3. Potential Alternative-Fuel Use Scenario

Fuel Utilization

A detailed scenario outlining a specific, albeit hypothetical, pattern of future alternative-fuel use provides a useful context for examining the potential impacts of the use of alternative transportation fuels. Clearly, many scenarios of future alternative-fuel use could be postulated. The one selected for the analysis reported here was developed for the U.S. Alternative Fuels Council in response to a request made by the council on December 12, 1990. The scenario described here benefited from substantial input provided at a special technical meeting of the staff of the council and other interested parties (March 5, 1991). It was presented to, and approved by, the council on May 17, 1991. It is not a projection of a most likely, economic, or necessarily desirable scenario. Indeed, the alternative-fuels initiatives in the National Energy Strategy (NES) recognize that choices among alternative fuels, and between alternative and conventional fuels, should ultimately be driven by market factors. However, as requested by the council, it represents one plausible scenario that would displace 25 percent of U.S. motor-fuel use (gasoline and diesel fuel) with alternative transportation fuels by the year 2010. Its purpose, in this report, is to provide an analytical context in which to examine alternative-fuel costs and benefits. This section describes the scenario, the constraints it was required to meet, and the assumptions used to develop it.

3.1 Input Assumptions

3.1.1 Target

The scenario outlined below displaces 2.5 million barrels per day (MMBD) of highway motor fuels with nonpetroleum fuels and fuel additives in the year 2010. It is therefore consistent with a resolution adopted by the U.S. Alternative Fuels Council that alternative fuels should be used in 25 percent of vehicle travel in the United States by 2005 (December 12, 1990). The 2.5-MMBD displacement represents 25 percent of highway motor-fuel consumption projected for 2010 in the base case of the Energy Information Administration's (EIA) *Annual Energy Outlook* (January 1990). Highway motor-fuel consumption is used as a surrogate for highway travel. Given the time required to produce sufficient vehicles to achieve this target, the council agreed that the goal of 25-percent displacement is more likely to be feasible in 2010 than in 2005 (February 14, 1991); therefore, the scenario focuses on 2010. A scenario of vehicle sales and the evolution of an alternative-fuel vehicle (AFV) fleet consistent with this scenario are described in the following chapter, as is the refueling infrastructure required to support the scenario.

3.1.2 Oxygenates

Under the Clean Air Act Amendments (CAAA) of 1990, a substantial amount of nonpetroleum fuels will be blended into the gasoline pool to help reduce motor-vehicle emissions. Liquids containing oxygen, such as alcohols and ethers, will be blended with gasoline to reduce carbon monoxide emissions in certain areas during cold weather. These oxygenates will also comprise a significant part of lower emission, reformulated gasoline. Oxygenation of gasoline for these purposes can achieve substantial oil displacement. Given the relative ease of increasing the use of oxygenates in the United States (compared to increasing the use of AFV's, it is assumed that use of oxygenates will be maximized. Oxygenation of all gasoline (approximately 120 billion gallons per year in 2010) is estimated to result in a maximum potential oil displacement of about 700,000 barrels per day.

The degree to which alternative fuels are used will reduce the volume of gasoline into which oxygenates can be added and the displacement that can be achieved with oxygenates. An iterative process was used to determine the relative displacement required from both oxygenates and

AFV's to achieve the scenario target. It was estimated that a maximum of approximately 90 billion gallons of gasoline would be oxygenated, achieving about 0.5-MMBD displacement, and that AFV's would be used to displace 2 MMBD.

The oxygenates most likely to be used are methyl tertiary-butyl ether (MTBE), ethanol, and ethyl tertiary-butyl ether (ETBE). MTBE and ethanol are currently the predominant oxygenates in use in the United States. Because Reid vapor pressure (RVP), which is related to evaporative emissions, increases when neat ethanol is blended (at a 10-percent level) in gasoline, ethanol is unlikely to be used in the gasolines used in ozone nonattainment areas (ICAAMF, December 1990). However, use of ETBE, which contains ethanol, does not increase RVP. Because of the lower RVP of gasoline with ETBE than with ethanol, the large proportion of gasoline sold in ozone nonattainment areas (estimated to be 55 percent), the fact that the ethanol used in the manufacture of ETBE qualifies for the ethanol blender tax credit, and the availability of ethanol for ETBE production, it is assumed that use of ETBE will grow significantly (ICAAMF, December 1990 and Shiblom, 1990).

