
- SQDTRUCKSL = Total light truck sales in a given year, obtained from the NEMS Macroeconomic Module
- FLTSHR = Fraction of fleet trucks purchased by a given fleet type
- VT = Index of vehicle type: 1 = cars, 2 = light trucks
- ITY = Index of fleet type: 1 = business, 2 = government, 3 = utility

The fleet allocation factor, FLTTRAT, has been previously extracted from data provided in the Transportation Energy Data Book,<sup>25</sup> which provides an estimate of the fraction of light trucks sold for personal use, and a survey of fleet vehicles,<sup>26</sup> which provides a mechanism for further stratifying non-personal sales into fleet/non-fleet categories. Under the current revision, only the personal/non-personal distinction is used, with all non-personal sales of light trucks being allocated to the fleet module. There are two reasons to re-estimate the value of FLTTRAT rather than merely redefining it as the percentage of trucks sold for non-personal use: first, the value of the personal-use sales share reported by ORNL is derived from the 1987 TIUS, which has been superseded by the recently published 1992 survey; and second, because TIUS does not survey government and publicly-owned vehicles, the sales share derived from its summary tends to overestimate the fraction of LDT's sold for personal use. A derivation of the updated value for FLTTRAT follows.

In estimating this factor, it is necessary to combine elements of two different data samples: the relevant components of TIUS,<sup>27</sup> and the annual data collected by FHWA.<sup>28</sup> Although these surveys are drawn from different populations and are not directly comparable, it is assumed that the relationships among elements of one data set are also valid in the other. Vehicle characteristics from the 1992 FHWA survey are tabulated below:

<b>Table C.4: FHWA Highway Statistics 1992</b>		
Total Number of Trucks (All Types)	45,504,067	Table VM-1
Total Light Duty Trucks (2-Axle, 4-Tire)	39,533,142	

<sup>25</sup>*Transportation Energy Data Book: Edition 12*, Oak Ridge National Laboratory, ORNL-6710, March 1992, Page A-12.

<sup>26</sup>*Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices*, Oak Ridge National Laboratory, ORNL-6717, May 1992.

<sup>27</sup>*1992 Census of Transportation: Truck Inventory and Use Survey*, U.S. Department of Commerce, Bureau of the Census, TC92-T-52, May 1995.

<sup>28</sup>*Highway Statistics 1992*, U.S. Department of Transportation, Federal Highway Administration, FHWA-PL-93-023.

Total Federally-Owned Trucks	281,623	Table MV-1
Total State & Municipal Trucks	1,547,020	

1) First, the FHWA data is used to estimate the fraction of two-axle, four tire trucks in the truck population:

$$\text{Percent LDT} = \frac{\text{Total LDT}}{\text{Total Trucks}} = 86.88\%$$

2) Assuming that the distribution of trucks is uniform across sectors, the number of LDT's owned by federal, state, and municipal agencies can be estimated:

$$\text{Public LDT} = (\text{Federal Trucks} + \text{State \& Municipal Trucks}) \cdot \text{Percent LDT} = 1,588,6$$

3) Using the numbers above, the fraction of LDT's owned by public agencies is estimated:

$$\text{Percent Public LDT} = \frac{\text{Public LDT}}{\text{Total LDT}} = 4.02\%$$

It is assumed that this figure represents the degree of underestimation of LDT stock in the TIUS survey, which does not include publicly-owned vehicles.

4) To reconcile this discrepancy, the total number of privately-owned LDT's from the TIUS microdata file (on CD-ROM) is subsequently adjusted:

$$\text{Implied TIUS LDT Population} = \frac{\text{Total TIUS LDT}}{1 - \text{Percent Public LDT}}$$

5) Using TIUS estimates of the number of LDT's employed for personal use, the percentage of personal-use trucks can then be calculated:

$$\text{Percent Personal LDT} = \frac{\text{Total TIUS Personal LDT}}{\text{Implied TIUS LDT}}$$

6) Finally, the percentage of LDT's assigned to the Fleet Module is simply calculated:

$$\text{Fleet Percent} = \text{FLTTRAT} = (1 - \text{Percent Personal LDT})$$

The results are tabulated below.

