The Transitional
Alternative Fuels and Vehicles Model

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The Transitional Alternative Fuels Vehicle (TAFV) Model simulates the use and cost of alternative fuels and alternative fuel vehicles over the time period of 1996 to 2010. It is designed to examine the *transitional* period of alternative fuel and vehicle use. It accounts for dynamic linkages between investments and vehicle and fuel production capacity, tracks vehicle stock evolution, and represents the effects of increasing scale and expanding retail fuel availability on the effective costs to consumers. Fuel and vehicle prices and choices are endogenous. Preliminary results which illustrate the role of potentially important transitional phenomena are discussed. This model extends previous, long-run comparative static analyses of policies which assumed mature vehicle and fuel industries. As a dynamic transitional model, it can help to assess what may be necessary to reach mature, large scale, alternative fuel and vehicle markets, and what it would cost.

Keywords: Alternative Fuels, Energy, Transportation, Dynamic Transition Model

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 higher-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.

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 a developed alternative fuel retail sector. Other studies, which examine AFVs in a multi-year, dynamic setting (e.g., Rubin 1994 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, investment in alternative fuel retailing infrastructure, 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 Act 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 making the scale of alternative vehicle and fuel production and the retail availability of alternative fuels endogenous, the TAFV model 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. The results from the TAFV model do, necessarily, reflect its many primary assumptions such as the unit prices for vehicle and fuel production capital, the costs of raw materials, and input-output assumptions which describe the productivity of a unit of capital in its respective employment.

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. One use of the TAFV model is to assess 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 introduce new models with AF capability, the number of vehicle 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 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.

1.2 Features

As currently configured, the TAFV 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.

1.3 Major Components and Modules 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,
- flexibly-fueled and dual-fueled vehicle choice and use,
- retail fuel supply and availability,
- vehicle production,
- motor fuel production, and,
- raw material (retail fuel feedstock) supply.

1.4 General Model Structure

Figure 1 broadly illustrates the structure of the model. Supply modules give the marginal cost of producing primary commodities (fuel feedstocks or vehicles). Fixed input-output conversion processes account for the transformation from primary fuels to motor fuels, and for the distribution and retail activities. The “activity levels” for each of these processes determine the quantities of inputs used, outputs produced and conversion costs. These activity levels are chosen to satisfy consumer demands for fuels and vehicles.

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.

1.5 Principal Variables

In each period ***t*** , region ***r***, for the commodities ***f*** and conversion processes ***c***, the principal decision variables (using subscripts as indices) are:

- demand quantities for commodities ***f*** (vehicle services) $\boldsymbol{d_{trf}}$,
- supply quantities for commodities (fuel feedstocks, vehicles) $\boldsymbol{s_{trf}}$,
- conversion processes activity levels for process ***c*** $\boldsymbol{a_{trc}}$,
- investments in new process capacity $\boldsymbol{I_{trc}}$,
- levels of installed capital for conversion processes ***c*** $\boldsymbol{K_{trc}}$,
- fuel retail supply availability (share of stations offering) $\boldsymbol{\sigma_{trf}}$,
- vehicle supply diversity (makes & models) for fuel type v $\boldsymbol{\rho_{tv}}$.

Endogenous vehicle diversity not operational in the illustrative results presented here, but is operational other versions of the model.

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. 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 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 some cases the module involves investments I_t in fixed capital stocks K_t with long-lived (multiperiod) costs and benefits. If so, the module cost function includes the net cost of current activities (C^v) *plus* the costs of current investments ($I_t\, C_t^K$) minus the estimated discounted future value of all remaining fixed capital stock $F_{t+1}(K_{t+1})$ at the end of the period. Estimated future capital value may be determined from either perfect foresight or a myopic valuation rule based on recent prices.

1.7 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:

i. the marginal (private) cost of producing each commodity equals its price;

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.

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.

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. The market solution is calculated with GAMS (Brooke, Kendrick and Meeraus 1992). This equation states that supplies, plus net output from conversion activities plus net trades between regions must be greater or equal to demand.

$$s_{trf} + \sum_c A_{fc} a_{tcr} + \sum_i (x_{tfri} - x_{tfri}) \geq d_{trf} \quad \forall\ f,r,t \tag{1}$$

where:

r, i	index regions,
f	indexes commodities (fuels, vehicles),
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 ρ to r.

