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# The Transitional Alternative Fuels and Vehicles Model (TAFVM)[1]

## Purpose and Overview

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## 1.0 Introduction to the TAFVM

The Transitional Alternative Fuels Vehicle (TAFV) Model simulates the use and cost of alternative fuels and alternative fuel vehicles (AFVs) over the time frame of 1996 to 2010. As the model's name suggests, the TAFV model is designed to examine the *transitional* period of alternative fuel and vehicle use. That is, the model is a first attempt to characterize how the United States' use of AFVs might change from one based on new technologies available at a high-cost and low-volume, to a world with more mature technologies offered at lower cost and wider scale. It also seeks to explore what would be necessary for this transition to happen, and what it would cost.[2]

Previous studies of alternative fuels and vehicles differ in their estimates of the penetration rates and costs of AFVs. The Alternative Fuels Trade Model (AFTM, USDOE 1995, Leiby 1993) for example, found that there could be substantial penetration of alternative fuels and vehicles in 2010. Many of these studies are limited in that they examine AFVs in a single year. They present a 'snapshot' of AFV use given assumptions about technological maturity and price. The AFTM, notably, assumed mature vehicle technologies produced at large scale and a well developed alternative fuel retail sector. Other studies, which examine AFVs in a multi-year, dynamic setting (e.g., Rubin 1993 and Fulton 1994) take technologies and prices as exogenously given. That is, they do not examine the important linkages between investments in alternative fuels and vehicles and the prices and availability of those technologies.

This work follows up on the long-run equilibrium analysis done with the AFTM. The AFTM was developed to evaluate the long-run (2010) substitution of alternative fuels for gasoline, for a study pursuant to the Energy Policy of 1992 (Section 502b). The AFTM tracks supply, trade, and demand for multiple liquid and gaseous fuels in the interrelated energy markets of six world regions. It is a partial equilibrium model, used for long-run comparative static analyses. These analyses suggested that the prospective long-run substitution of alternative fuels for gasoline could be substantial, assuming that vehicles and fuels are widely available to consumers, and that the needed investments are made over time for the fuel and vehicle supply industries to gain cost savings from large scale production. By relating these assumptions, the TAFV fills a gap in alternative fuel analysis. In contrast to the AFTM, the TAFV model specifically characterizes the time path of investment and adjustment, in order to consider whether some of these transitional issues may be important.

We can posit possible ways in which early AFV mandates or incentives *may* influence the AFV transition. As alternative vehicle and fuel producers gain cumulative experience, some cost reductions through learning and economies of scale are expected. If vehicle manufacturers are encouraged to design and to introduce new models with AF capability, the number of makes and models offering AF capability rises, and consumers value this greater choice. Incentives or programs leading to the earlier development of fuel distribution infrastructure can increase fuel

[2]For a more detailed specification of the TAFV model, see Leiby and Rubin (1996), "Documentation of the Transitional Alternative Fuel Vehicle Model," Oak Ridge National Laboratory, Draft.

availability. This can greatly lower the inconvenience cost associated with refueling, lowering the effective cost of alternative fuels. Promoting the introduction of AFVs may allow consumers to gain familiarity, reducing their uncertainty about fuel/vehicle performance and reliability. Programs calling for the purchase of AFVs by fleets lead eventually to the sale of used fleet vehicles to private consumers, making AFVs available to used-vehicle buyers, increasing consumer familiarity with AFVs and alternative fuels, and possibly leading to expanded private demand for alternative fuels and AFVs. Each of these possible linkages may work slowly, as investments are made and vehicle and capital stocks adjust. The TAFVM represents some of these dynamic transitional processes.

### 1.1 Principal Objectives of the Model

The principal objective of the TAFVM is to provide a flexible, dynamic-simulation modeling tool that can be used for policy analysis. In particular, the TAFVM is designed to evaluate the effects of DOE's AFV fleet vehicle program and other incentives on the future prices, availability, and penetration rates of AFVs and on the usage rate of alternative fuels. The TAFVM seeks to account for:

- the effects of AFV policies on the price and quantity of AFVs over the time period of 1996 - 2010;
- the effects of AFV policies on the price and availability of alternative fuels over the time period of 1996 - 2010; and,
- the feedback effects of consumer and fleet purchases on fuel and vehicle production costs.

### 1.2 Features

The TAFVM is adaptable to a variety of policy scenarios. As currently configured, the model

- solves yearly, 1996 - 2010;
- is parameterized for the US urban and non-urban regions;
- tracks the on-road vehicle stock by vehicle technology, fuel type, and vintage;
- tracks sales of new vehicles in each year by vehicle technology and fuel;
- tracks installed capacity of methanol production;
- tracks installed retail fuel capacity by fuel type;
- tracks capacity utilization for vehicle production, fuel production, and fuel retail capacity;
- accounts for the impacts of fleet mandates on manufacturer, consumer, and fuel retail behavior; and
- estimates the societal costs and benefits of various policy scenarios.[3]

[3]Since the model produces the competitive outcome, it optimizes with respect to private net benefits, but it can track measures societal welfare.