<b>Table C.5: TIUS LDT Data and Distributions</b>	
Total LDT's, from TIUS	53,435,873
Implied Total LDT's	55,673,175
Total Personal-Use LDT's, from TIUS	39,766,945
Percent Personal-Use	71.43%
Percent Fleet (FLTTRAT)	28.57%

The use of this revised allocation factor will result in a more accurate distribution of light-duty trucks in both the personal-use and fleet modules.

### **Fleet Share Distribution**

The above information, combined with vehicle-use information from TIUS can be used to re-estimate the allocation of trucks among fleet types. This parameter, FLTTSHR, allocates total fleet LDT purchases among business, government, and utility fleets according to a fixed ratio, the derivation of which has not been previously documented. Using the implied estimate of the number of publicly-owned LDT's, presented above, and TIUS estimates of the number of utility and commercial LDT's (excluding those used for personal transport), the following distribution has been incorporated into the LDV Fleet Model.

<b>Table C.6: Current and Previous Fleet LDT Allocation</b>			
<b>Fleet Type</b>	<b>Number</b>	<b>Current NEMS FLTTSHR</b>	<b>Previous NEMS FLTTSHR</b>
<b>Business</b>	13,285,511	83.5%	73.6%
<b>Government</b>	2,237,302	14.1%	17.8%
<b>Utility</b>	383,421	2.4%	8.8%

### **Vehicle Distribution Within Fleets**

Under the provisions of EPACT, purchases of vehicles by fleets meeting certain criteria are affected by the requirement that a proportion be alternatively fueled. The specific conditions under which these provisions are in effect, and the fleet sizes which are affected are not static, but are subject to revision. Obtaining an accurate estimate of the number of automobiles in fleet service is necessary

in order to derive a forecast of the purchase of alternative fuel vehicles mandated under EPACT, and the consequent demand for petroleum, electricity, and alternative fuels used for transportation. Under the previous model, a fixed proportion of annual automobile and light truck sales (which were exogenously obtained) were assigned to business, utility, and government fleets. As the alternative fuel provisions of EPACT attach to fleets at or above a given size, it is important to develop a means of estimating the affected population of vehicles under the current, or any future definition of a "fleet". Due to the dissimilarities of the data available, separate approaches have been developed for light trucks and automobiles, as described below.