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

$$s_{trf} = S_{trf}(P_{trf}), \qquad d_{trf} = D_{trf}(P_{trf}) \ . \tag{2}$$

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. 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

In each period transportation service 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 (in kilometers traveled per year) is fixed by age. Based on historical data, vehicle usage declines with age at 5.4% per year.

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 a Nested Multinomial Logit (NMNL) choice formulation (Greene, 1995; Leiby and Greene, 1995) based on vehicle capital costs, non-price attributes, vehicle make and model diversity, and lifetime nested fuel choice costs. In this way, long-lived investment consequences are reflected in vehicle choice.

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. Fixed scrappage rates γ_{av} are specified by age *a*, and may vary by vehicle type *v*. The vehicles are tracked like any other durable, vintaged capital, and new vehicle purchases I_{trv} are akin to new investment. For each region *r*, time t+1, and vehicle category *v*, the vintaged vehicle stock adjustment equations are:

$$K_{(t+1)r(a+1)v} = K_{trav}(1-\gamma_{av}) \qquad \forall\ t < T, r, a, v$$
$$K_{tr0v} = I_{trv} \tag{3}$$

where $\boldsymbol{K_{trav}}$ is the number of vehicles of age a in region r. These equations show that the stock of new (age zero) vehicles is given by vehicle purchases, *I*, and that each year the surviving stock ages one year.

2.1.2 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.

2.1.3 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. Consumers' demand mix for new vehicles is derived from a price-responsive demand curve for vehicle services, which will be satisfied by an endogenously determined mix and quantity of vehicles and fuels. Note that price and non-price attributes may vary by time and region.

For composite vehicle services demand the choice among input alternatives, *v*, will depend upon their (conditional expected indirect) utility, V_{trv}, which is a linear function of new vehicle price P_{trv} and non-price attributes:

$$V_{trv} = \beta(P_{trv} + \alpha_{vD} + \alpha_{vW} + \frac{\beta_v}{\beta} C_{Fv}) \ . \tag{4}$$

The attributes include, for example:

- α_{vD} vehicle range (distance between refuelings);
- α_{vW} vehicle weight/performance;
- β_v fuel price sensitivity for vehicle v;
- β utility value of a dollar, and,
- C_{Fv} 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 the fuel technology-related ones we have made explicit. 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 soon include four vehicle size classes (e.g., small car, large car, passenger van, cargo van) , there is no plan for the explicit representation of make and model. 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 $\boldsymbol{v}$, a term $\boldsymbol{\rho_v}$ is included in the generalized vehicle cost to account for the limited diversity of makes and models:

$$\rho_v = \frac{1}{\beta} \ln\left(\frac{M_v}{M_0}\right) \ . \tag{5}$$

where $\boldsymbol{M_0}$ is the number of makes and models offered for conventional vehicles, and $\boldsymbol{M_v}$ is the number offered with alternative fuel type $\boldsymbol{v}$.

2.2 Retail Motor Fuel Demand and Choice

Drivers' demand for transportation services can be met by a variety of fuel and vehicle combinations. This leads to a derived demand for fuels. Vehicles require a fixed amount of fuel per kilometer of use, and the efficiency may vary by vehicle fuel-type. For example, a liter of M85 used in a dedicated vehicle will provide more vehicle kilometers than the same fuel used in a flexible fuel vehicle due to the superior engineering efficiency that can be obtained in a dedicated fuel engine.

Dual and flex-fuel vehicles must choose among fuels. The nesting of this choice within the new vehicle choice problem is handled by the passing of composite fuel prices (including fuel choice sharing costs) to the vehicle choice function through a modification of (4). 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 or inconvenience which is required to refuel when stations are rarer, and on the consumer's valuation of the cost of those additional kilometers of travel. To model the cost of fuel availability we follow the approach of Greene (1995). 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 kilometer is given by the Poisson distribution.

$$P(N) = \frac{(SL)^N}{N!} e^{-SL} \tag{6}$$

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 kilometer, 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*, σ_{tf}^R.