### 1.3 Sectors Represented

The TAFVM characterizes, in varying degrees of detail, interactions among the following major components or modules:

- consumer and fleet vehicle demand and vehicle choice,
- consumer and fleet fuel choice and use,
- retail fuel supply and availability,
- vehicle production,
- motor fuel production, and,
- raw material (retail fuel feedstock) supply.

The interaction of these modules are depicted in Figure 1.

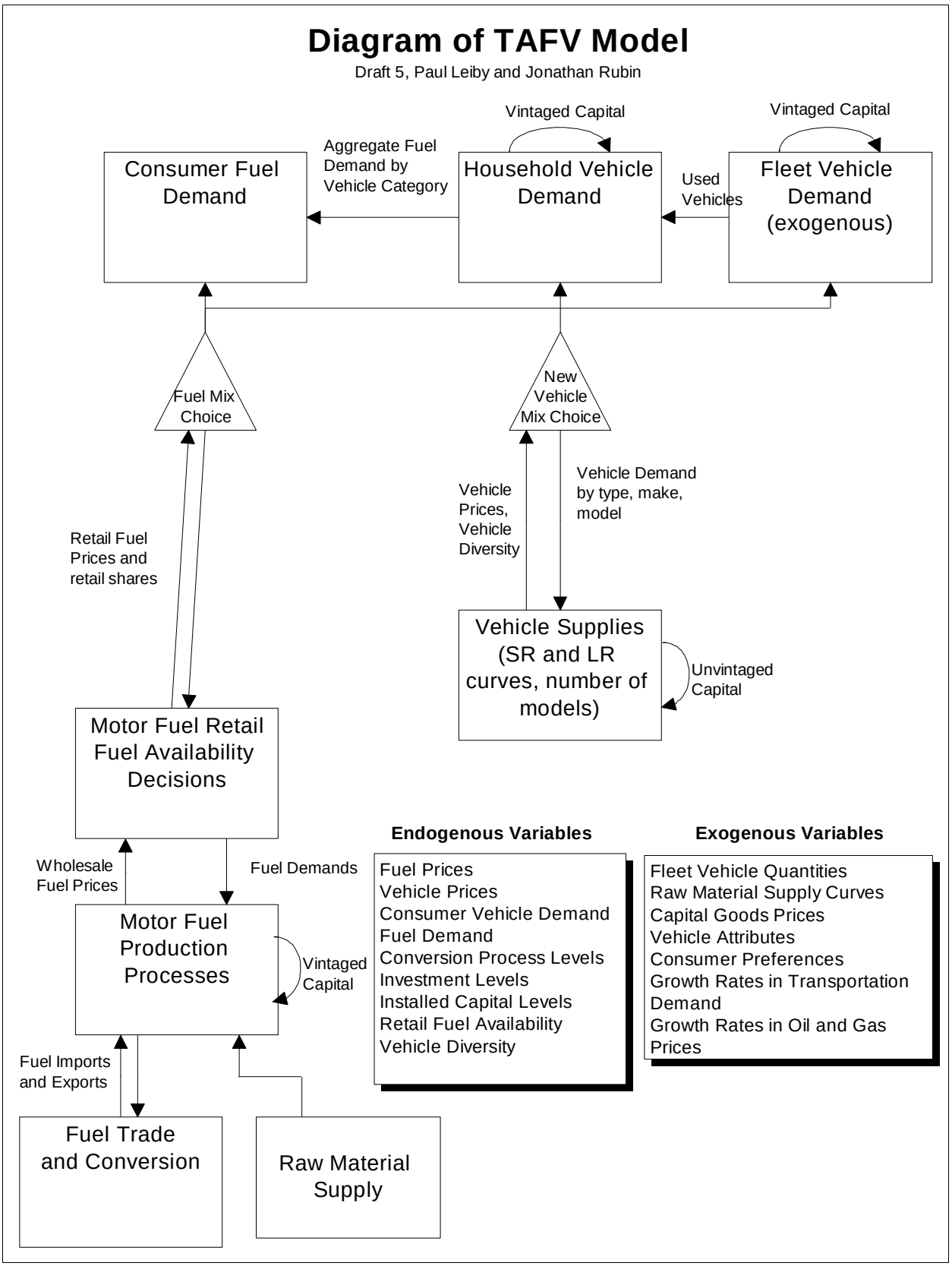
Diagram of TAFV Model
Draft 5, Paul Leiby and Jonathan Rubin
Vintaged Capital
Vintaged Capital
Consumer Fuel Demand
Aggregate Fuel Demand by Vehicle Category
Household Vehicle Demand
Used Vehicles
Fleet Vehicle Demand (exogenous)
Fuel Mix Choice
New Vehicle Mix Choice
Vehicle Prices, Vehicle Diversity
Vehicle Demand by type, make, model
Retail Fuel Prices and retail shares
Vehicle Supplies (SR and LR curves, number of models)
Unvintaged Capital
Motor Fuel Retail Fuel Availability Decisions
Endogenous Variables
Exogenous Variables
Wholesale Fuel Prices
Fuel Demands
Fuel Prices
Vehicle Prices
Consumer Vehicle Demand
Fuel Demand
Conversion Process Levels
Investment Levels
Installed Capital Levels
Retail Fuel Availability
Vehicle Diversity
Fleet Vehicle Quantities
Raw Material Supply Curves
Capital Goods Prices
Vehicle Attributes
Consumer Preferences
Growth Rates in Transportation Demand
Growth Rates in Oil and Gas Prices
Motor Fuel Production Processes
Vintaged Capital
Fuel Imports and Exports
Fuel Trade and Conversion
Raw Material Supply