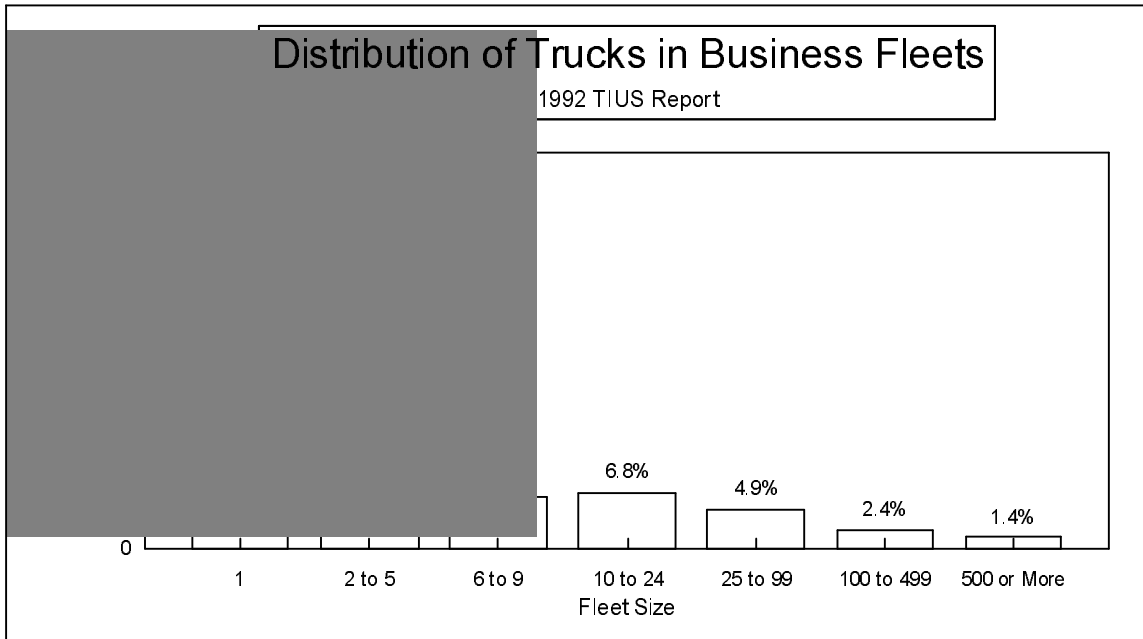
### ***Trucks***

The proposed approach uses the fleet-size data from the TIUS survey to derive a functional form for estimating the affected population of LDT's in fleets. The applicability of this approach is constrained by the aggregate nature of the survey, but should serve as a good first approximation. The first step is to look at the distribution of trucks by fleet type; only business and utility fleets are considered as all government vehicles are assumed to be affected by the legislation (and are not represented in TIUS). The number of trucks within each considered fleet type, stratified by fleet size, are tabulated below. These distributions are also graphically depicted on the following pages. It is clear from these figures that business and utility fleets have significantly different size characteristics, as is to be expected. Most commercial light trucks exist in fleets of less than 20 vehicles, and are therefore unaffected by EPACT legislation, while the overwhelming majority of utility vehicles are in large fleets.

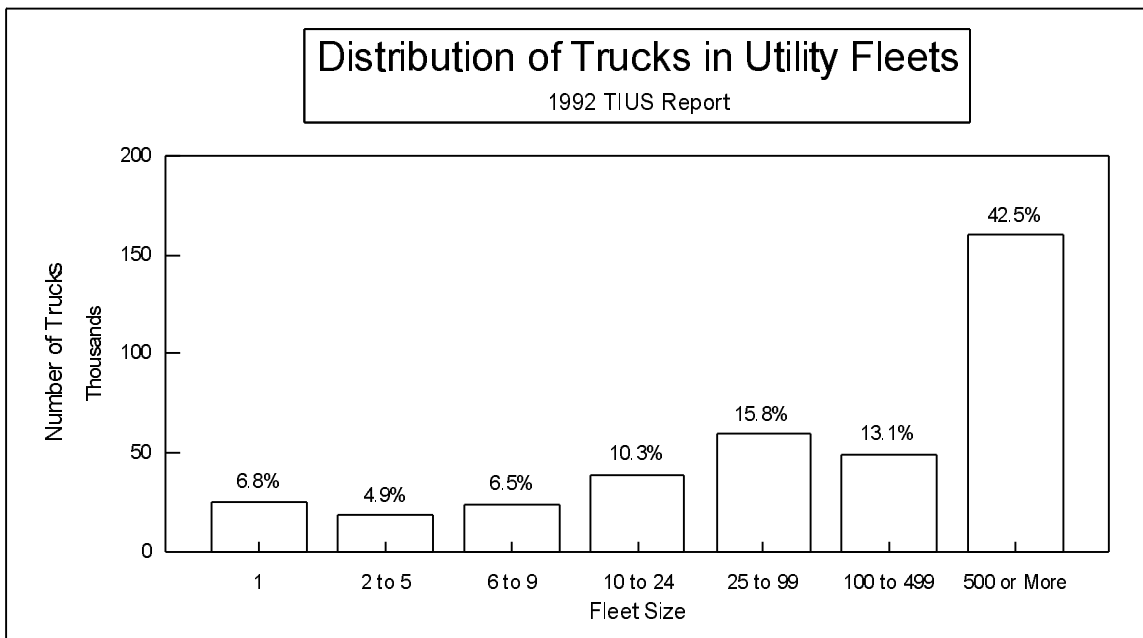


<b>Table C.7a: Light Truck Distribution in Business Fleets</b>				
<b>Fleet Size</b>	<b>Number</b>	<b>Percent of Total Defined</b>	<b>Cumulative Percentage: P(n)</b>	<b>Reverse Cumulative: Q(n)</b>
1	5,422,935	43.7%	43.7%	100.0%
2 to 5	4,261,155	34.3%	78.0%	56.3%
6 to 9	799,876	6.4%	84.5%	22.0%
10 to 24	843,262	6.8%	91.3%	15.5%
25 to 99	613,610	4.9%	96.2%	8.7%
100 to 499	295,196	2.4%	98.6%	3.8%
500 or More	176,383	1.4%	100.0%	1.4%
<b>Undefined</b>	<b>873,094</b>			
<b>Total Defined</b>	<b>12,412,417</b>			