$$L_f = \frac{e^{-S^R \sigma_{tf}^R L}}{S^R \sigma_{tf}^R} \tag{7}$$

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 liter equivalents (GLEs)) purchased on a trip, then the following formula gives the expected availability cost per gasoline equivalent liter of fuel *f* in year t. In this formula, the time cost and financial cost per-kilometer of travel are summarized in the one variable, ν^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 basis) per refueling. Hence this cost would reflect the cost of more trips.

$$C_{tf}^R = \left(\frac{e^{(-S_r^R \sigma_{tf}^R L)}}{S_r^R \sigma_{tf}^R} \right) * \frac{\nu^R}{F_f} \tag{8}$$

We parameterize this formulation so that the incremental availability cost of alternative fuel *f* over a fuel which is universally available is roughly \$0.05/liter (\$0.20/gallon) at 10% availability and \$0.26/liter (\$1/gallon) at 2% availability (see Table 1). Recognizing the importance of these assumptions, we treat this an area for sensitivity analysis.

2.3 Vehicle Production Module

Vehicles are either dedicated to a particular fuel type or capable of using both gasoline and an alternative fuel. The TAFV model has been planned to estimate the costs of production for two car classes and two light truck classes using the following fuels: LPG, CNG, alcohols, and electricity. In the results here, the model only includes estimates for methanol and ethanol fueled light-duty vehicles using both flexible and dedicated fuel technology and dedicated gasoline vehicles using standard and reformulated gasoline.

AFV costs are calculated by using engineering-economic estimates of the *incremental* cost of having AFV technology compared to conventional vehicle technology (EEA , 1995c). EEA 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. The volume of production in any given year is constrained by the level of cumulative investment less decay. These concepts are illustrated by the declining function in Figure 2, which emphasizes that vehicle price is an endogenous variable. This has the advantage of admitting the positive feedback effects from policies (such as AFV fleet programs) that encourage the adoption (and larger scale production) of AFVs. Table 1 shows some of the vehicle cost data.

Vehicle costs (for each vehicle class/fuel technology) are expected to increase as the richness of offerings (by make and model) increases. For vehicles, each additional model variant produced will require some amount of specialized capital representing product line fixed costs, and increased diversity will (all else constant) imply smaller scale production. 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. 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. Alternative 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. The technical assumptions concerning fuel retailing capacities, costs and characteristics come from EEA (1995a, 1995b) and discussions with the TAFVM working group. 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, σ^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 trade off additional travel time costs for refueling with higher fuel costs per GLE. 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) per station, 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.

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 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.

2.6 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 ILLUSTRATIVE RESULTS

We present results below which are illustrative since the model, as described above, is not fully implemented or benchmarked. Nonetheless, the results indicate the ability of the model to capture important feedback effects from transitional programs such as fleet AFV mandates. As is described below, this initial analysis supports our original hypothesis that the important question about AFVs is not whether they can compete on a level playing field assuming mature technologies, but rather, how could a transition to AFVs occur under various plausible scenarios?

3.1 Fleet Vehicle Policies

We consider the effects of the introduction of AFVs into fleets by mandate. Four hypothetical policies are considered:

A) No policy, fleets can choose any vehicle;

B1) Fleets can choose among flexible and dedicated fuel methanol and ethanol vehicles -low refueling costs;

B2) Fleets can choose among flexible and dedicated fuel methanol and ethanol vehicles -high refueling costs;

C) Fleets must choose dedicated AFVs which require M85 or E85.

D) Fleets may buy any AFV, but 50% of the fuel used must be M85 or E85.

In all the scenarios private consumers freely choose among the vehicle and fuel types. The exogenously mandated fleet AFV purchases grow from roughly 1.5% of total vehicle sales in the late 1990s to 5% in 2010.

Without any specific vehicle purchase requirements on fleets, and in the absence of any other exogenous drivers to force AFVs into service, our illustrative model results show that virtually no AFVs are introduced in the 1996-2010 time period. This non-result is striking in that it says that the path to AFV introduction could be barred by start-up inertia even though high-volume production costs could make methanol and ethanol vehicles competitive with gasoline vehicles.