## 1.4 Demand for Vehicle Transportation Services Drives Model

The model is driven by the final demand for passenger vehicle transportation services. Satisfying this demand provides benefits to consumers, which must be weighed against the cost of providing the services. The final demand for transportation services is divided into three broad sectors: urban, non-urban, and fleet. These broad aggregates may be broken down further into separate market segments (e.g. size classes). For each market segment, the model finds a point on the vehicle services demand curve where the marginal benefits of consumption (willingness to pay or price) equals the marginal costs of producing the needed composite mix of vehicles and fuels. In each period this balance is found subject to the limits of current vehicle and fuel production capacities, and the existing vehicle stocks. Investment in durable new vehicle and fuel production capacity and in new vehicles is made based on a balance of the marginal investment cost with the expected lifetime value of the investment. When the model is solved from period-to-period, the expected lifetime value of the investment is estimated as the current return plus the expected future value or scrappage value.

## 1.5 Principal Variables

In each period $\boldsymbol{t}$ and region $\boldsymbol{r}$ the principal decision variables are:

- demand quantities for commodities $\boldsymbol{d_{trf}}$,
- supply quantities for commodities (fuels, vehicles) $\boldsymbol{s_{trf}}$,
- conversion process activity levels $\boldsymbol{a_{trc}}$,
- investments in new process capacity $\boldsymbol{I_{trc}}$,
- levels of installed capital for conversion processes $\boldsymbol{K_{trc}}$,
- fuel retail supply availability (share of stations offering) $\sigma_{trf}$, and
- vehicle supply diversity (makes & models)[4] $\rho_{tgv}$.

## 1.6 Cost Function Representation of Modules

Each module is represented in terms of its current single-period cost function $C_{trf}$, defined for each time period, region, and fuel. Examples of costs are: vehicle production costs, fuel production/conversion costs, fuel retailing costs, raw material supply costs, and sharing or mix costs associated with vehicle and fuel choice.[5] The cost functions summarize the way in which changing levels of activities, inputs, and outputs affect the costs for each module, and implicitly define the cost minimizing behavioral relations for those module variables.

In cases where the module involves investments with long-lived (multiperiod) cost and benefits,

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[4]This feature is not currently operational.

[5]The "sharing" cost associated with particular fuel or vehicle mix is equivalent to the negative of the benefits of diversity for discrete choice (Small and Rosen 1981, Anderson, de Palma and Thisse 1988, Leiby and Greene 1995).

the module cost function also includes the costs of current investments minus the (expected) future value function $F_{t+1}$ for all remaining fixed investments $K_{t+1}$ at the end of the period. Thus each module presents itself to the integrating framework/equations in terms of the net cost of current activities and investments:

$$C_{trf} = C^{v}_{trf}(s_{tr},d_{tr},a_{tr},K_t) + I_{tr}\cdot C^{K}_{t} - \frac{\delta_{t+1}}{\delta_t}F_{t+1}(K_{(t+1)r},s_{tr},d_{tr},a_{tr},\vec{P}_0,\vec{P}_1,\ldots,\vec{P}_{t-1})$$

Here we are purposefully general about which supply, demand, conversion activity, or capital stock variables may determine a module's contemporaneous variable cost function $C^{v}_{trf}$ or future value function $F_{t+1}$.

### 1.7 Influencing Investment Through Expected Future Value

When producers or consumers invest in durable alternative fuel or vehicle equipment, their *expectations* about the future value of that long-lived capital determine the level of investment. The TAFVM allows differing assumptions about expectations and the degree of foresight consumers and producers have regarding the future value of their investments. Simulation results may include both the cases of perfect foresight and myopia, as well as an in-between case, where some anticipatory behavior is allowed. This allows for more realistic public policy evaluation by recognizing that individual consumers and producers make decisions under limited information about the future.

An important determinant of expectations is the current value that consumers and producers receive from their installed stocks of capital. Consumers receive value from the vehicles they purchase and producers receive value through the earnings that investment makes possible. Investments in capital are made given the expected future value of the surviving stocks of capital and the price of new investments. Future values of capital are based upon estimates of the marginal value of capital. For the case of investment in productive equipment (e.g. fuel production capacity), it can be shown [following Abel (1990)] that efficient multiperiod investment decisions are approximated by a sequence of single period choices if each single period choice accounts for a future value function $F_{t+1}$ given by:

$$F_{t+1}(K_{t+1}) = q_t K_{t+1}$$

where $q_t$ is an estimate or expectation of the net present value of the stream of future marginal revenues flowing from a marginal unit of capital. A variety of expectational rules may be applied to form the estimate of marginal future value $q_t$. For example, in the special case where we consider a constant annual depreciation rate $\gamma$, producer interest rate (cost of capital) $r$, and apply simple expectations which assume that marginal revenue (product price) grows at the rate $g$, the expected marginal future value of capital $q_t$ is a fixed multiple of current marginal revenue $R_t'$:

$$E(q_t) \cong \frac{R_t^{/}}{r+\gamma-g}.$$

For other simple expectations and depreciation schedules, similar approximations of the expected

future value of capital can be constructed. It is important to remember that expectations enter only in the investment decisions, since this is the only way in which longer-run (multiperiod) considerations enter the model. The purchase of a vehicle is treated as a long-lived investment decision.