<b>Table C.7b: Light Truck Distribution in Utility Fleets</b>				
<b>Fleet Size</b>	<b>Number</b>	<b>Percent of Total Defined</b>	<b>Cumulative Percentage: P(n)</b>	<b>Reverse Cumulative: Q(n)</b>
1	25,677	6.8%	6.8%	100.0%
2 to 5	18,573	4.9%	11.8%	93.2%
6 to 9	24,296	6.5%	18.2%	88.2%
10 to 24	38,717	10.3%	28.6%	81.8%
25 to 99	59,301	15.8%	44.3%	71.4%
100 to 499	49,294	13.1%	57.5%	55.7%
500 or More	159,804	42.5%	100.0%	42.5%
<b>Undefined</b>	<b>7,759</b>			
<b>Total Defined</b>	<b>375,662</b>			

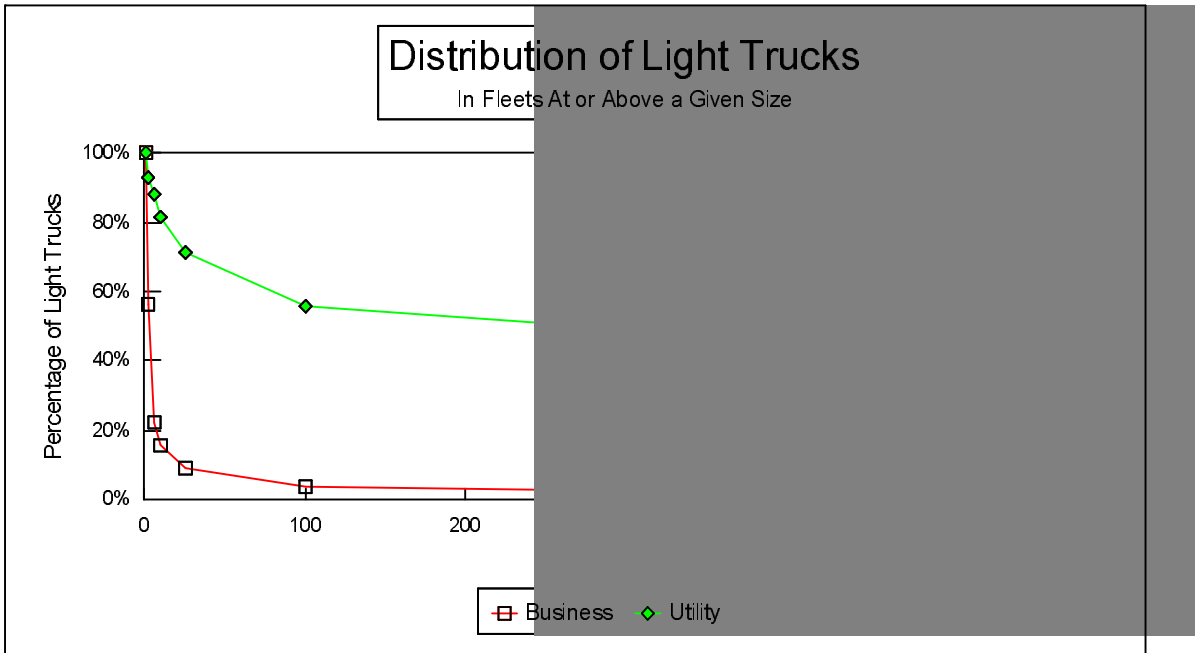


**Figure 8**

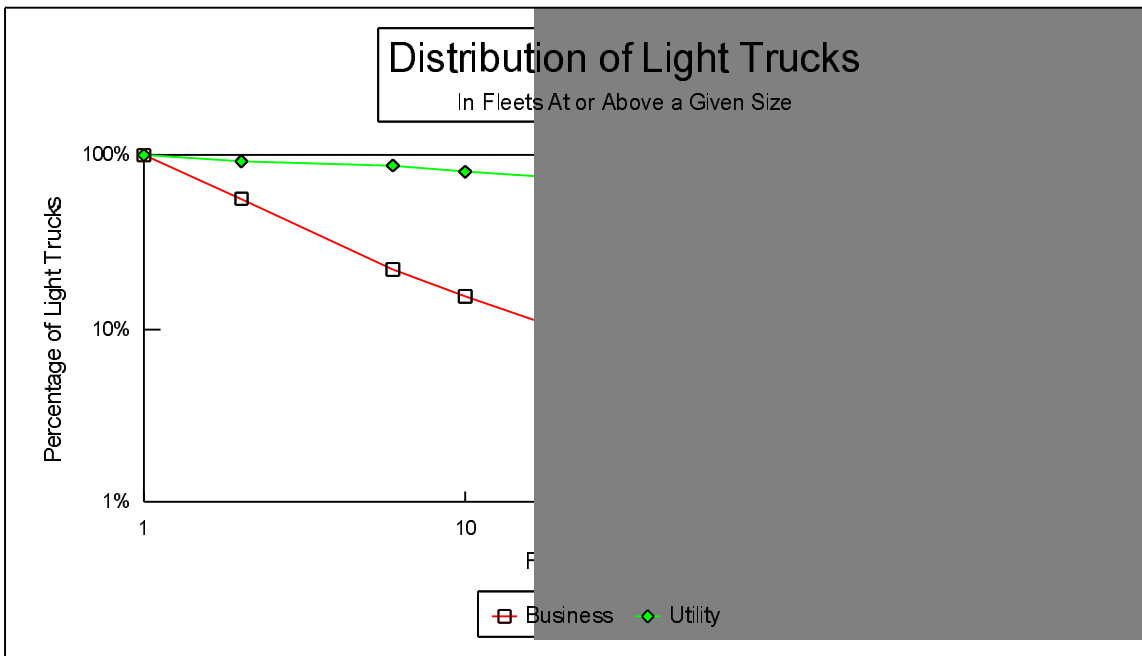


**Figure 9**

As the strata defined in the TIUS survey do not correspond to the fleet sizes addressed in EPACT, it is necessary to derive a functional form for each