When AFVs are forced into service by mandate (Cases B1 and B2), then private, non-fleet, purchases of AFVs occur (see Figure 3). This induced private demand stems from moving down the vehicle production cost curves. In this policy Case B, fleets were free to choose between dedicated and flexible fuel vehicles. As seen in Figure 4, the chosen mix between dedicated and flexible fuel vehicles depends on the assumed refueling inconvenience cost. By refueling inconvenience cost, we mean the effective cost to consumers for a given low level of retail availability. These inconvenience costs stem principally from the extra time and distance consumers must travel to a station with the fuel. Since the extra distance, time, and the valuation of that distance and time are not well understood, we have treated the refueling inconvenience cost parametrically here to reveal its importance. In case B1, low refueling inconvenience costs lead to no initial FFV use under a vehicle mandate, since fleets first choose to purchase lower-cost dedicated vehicles and accept the refueling inconvenience cost. As fleet fuel use drives availability costs even lower, in 2003 and beyond, FFVs become preferred by some private vehicle owners since they can use either gasoline or alcohol. At higher refueling inconvenience costs, Case B2, fleets choose to purchase FFVs since this allows them the opportunity to use gasoline when the alternative fuel is not nearby. However, the total penetration of flexible and dedicated alcohol vehicles by the year 2010 is less given the higher effective cost of refueling inconvenience.

Mandates to buy AFVs can have very different effects on the amount of alternative fuel used depending on the program details. Mandates to buy AFVs will, necessarily, get the mandated vehicles on the road, and may have spill over effects on the private fleet stock. Flexible fuel vehicles, however, allow fleet operators to use gasoline rather than alcohol fuels. When this happens, there is no creation of a retail infrastructure and no private or fleet use of the alcohol fuels. In contrast, Policy C (which requires the purchase of dedicated alcohol vehicles) is most effective in promoting alternative fuel *use* while policy D (which requires 50% alcohol fuel use) has intermediate results.

4.0 CONCLUDING COMMENTS AND FUTURE WORK

The TAFV model has been designed to examine the *transition* to alternative fuels. The model is constructed to recognize the requirement for large investments in vehicle and fuel infrastructure. By making the supply of fuels, vehicles, and retailing infrastructure endogenous to the model, the TAFV model is able to capture the difficult-to-model intermediate years between nascent and fully-developed alternative fuel and vehicle industries. This is substantial step forward over other attempts to estimate the economic and emission impacts from alternative fuels and vehicles.

It is, however, important to stress that the simulation results presented above are quite preliminary. In particular, only a few of the alternative fuels and vehicles are specified, and the primary data has not been fully benchmarked to reproduce currently observed fuel and vehicle quantities and prices. One of our greatest concerns is whether we adequately characterize the costs of limited fuel retail availability. Important clustering and other regional factors can significantly affect fuel costs and availability. Ongoing work will also allow the estimation of the welfare effects of alternative policies. Notwithstanding the above disclaimers, we do observe some interesting and, we believe, illuminating results. First, in the absence of governmental or other policies to jump-start the alternative fuel and vehicle market, it may be hard for alternative fuels and vehicles to make a substantial contribution to the nation’s transport needs. Secondly, mandates that require fleets to purchase alternative fuel vehicles may induce greater private sector demand for alternative vehicles and fuels, through vehicle production scale economies. Third, the level of induced private sector demand for fuels depends on the form of vehicle mandates, since limited initial retail fuel availability is a potential hurdle. The effective cost to consumers of limited retail fuel availability is an important issue for further study. Policies intended to encourage the use of alternative *fuels* should consider fuel retailing and fuel use incentives as well as programs to simply get the vehicles on the road.

We stress that our analysis to date is illustrative, but reaffirms the importance of explicitly modeling transition dynamics. Cost-effective technologies may never get to be used without a pathway that allows them to benefit from scale economies and other cost-reducing (or benefit enhancing) mechanisms.