Table 3 presents the assumptions used to estimate the displacement achieved by each of the oxygenates. The blends were generally held to a 2.7-percent oxygen content (weight). Environmental Protection Agency regulations generally limit the oxygen content of fuels to 2.0 percent by weight. However, the Environmental Protection Agency can and has granted waivers that permit the oxygen content to be higher. Specifically, a waiver has been granted to allow the use of MTBE at 15 percent by volume or 2.7-percent oxygen by weight. It is expected that a similar waiver will be granted ETBE. A waiver has also been granted for ethanol: up to 10 percent by volume. This level achieves a 3.5-percent oxygen content. Given the averaging allowed in the oxygenated fuels program set up by the CAAA, ethanol's oxygen content could also have been set in the scenario at 2.7 percent. However, because some CO nonattainment areas may be required under the CAAA to use fuels with a 3.1 percent oxygen content, and because ethanol is the only one of the three oxygenates that currently is allowed to have that much oxygen, the oxygen content of gasolines oxygenated by ethanol is set at 3.1 percent in this scenario. This percentage is within the range of feasibility, if technology continues to develop at its current pace.

MTBE and ETBE are produced from methanol or ethanol, respectively, plus butane or isobutane, some of which is obtained from petroleum. Two-thirds of the butane and isobutane currently produced are produced from natural gas (EIA, May 1990). Approximately one-third of the butane marketed in the United States is produced by refineries. Refineries also produce a substantial amount of butane that is consumed internally in the gasoline-manufacturing process. It is assumed that these proportions will continue in the future.

Oil is also used in the production of ethanol (harvesting of the feedstock, fertilization, electricity generation, and so forth). Petroleum use for ethanol production is estimated to be equivalent to 15 percent of the energy content of a gallon of grain-based ethanol (derived from Ho, October 1989).

Potentially all the energy needs for cellulosic ethanol production could come from the cellulosic material itself (EPA, 1990). For purposes of

Table 3. Oxygenate Assumptions

Item	Ethanol	ETBE	MTBE
Proportion of Gasoline Oxygenated	0.25	0.25	0.5
Oxygen Content of Gasoline (volume)	3.1%	2.7%	2.7%
Oxygenate Content of Gasoline (volume)	9% (avg)	17.1%	15%
Alcohol Content of Oxygenate (volume)	100%	42.5%	33.9%
Nonpetroleum Content of Isobutylene (volume)	N/A	67.0%	67.0%
Petroleum Required to Produce Ethanol: Proportion/Gallon EToH	0.075	0.075	N/A

estimating petroleum use in ethanol production, we have assumed that the ethanol used in this scenario will be one-half grain-based and one-half cellulosic. While some petroleum may actually be used to produce cellulosic ethanol, particularly in the early stages of commercialization, we expect the amount to be quite small. As an approximation of the actual amount, we have assumed that no petroleum will be required.

3.1.3 Alternative-Fuel Vehicles: Fuel-Volume and Vehicle-Production Constraints

The five alternative fuels most likely to be used in vehicles in significant volumes over the period covered between 1990 and 2010 are included in the scenario. These are liquefied petroleum gases (LP Gas), compressed natural gas (CNG), ethanol, methanol, and electricity. These five fuels are used in aggregate to achieve a 2-MMBD displacement.

Each fuel appears to have strong vehicle and regional markets. As a result, the most likely outlook for these fuels is for all five to be used in combination in the future. However, there are several constraints that would limit the use of several of the fuels. In the case of electricity, vehicle (battery) production limitations exist that could restrict electricity's share by 2010. In 2010, there may be fuel-production constraints on LP Gas and ethanol. Methanol and CNG do not appear to be as constrained and therefore should be able to achieve relatively high levels of displacement (Difiglio, 1989).