### 1.8 Overviews of Solution Procedures for the Limited Foresight Model Specifications

This section gives a overview of the solution procedures used to solve the two limited-foresight versions of the model. What varies between the models is the degree of foresight granted the models agents. This degree of foresight shows up in the way that the stocks of installed capital are valued at the end of each year.

Different solution procedures are employed depending on the degree of foresight granted to the model's agents. The simplest solution procedure is to simultaneously solve over all periods for the social optimum (e.g. Dervis, de Melo and Robinson 1982). Solving the model simultaneously is equivalent to agents (producers and consumers) having perfect foresight. While not realistic, the perfect-foresight simulation results suggest what an omnificent "social planner" might do, and provide some insight on the consequences of myopia and intermediate degrees of foresight. To capture better "real world" decisions, it was decided to allow the model's agents to form expectations about the future based upon current and past prices. This represents "myopic" or "adaptive" expectations.

As one might suspect, there are many ways to use past and current prices to form non-perfect expectations about the future. Two methods were selected for use in the TAFVM model.[6] One method, we call, "true myopia," was selected because it represents the case when agents do not anticipate the future, and there is a one-period lag between the decision to invest and capital being available for use. The second method, we call "contemporaneous expectations," allows agents to see what the effects of their investment decisions would be if the investment were productively available today, which it is not. Both these techniques involve the solution for a *sequence of connected single-period equilibria*, connected through the evolution of installed capital equipment (e.g. Ballard, Fullerton, Shoven and Whalley 1985). This generates a multi-year, *dynamic model with myopic or adaptive expectations*.[7]

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[6]In the model design stage, several additional foresight specifications were investigated. These specifications are documented in working paper, "Foresight Specifications," TAFVM Modeling Background Document, Paul N. Leiby and Jonathan Rubin, August 25, 1995.

[7]Rational expectations models represent a additional approach [see the Pereira and Shoven (1988) review].

In general, the basic approach used is to solve for the market balance in each period by maximizing social surplus (net benefit) in that period.[8] Given the assumed competitive behavior of agents, this will yield a (static) competitive market equilibrium. In the TAFVM, prices and marginal values are determined at the end of each solution of the model as a model outcome. Thus, to guide the estimation of future capital values which are so important to investment decisions, contemporaneous prices and marginal values are obtained through multiples solves within a given time period. This technique is used in the imperfect-foresight investment methods considered.

### 1.9 Market Balancing Conditions

For each period, the objective is to represent a short-run market balancing which results from *competitive* behavior. This means that we wish to assure that the following short-run competitive conditions are met, unless activities are constrained:[9]

i. the marginal (private) cost of producing each commodity equals its price;[10]
ii. the marginal (private) benefit of each demand equals its price;
iii. the marginal profitability of each intermediate conversion activity is zero (unless constrained, in which case short-run profits can be positive or negative); and,
iv. the marginal current period value of investment equals the price of capital minus the discounted expected future value of the equipment from the next period forward.[11]

In each period $t$ and region $r$ we find market clearing supplies, demands, trade, and conversion process levels $s$, $d$, $x$, and $a$. That is, in maximizing consumption benefits minus production costs, the following balance equation must be met:

$$s_{trf}^{exog} + s_{trf} + \sum_{c} A_{fc} a_{tcr} + \sum_{\rho} (x_{tf\rho r} - x_{tr\rho f}) \geq d_{trf}^{exog} + d_{trf} \quad \forall\ f,r,t \qquad \textbf{(4)}$$

where:

| | |
|---|---|
| $r, \rho$ | index regions, |
| $f$ | indexes commodities (fuels, vehicles), |

[8]The actual calculation of the solution is performed by GAMS (Brooke et al, 1992).

[9]Each of these conditions corresponds to a first-order condition for single-period social surplus maximization used to determine the market solution.

[10]In the cases where the sector invests in long-lived capital, the marginal cost includes the shadow cost of any incremental capital required for production.

[11]We require incremental investment to be positive. If new investment is zero, the profitability of existing capital is insufficient to motivate new investment, and the stated condition is not met. Disinvestment may be desired, but is not allowed.

| | |
|---|---|
| $c$ | indexes conversion processes, |
| $t$ | indexes time, |
| $d_{trf}$, $s_{trf}$ | demand and supply quantities, |
| $a_{trc}$ | activity level for conversion process $c$, |
| $A_{fc}$ | coefficient indicating commodity $f$ output (input) per unit process $c$ activity, and, |
| $x_{tf\rho r}$ | shipment of commodity f from region $\rho$ to $r$. |

Final demands and basic commodity supplies are "price responsive" in that their quantities will depend on market prices in each period:

$$s_{trf} = S_{trf}(P_{trf}), \qquad d_{trf} = D_{trf}(P_{trf}) \ . \tag{5}$$

Fuel blending and conversion, fuel distribution and retail markup, and the combination of fuels with vehicles to provide vehicle services are represented with linear conversion processes. The terms $A_{fc}a_{trc}$ indicate the input or output of fuel $f$ by conversion process $c$ when it is operated at activity level $a_{trc}$ (at time $t$ in region $r$).