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Figure 1: Diagram of TAFV Model

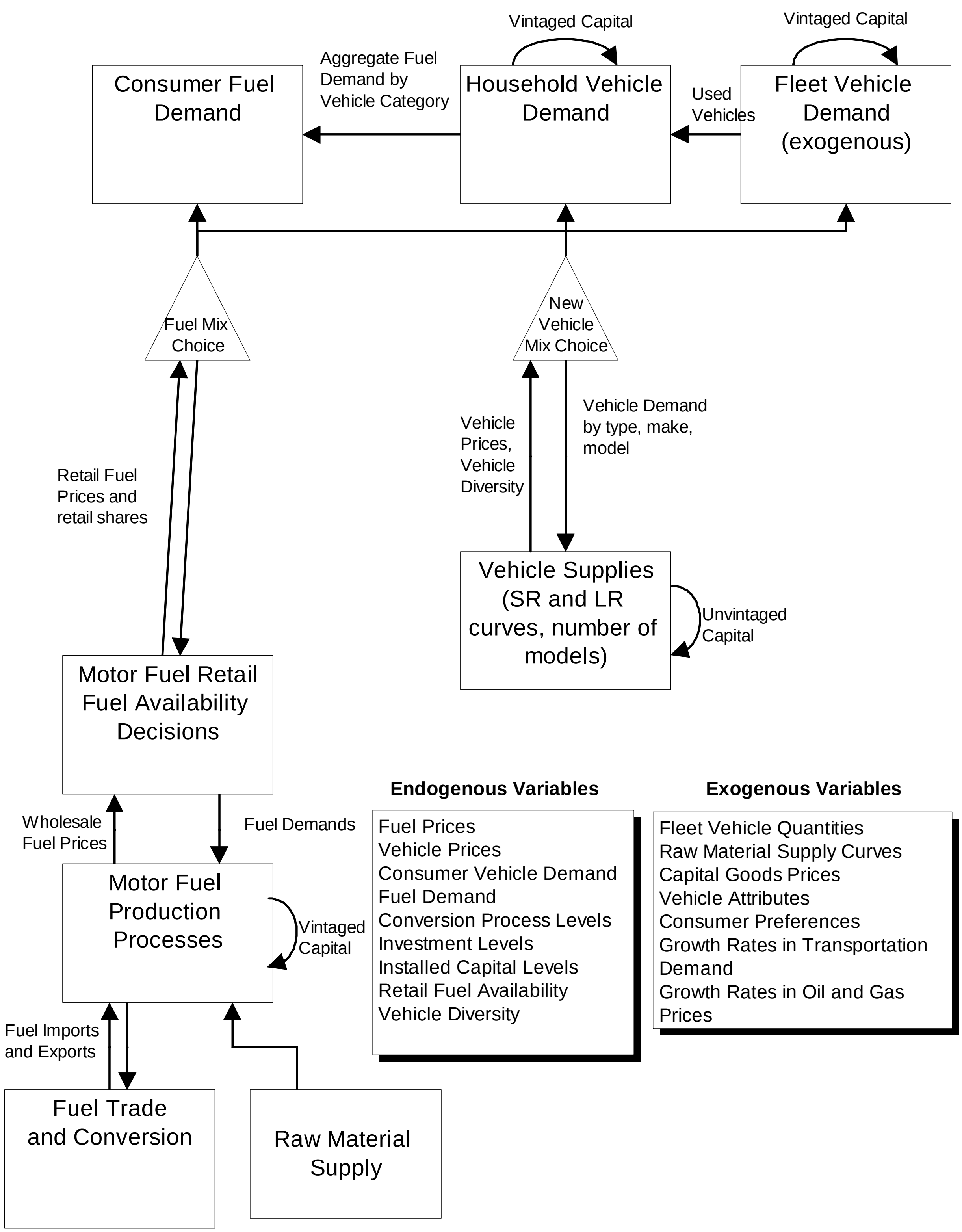
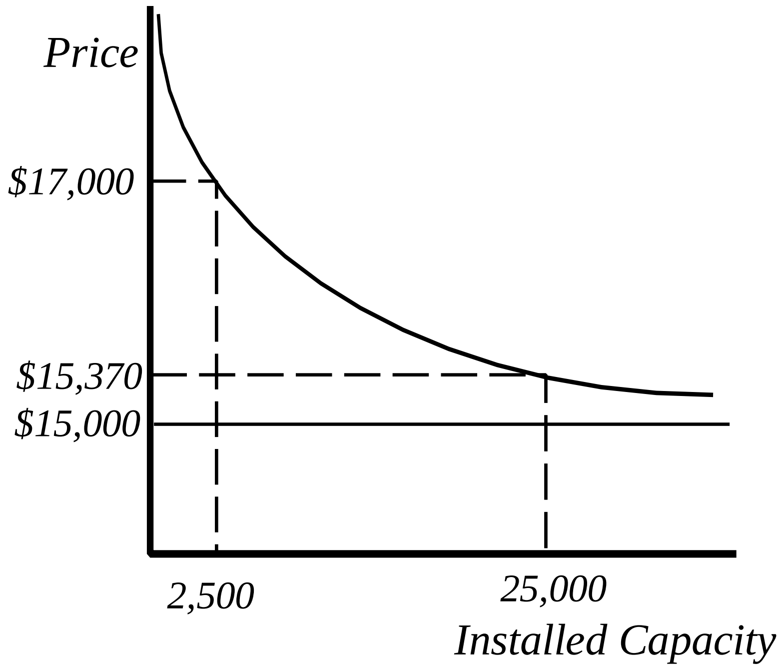