distribution. This is accomplished by considering the cumulative distribution of fleet trucks  $P(n)$ , or, more accurately, its complement:  $Q(n)$ , referred to, for lack of a better term, as the reverse cumulative distribution. This distribution describes the number of trucks in fleet sizes greater than or equal to  $n$ , as depicted below.



**Figure 10**



**Figure 11: Logarithmic Scale**

The most straightforward method of estimating a functional form is to transform the data so that it approximates a linear relationship, then use OLS to estimate the coefficients. As the figure above

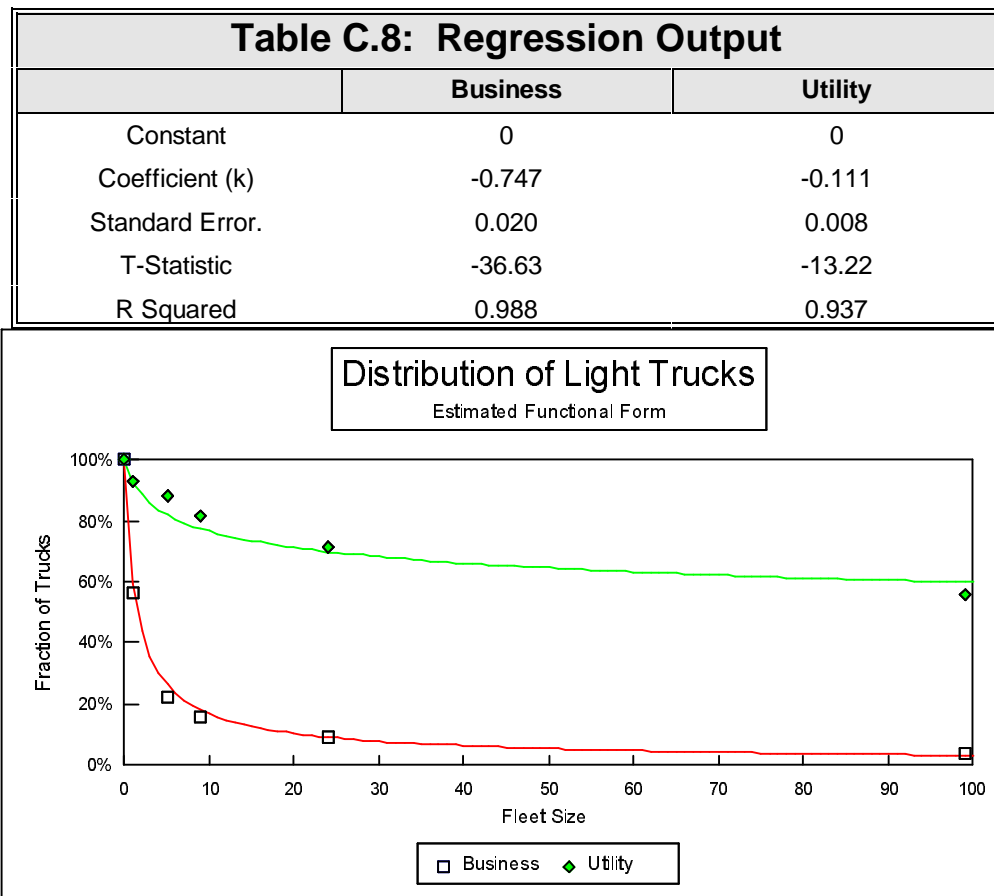
shows, plotting both axes logarithmically produces a reasonable approximation of linearity. This suggests the following form:

$$\begin{aligned} \ln Q(n) &= k \ln(n) \\ \text{or} \\ Q(n) &= n^k \end{aligned}$$

where:

$Q(n)$  = The reverse cumulative distribution: the percentage of trucks in fleets of size greater than or equal to  $n$ .

Testing this approach with the data described above provides the results tabulated below. The significance of the coefficients and the high R-squared gives confidence that this formulation will provide a satisfactory means of estimating the affected light truck population in business and utility fleets. A plot of these functions over TIUS data is provided below.



**Figure 12**

Applying this function permits a stratification of light trucks into three groups: non-fleet (<20 vehicles), small fleet (20-50 vehicles) and large fleet (>50 vehicles). The distribution of these percentages, by fleet type, are tabulated below. It should be noted, once again, that publicly-owned vehicles (federal, state, and municipal) are not subject to the fleet-size constraints, and are therefore not similarly stratified. Insofar as different components of the publicly-owned fleet of LTD's have different acquisition requirements under EPACT, it is suggested that a sales-weighted average of the requirements be used.

<b>Table C.9: Distribution of LDT's, by Fleet Type and Size (FLTSIZE)</b>				
<b>Fleet Size</b>	<b>Index (IFS)</b>	<b>Calculation</b>	<b>Fleet Type</b>	
			<b>Business</b>	<b>Utility</b>
Non-Fleet (<20 LDT's)	1	Q(1) - Q(20)	89.3%	28.4%
Small Fleet (20-50 LDT's)	2	Q(20) - Q(50)	5.3%	6.9%
Large Fleet (>50 LDT's)	3	Q(50)	5.4%	64.7%
<b>Total</b>			<b>100%</b>	<b>100%</b>

### ***Automobiles***

In a report on the characteristics of fleet vehicles in the United States,<sup>29</sup> Oak Ridge National Laboratory notes that no comprehensive nationwide automobile fleet vehicle survey is currently available. This stands in contrast to the abundance of census data available for the analysis of U.S. truck populations, and inhibits the development of a methodology to estimate the number of fleet vehicles covered by EPACT regulations. The *1992 Automotive Fleet Fact Book*,<sup>30</sup> which provides summary characteristics of fleet vehicles, represents the sole source of data used in constructing the following distribution.

Given the limitations of the data, several assumptions and manipulations are necessary to transform the published data into a form commensurate with the needs of the model. It is first assumed that both Government and Utility fleets are large enough to be affected by EPACT regulations, obviating the need for further analysis of their distributions. It is also assumed that the number of vehicles in business fleets should not include employee-owned, daily rental, or individually-leased vehicles, as these are outside the purview of the legislation. This exclusion is accomplished through the use of the function BFLTFRAC, described above. Aggregating business fleet data and subtracting excluded vehicles results in the distribution provided in the table below. As there are only three data points, this effectively precludes the use of regression analysis to estimate a distribution function for business fleet vehicles. The alternative is to assume the simplest functional form which can be adjusted to approximate the desired distribution. After testing a variety of specifications, the form selected is as follows:

$$Q(n) = \frac{k_3}{I.n(n)}$$

where:

$Q(n)$  = The percentage of vehicles in fleets of size greater than or equal to  $n$

$k_3$  = The constant of proportionality, chosen by normalizing the function to 1.0 when  $n = 4$ ; estimated to be 1.386.