For conversion processes requiring durable capital equipment (such as methanol fuel production or vehicle production), the amount of installed capital imposes a constraint on the maximum activity level for the associated conversion process. In addition, there is a capital stock evolution constraint that links depreciated capital and investment in each period to the next period starting capital stock.

## 2.0 Further Explanation of the Individual Modules

### 2.1 Vehicle Services Demand for New and Used Vehicles

Total short-run transportation service demand is specified as a composite demand curve in each region/market. In each period this composite demand may be satisfied by the use of existing vehicles and the purchase and use of new vehicles. The use of older vehicles is limited by the stock of each type. The capital cost of used vehicles is treated as sunk, and the allowable use of each vehicle is fixed by age.

Fuel choices must be made for the vehicles which are dual or multi-fueled. A mix of new vehicles is purchased to the extent that existing vehicle stocks are insufficient. New vehicles are chosen according to the Nested Multinomal Logit (NMNL) choice formulation (Greene, 1995; Leiby and Greene, 1995) based on vehicle capital costs, non-price attributes, vehicle make and model diversity, and *expected* lifetime nested fuel choice costs. In this way, long-lived investment consequences are reflected in vehicle choice. Note that under myopic expectations, lifetime fuel costs follow from current fuel costs.

The level of use of each vehicle type (in miles traveled) is assumed fixed. Since the capital costs of existing household vehicles is sunk, there is a strong expectation that transportation demand will be satisfied by existing vehicles before new (or used fleet) vehicles are purchased.

#### 2.1.1 Vehicle Stock Equations

The capital stock of vehicles is tracked, with vehicles vintaged to account for changing characteristics and to allow the application of an exogenous scrappage profile. A fixed scrappage rate is used for each age vehicle. We assume a fixed, possibly declining, vehicle use per year. Fleet alternative fuel vehicles are retired prior to their normal scrappage date, and are sold into the private household sector at a fixed age. Households do not reconvert AFVs to conventional vehicles.

Since vehicle scrappage rates are exogenous, they are independent of new vehicle choice. Scrappage rates $\gamma_{av}$ may vary with age *a*, and by vehicle type *v*. The vehicles are tracked like any other durable, vintaged capital, and new vehicle purchases $V_{trv}$ are akin to new investment. For each region *r* and vehicle category *v*, the private vehicle stock adjustment equations are:

$$K_{(t+1)r(a+1)v} = K_{trav}(1-\gamma_{av}) + V^{F}_{trav} \quad \forall\ t < T, r, a, v$$
$$K_{tr0v} = V_{trv} \qquad \textbf{(6)}$$

where $\boldsymbol{V_{trav}}^{F}$ is the influx of used fleet vehicles of age a into the private sector.

#### 2.1.2 The Choice of Vehicle Mix to Satisfy Vehicle Demand

Some demands may be satisfied by a mix of alternatives, where the mix is sensitive to relative prices and non-price attributes. In the TAFVM, examples are the demands for *new* vehicles, and for fuels by FFV's. Those demands may be represented by a composite good, $q_{trv}$, with the requirements:

a. That the level of demand for the composite good, v, equals the sum of the levels for its alternative inputs, which are designated by the set $F_v$, and,
b. That the shares of alternative inputs for composite good v conform to the expected sensitivity to relative price $P_{vf}$ and non-price attributes $\alpha_{vf}$ .

Note that price and non-price attributes may vary by time and region (as could the attribute sensitivity parameter β). Consumers' demand for vehicles is driven by a price-responsive demand curve for vehicle services, which will be satisfied by an endogenously determined mix and quantity of vehicles and fuels.

Some attributes of flexible choice for new vehicles in particular may depend on both historical experience and future expectations. For composite vehicle services demand of type *g* ($q_{trg}$) the choice among input alternatives, *v*, will depend upon their (conditional expected indirect) utility, $V_{trgv}$, which is a linear function of new vehicle price $P_{trv}$ and non-price attributes:

$$V_{trgv} = \beta_g(P_{trv} + \alpha_{vD} + \alpha_{vW} + \alpha_{vR} + \frac{\beta_v}{\beta_g} C_{gv}) \ .$$

The attributes include, for example:

$\alpha_{vD}$ vehicle range (distance between refuelings);
$\alpha_{vW}$ vehicle weight/performance;
$\alpha_{vR}$ expected vehicle reliability, given current installed based of similar vehicles
$\beta_v$ fuel price sensitivity for vehicle v; and,
$C_{gv}$ *expected* effective fuel cost over vehicles lifetime, given current prices and expected growth of absolute and relative prices for the fuels vehicle *v* may use, and accounting for expected fuel availability.