Figure 2: Retail Vehicle Prices Versus Installed Capacity



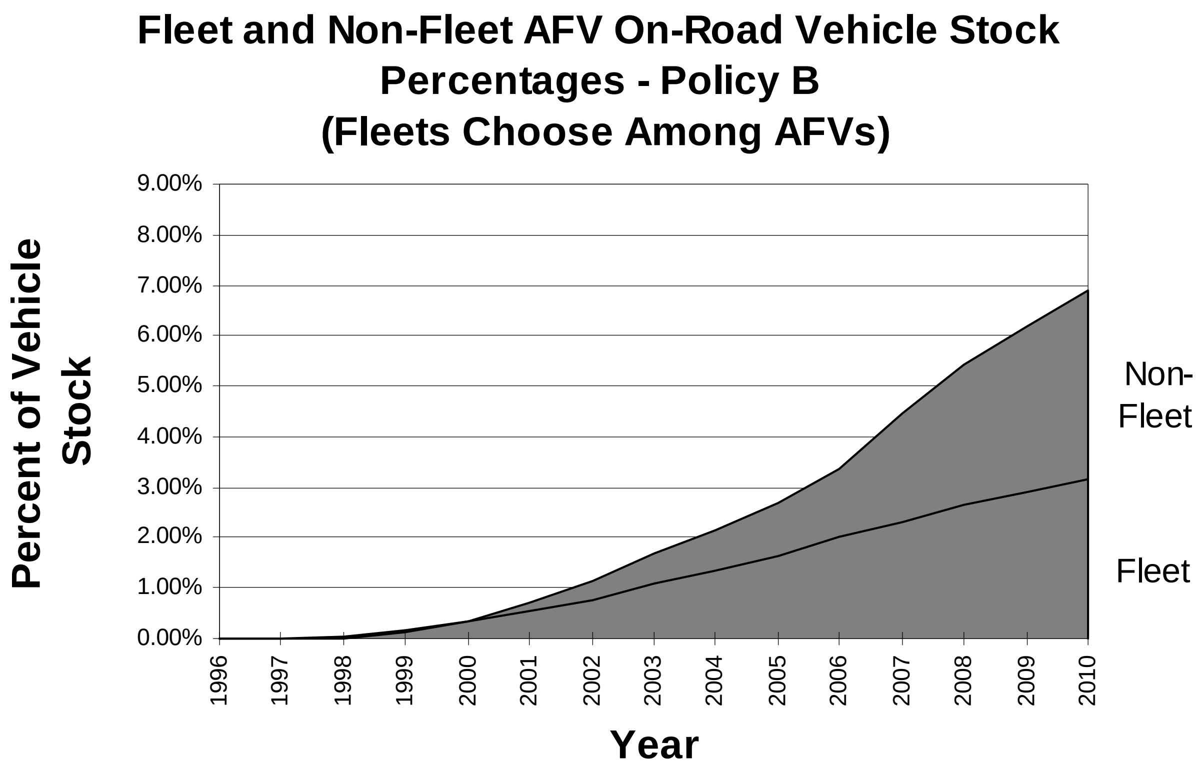


Figure 3 Fleet and Non-Fleet AFV On-Road Vehicle Stock Percentages - Policy B (Fleets Choose Among AFVs)