**Table C.10: 1992 Bobit Fleet Data**

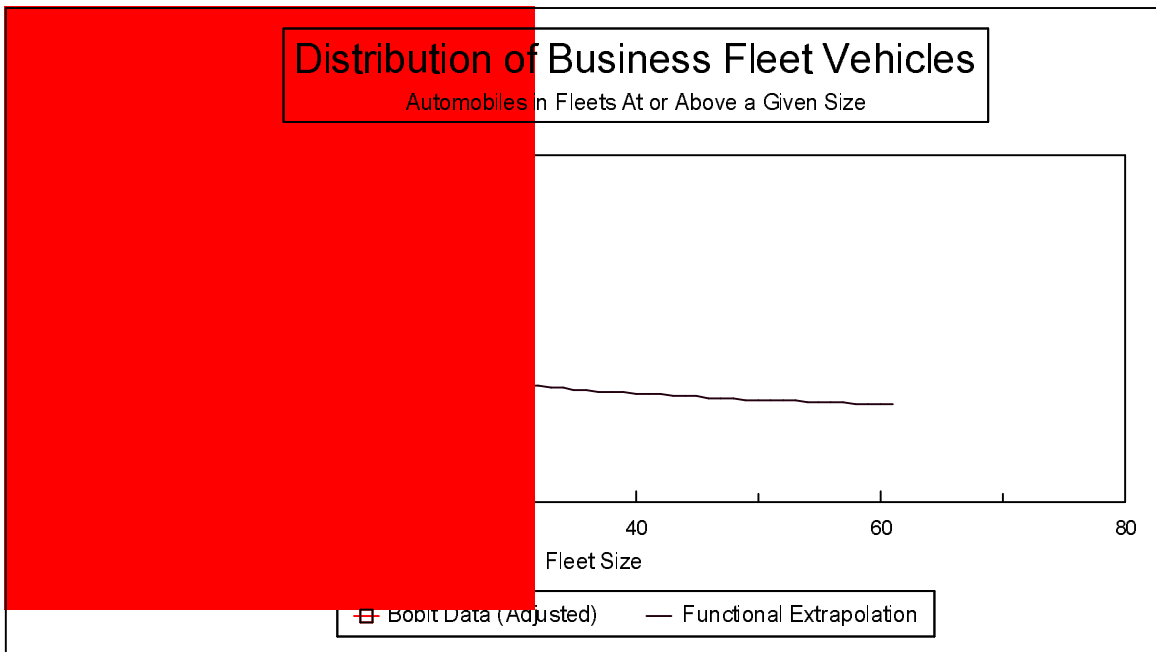
---

<sup>29</sup>*Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices*, Oak Ridge National Laboratory, ORNL-6717, May 1992.

<sup>30</sup>*Automotive Fleet Fact Book, 1992*. Bobit Publishing Company, pp. 16, 20.

Fleet Type	Number of Vehicles (Thousands)
<b>Business Fleets (by Size)</b>	
>= 4 Vehicles	5,261
>= 10 Vehicles	2,820
>= 25 Vehicles	2,323
<b>Government Fleets</b>	504
<b>Utility Fleets</b>	544

This function is graphically displayed below, along with the original data. Applying this function permits a stratification of business fleet automobiles into three groups: non-fleet (<20 vehicles), small fleet (20-50 vehicles) and large fleet (>50 vehicles). The distribution of these percentages is tabulated below.



<b>Table C.11: Percentage of Business Fleet Automobiles (FLTSIZE)</b>			
<b>Fleet Size</b>	<b>Index (IFS)</b>	<b>Calculation</b>	<b>Percent</b>
Non-Fleet (<20 Cars)	1	Q(1) - Q(20)	53.7%
Small Fleet (20-50 Cars)	2	Q(20) - Q(50)	10.8%
Large Fleet (>50 Cars)	3	Q(50)	35.4%
<b>Total</b>			<b>100%</b>

The incorporation of these modifications will, in all likelihood, not result in significant changes in the output of the NEMS Transportation Model, but will more easily permit the inclusion of users' assumptions and will be able to withstand a higher level of scrutiny of the methodology.