Consumers care about many vehicle attributes other than those related to its fuel technology. Accordingly, the demand for a particular AFV technology will increase with the diversity of vehicle classes and makes and models for which it is offered. While TAFVM will include four vehicle size classes, the explicit representation of make and model choice is omitted for simplicity. Instead, to capture the value of diversity we adopt the simple alternative specification proposed by Greene (1995). In this approach, for vehicles of each fuel type ***g***, a term $\boldsymbol{k_g}$ is included in the generalized vehicle cost:

$$k_g = \frac{1}{\beta_v} \ln(\rho_{gv}) \ .$$

The parameter $\rho = \boldsymbol{M_{gv}}/\boldsymbol{M_v}$ accounts for the relative diversity of makes and models, where $\boldsymbol{M_v}$ is the number of makes and models offered for conventional vehicle size class ***v***, and $\boldsymbol{M_{gv}}$ is the

number offered to fuel type ***g*** and class ***v***.

### 2.1.3 Motor Fuel Choice

The nesting of this choice within the vehicle choice problem is handled by the passing of composite fuel prices (including fuel choice sharing costs) to the vehicle choice function.

Fuel choice depends on fuel attributes such as price, vehicle performance using the fuel, and refueling convenience. It also depends upon current fuel availability, that is the fraction of retail stations offering the fuel. This availability variable is endogenously determined in the fuel retail sector. The multinomial fuel choice function uses an indirect utility for each fuel which is linear in fuel price and includes a constant term to reflect most other attributes. However, the indirect utility (or effective cost) for each fuel varies non-linearly with endogenous fuel availability. The effective cost of fuel availability is expected to be quite high for availabilities below a few percent, and to decline to near zero as availability exceeds some moderate level (currently on the order of twenty percent). The cost of low retail fuel availability is an important factor in the transitional analysis. It depends on the additional travel which is required to refuel when stations are rarer, and on the consumer's valuation of the cost of those additional miles of travel.

## 2.2 Fleet Vehicles

The total demand for new conventional and alternative vehicles by fleets is determined exogenously by policy. In particular, fleet vehicles are required to be used under the Energy Policy Act of 1992. The number of vehicles required by this act and subsequent regulations has been estimated by DOE's Office of Transportation Technology. While the total number of vehicles is given exogenously, the choice among vehicle types is performed by the model. The approach treats fleet vehicle demand as a separate category of overall vehicle demand. Therefore, fleet vehicles are chosen according to the nested MNL choice model, but vehicle preferences may differ from those of households. Fleet vehicle choice will depend in part on expected vehicle resale value. The expected resale value is based on prior model runs, but is not otherwise endogenous to the model.

New fleet vehicles age and pass from fleet ownership to household ownership when they reach a certain age. The model does not allow for the possibility that used AFVs are dismantled or re-converted. When their ownership changes, however, their use pattern will follow a household rather than a fleet pattern. Used vehicles from fleets will be treated as equivalent to used private vehicles of the same (or somewhat older) chronological age.

## 2.3 Vehicle Production Module

Following Duleep (1995) and EEA (1994), the AFV supply module will estimate the retail prices

for two car classes and two light truck classes using the following fuels: LPG, CNG, alcohols, and electricity[12]. Vehicles types include vehicles dedicated to a particular fuel type or those capable of using both gasoline and an alternative fuel, including electric hybrid vehicles. This means that there are a maximum of 32 fuel-vehicle types whose costs will estimated.[13]

The costs of AFVs are calculated by using technology price estimates. In this context, the price of AFVs reflect the *incremental retail price* (IRP) effects of having AFV technology compared to conventional vehicle technology.

Duleep believes that AFV technologies, except for electric vehicles, are mature. Here "mature" means that further cumulative production will not significantly reduce per-unit production costs at a faster rate than conventional vehicle production costs will decline. There do exist, however, potential per-unit cost savings with large scale production. Per-unit production costs are modeled as a declining function of the production capacity available in a given year. However, they are an increasing function of actual production level in each year, given the available production capacity. The volume of production is constrained by the level of cumulative investment (less decay) by manufacturing firms in technology-specific capital. These concepts are illustrated by the declining step function in Figure 2. It is seen that incremental retail prices decrease as vehicle manufacturers produce more vehicles of given fuel type in each year. It is assumed that the incremental retail price equivalents can only decrease down to some minimum level ($IRP^{min}$). Since the incremental retail prices are characterized as a function of production volume, the price of vehicles is an endogenous variable. This has the advantages of showing the positive feedback effects from policies (such as AFV fleet programs) that encourage the adoption (and production) of AFVs.

[12]Gasoline vehicles are the basis of comparison.

[13]Including both flexible and dedicated vehicles this means that there are 4x4x2 = 32 vehicle types.