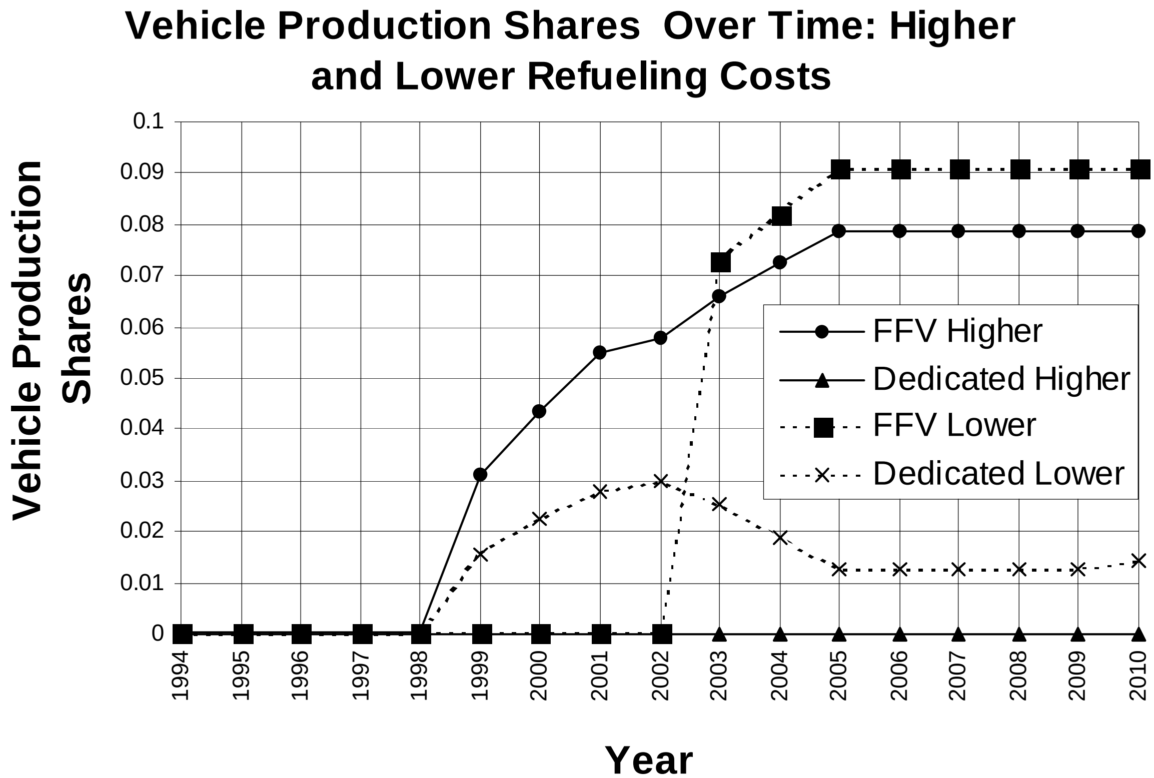


Figure 4 Vehicle Production Shares over Time: Higher and Lower Refueling Costs

Table 1
Cost Data for Vehicle Production and Fuel Retailing

Incremental Vehicle Production Costs (Compared to a Gasoline Vehicle)				
	Plant Scale (Vehicles per Year)			
Vehicle Type	2,500	25,000	100,000	
Alcohol Dedicated	$2,209	$344	$189	
Alcohol Flexible	$1,909	$375	$247	
Fuel Retailing Costs Versus Scale of Deployment at Station ($/GGE)[a]				
Share of Station Pumps Offering Fuel	1/6 Pumps	1/3 Pumps		All Pumps
Fuel Type	16.7%	33.3%		100.0%
Gasoline	$0.090	$0.082		$0.070
M85	$0.130	$0.118		$0.101
E85	$0.130	$0.118		$0.101
Effective Cost of Limited Fuel Availability to Consumer ($/GGE)				
Share of Stations Offering Fuel	1%	5%	10%	20%
Cost per GGE	$1.839	$0.385	$0.204	$0.114

[a]GGE are gasoline gallon equivalent units based on energy content.

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