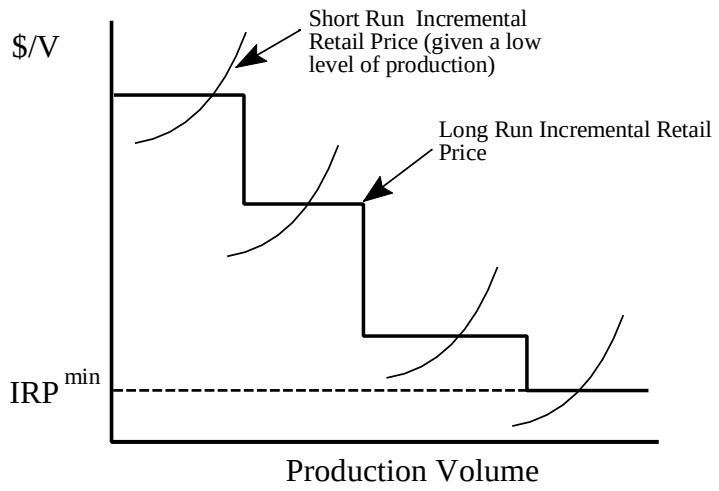


**Figure 2:**
**Short and Long-Run Incremental Retail Prices of AFVs**

### 2.3.1 Variation of Variable Costs with the Proportion of Capacity Utilization

In each period, variable vehicle production costs (or vehicle markups) increase as output approaches the short-run capacity constraint.[14] This is because variable factors such as labor can be used more intensively to produce greater output, and because the vehicle producers and retailers can obtain more profit (markup) for their differentiated product. Following this approach, short-run (single year) incremental retail prices will be lower for production levels below the maximum output, given the installed level of vehicle-specific capital.[15] As production levels reach short-run capacity constraints, prices (markups) rise. Capacity constraints are determined by the amount of fixed capital invested by manufacturing firms. This kind of pricing/cost behavior is consistent with a short-run supply curve. It is also consistent with the historically observed variation in vehicle price markups with capacity utilization and vehicle inventories (Duleep 1995).

### 2.3.2 Vehicle "Availability" or "Diversity" Effects on Production Costs

Vehicle costs (for each vehicle class/fuel technology) increase as the richness of offerings (by make and model) increases. For vehicles, each additional model variant produced will require

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[14] In the AFTM, variable costs for fuels increased at higher demand levels due to feedstock scarcity, but capital charges were assumed to be constant. The same will be true in this model for fuels.

[15] It is possible that low volume production (in the hundreds of units per year) would have unit production costs so high that no vehicles would be demanded. Nonetheless, some vehicles may be sold at a loss by vehicle manufacturers to meet regulatory requirements or as a form of corporate good citizenship. Initially, this behavior will not be explicitly modeled. Scenarios that assume different levels of per-unit vehicle subsidies will be run to examine the importance of this issue.

some amount of specialized capital representing product line fixed costs.[16] Vehicle diversity is a choice variable under the control of the vehicle producer that reflects the relative richness of makes and models for each vehicle fuel-class type. The diversity parameter is the ratio of the number of makes and models offered for vehicles of fuel type g and class v to the number offered for some reference vehicle type (e.g., conventional vehicle type). This statistic is adequate to inform the consumer choice module with the simplified make and model representation described by Greene. Note that while model diversity adds to the vehicle producers' costs, there is a motivation for producing diversity since it makes a vehicle (fuel-class) type more attractive to consumers. Methods for modeling producer decisions about the level of make and model diversity are still under consideration.

## 2.4 Fuel Retail Supply Module

The motor fuel retail supply module is designed to capture the cost of retailing the various motor fuels. All fuels, except electricity, are assumed to be sold at commercial retail fuel outlets, with no consideration of specialized locations or fuel-only versus convenience mart installations.[17] In particular, vertically integrated fuel suppliers and retailers are assumed to price no differently than non-vertically integrated producers and retailers. A key variable to be determined is retail fuel availability, $\sigma^R_{tf}$, the fraction of retail stations offering fuel *f* in year t. If retail fuel availability for a particular fuel is low, then consumers will bear additional travel time costs to refuel. Consumers, therefore, can be expected to tradeoff additional travel time costs for refueling with higher per GGE costs for fuel. The retail sector is designed to be able to accommodate this tradeoff by allowing fuel retailers to maintain additional retail availability by increasing capacity in low volume fuels and by bearing additional expenses equal to the cost of spreading out the retail fuel infrastructure costs over a larger number of stations. Retail fuel availability is thus endogenous to the retail model.

There are some other important assumptions which characterize the retail sector. In particular, fuel distribution capacity is added in variable quantities with a minimum installation requirement (currently 16.67 %, or one of six pumps) and priced to cover the full costs of capacity increment even though capacity utilization may vary. The unit costs of retailing increase as the fraction of the station devoted to the fuel decreases (i.e., as a given level of retail capacity becomes spread out over more stations). It is further assumed that there is no lead time for capacity expansion decisions since the time-step of this model is one year and retail capacity can be expanded as needed. It is assumed that retail capacity, once installed, remains in place subject to depreciation in each period. Retail capital costs are amortized into annual fuel sales, and are not accrued at the time of installation. This assumption is consistent with assuming that there are no excess or sub-normal short-run profits. But, as described above, less than full utilization of capacity is possible provided normal rates of return are achieved by increasing per-unit markups.

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[16] For example, see Harris (1984).

[17] The technical assumptions concerning fuel retailing capacities, costs and characteristics come from EEA (1995) and discussions with the TAFVM working group.

In making decisions about whether to concentrate alternative fuel capacity in a few stations or to disperse it over a smaller fraction of the pumps at more stations, and in deciding whether or not to install excess retailing capacity, the model implicitly defines a cost function for supplying both retail *fuel* and retail *availability*. This feature provides a mechanism to gauge the effectiveness of subsidies or other policy levers which could promote availability and reduce the search and travel time of refueling.

### 2.5 Retail Fuel Demand

Drivers have a demand for transportation services which can be met by a variety of fuel and vehicles. The demand for fuel arises from a demand for the benefits that the fuel provides. Fuel demand, like the demand for any other good, is determined by the price of the good, the price of substitute goods and a host of socio-economic factors. Final demand for the fuels reflects the efficiency of the fuels as used by the vehicle on a per-mile basis. For example, a gallon of M85 used in a dedicated vehicle will provide more vehicle miles than the same fuel used in a flexible fuel vehicle due to the superior engineering efficiency than can be obtained in a dedicated fuel engine.

The most important non-market cost associated with fuels is the cost of availability. By availability cost we mean the cost that drivers must incur in terms of travel distance and time to refuel. To model the cost of fuel availability we follow the approach of Greene (1995) who models availability cost as the time drivers will spend traveling to refuel in a world of streets represented in one dimension. Greene assumes that the effective distance to refuel on any given trip is a function of the average station density carrying the appropriate type of fuel and the length of a given trip. He further assumes that the probability of encountering N stations on a trip of length $L$ over roads with an average of density of S stations per mile is given by the Poisson distribution.

$$P(N) = \frac{(SL)^N}{N!} e^{-SL}$$

The expected refueling distance, $L_f$, for fuel $f$ is the product of the probability of not encountering a station selling fuel $f$ on any given trip of length $L$ times the expected length of time traveling until a station is encountered. Note that the number of stations carrying fuel $f$ per mile, $S_f$, is equal to the to product of the station density for all fuels, S, and the proportions of stations that carry fuel $f$, $\sigma_{tf}^R$.

$$L_f = \frac{1}{S^R \sigma_{tf}^R} e^{-S^R \sigma_{tf}^R L}$$

In addition, if we know the value of time, the average speed of travel, the financial cost of travel, and the quantity of fuel (measured in gasoline equivalent gallons) purchased on an a trip, then the following formula gives the expected availability cost per gasoline equivalent gallon of fuel $f$ in year t. In this formula, the time cost and financial cost per-mile of travel are summarized in the one variable, $\nu^R$, and the average quantity of fuel $f$ purchased on a given trip is given by $F_f$. Since

some vehicle types have a more limited range, they purchase less fuel (or a gasoline equivalent basic) per refueling. Hence this cost would reflect the cost of more trips.

$$C_{tf}^{R} = \left( \frac{e^{(-S_r^R \sigma_{tf}^R L)}}{S_r^R * \sigma_{tf}^R} \right) * \frac{v^R}{F_f}$$

The incremental availability cost of alternative fuel *f* over a fuel which is universally available is given by

$$C_{tf}^{R} = \left( \frac{e^{(-S_r^R \sigma_{tf}^R L)}}{S_r^R \sigma_{tf}^R} - \frac{e^{(-S_r^R * 1 * L)}}{S_r^R * 1} \right) * \frac{v^R}{F_f} \ .$$

## 2.6 Wholesale Fuel Production

Fuel production may occur with more than one technology. New investments in fuel production capacity are explicitly tracked and costed. The model may choose to bring new technologies on line by new investment, should they be available and if the derived demand for fuels is sufficient to warrant the investment. Interesting issues arise because the capital investments are large and essentially irreversible, yet future prices and market conditions are uncertain. Uncertainty is not treated explicitly, but is reflected in planning based on contemporaneous price expectations which may differ from future revealed prices.

## 2.7 Fuel Feedstock Supply Module

This module is straightforward. Given supply (marginal cost curves) for natural gas and ethanol feedstocks (grain and cellulosic), a cost function associated with the supply of each is easily constructed. The functional forms for feedstock supply curves are those used in AFTM, although constant elasticity forms could also be used.

## 3.0 Status of the Model

As of January 1st, 1996, the model development status is:

- The model is operational, though incomplete
  - Does not include all vehicles and fuel types yet,
  - Some features not operational yet.

- Some parameters use only placeholder values
  - Hence any numerical results are illustrative

- Model includes:
  - Natural gas supply curves,
  - Methanol production from long-lived plants
  - Complete fuel retail sector
  - Nested multinomial vehicle and fuel choice, for
    - Four fuels (gasoline, reformulated gasoline, M85, E85)
    - Three vehicle types (conventional, alcohol FFVs, dedicated alcohol)
  - Vintaged vehicle stock
  - Durable investment in vehicle production and fuel production

- Feedback effects included
  - Vehicle economies of scale
  - Endogenous retail sector:
    - Retail economies of scale
    - Fuel availability cost to consumers

- Model is producing reasonable results

- Outcomes are responsive to the Fleet policies considered.

Principal changes planned for Phase II development are:

- Inclusion of ethanol, LPG, CNG, and electric fuels and vehicles

- Inclusion of ethanol production processes, with durable capital stock

- Represent the diversity of makes/models for each vehicle technology with an index, and account for the effects of diversity as vehicle supply costs and demand.

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