Obviously, at high enough energy prices, these, or any other, limitations can be overcome. However, in order to proceed with the analysis, judgments were required to determine reasonable upper bounds for battery, ethanol, and LP Gas production by 2010. These upper bound estimates were made with consideration given to practical, technological, and economic constraints (for example, closeness to competitive price, moderate expectation of research and development (R&D) success, and no major disruption of current markets for the fuels or feedstock. These estimates are documented below.

Ethanol Production Capacity. Ethanol is expected to be produced from both grain (corn) and cellulosic material. The Department of Agriculture has stated that it does not expect grain- or corn-based production levels to exceed two to three times current production levels (about 1 billion gallons per year) without exerting strong upward pressure on feedstock prices (USDA, April 1988). The Department of Energy (DOE) estimates that approximately 3 billion gallons of cellulosic ethanol per year can be produced at competitive prices by 2010 as a result of its enhanced R&D program (DOE, 1991). Therefore, 6 billion gallons of ethanol appear to be the maximum ethanol volume that reasonably could be expected to be produced in 2010. However, representatives of the ethanol industry have argued that an 8-billion-gallon capacity is possible for 2010 (National Corn Growers Association, 1991). Considering the uncertainty associated with such estimates, this total is reasonably close to DOE and Department of Agriculture estimates and has been adopted in this scenario. It is within the range of feasibility, if technology continues to develop at its current pace.

LP Gas Production Capacity. In 2010, 13.7 billion gallons per year of LP Gas is assumed to be available as a transportation fuel. This estimate is based on the March 1991 report by R.F. Webb for the LP Gas Clean-Fuels Coalition, the February presentation of R.F. Myers of the Coalition to the New Fuels for Cleaner Air Conference, and conversations with L. Osgood of Phillips 66 Company in March and April 1991 (CFC, March 1991 and Myers, February 1991).

Table 4 presents Webb's estimates of LP Gas availability and served as the basis for the estimate. The estimates presented for 2005 were assumed to hold for 2010. The total North American supply increase of 27.3 billion gallons shown in the table was reduced to 17.7 billion gallons by eliminating the estimates of LP Gas production from Devonian shale, the Alaskan North Slope, or synthesis from gas or coal. We considered these sources to be too speculative in terms of their actual realization by 2010 to be included in the scenario.

The 17.7 billion gallons available was further reduced to account for growth in demand from

Table 4. LP Gas Clean-Fuels Coalition Estimates of Availability of LP Gas as a Transportation Fuel
(billions of gallons per year)

New Sources	Year 1995	2000	2005
USA			
Increased Gas Plant Recovery	4.6	4.6	4.6
Devonian Shale	—	—	0.9
Alaska North Slope	1.0	1.0	1.0
Increased Refinery Recovery	1.5	1.5	1.5
Increased Refinery Production	3.8	3.9	3.9
Displacement of Low-Value Uses	4.3	2.7	3.1
LP Gas Synthesis from Gas, Coal, or Both	—	3.8	7.7
Subtotal	15.2	17.0	22.7
Canada	2.4	3.3	3.7
Mexico	0.9	0.9	0.9
Total North American Supply Increase	18.5	21.2	27.3
Vehicles on Auto LP Gas* (millions)	14.6	16.7	21.4
Percent of U.S. Vehicle-Fuel Market	10.0	10.6	12.5

* Includes current 330,000.

other end-uses, because data presented in Table 4 assume that there is no growth in the base demand for LP Gas. However, from the Myers presentation, an estimate of a minimum of 4 billion gallons increase in "premium/captive" demand for LP Gas can be derived. (By "premium/captive" demand, we assume that Myers means demand that is relatively inelastic at current prices.) The 1991 EIA Annual Energy Outlook projects an increase of 8 billion gallons per year in LP Gas demand in the industrial sector by 2010. This increase is partially offset by a decrease in the residential sector. The net effect is an approximately 6-billion-gallon-per-year increase for all uses, "premium/captive" or otherwise. We estimate that the "premium/captive" demand is currently two-thirds of total demand for LP Gas. Thus, the 4-billion-gallon projected increase in "premium" demand is consistent with the 6-billion-gallon increase in total demand. Using the Myers estimate as a minimum demand increase, we estimate that a net of 13.7 billion gallons per year is potentially "available" for transportation.

Some of the LP Gas will come from petroleum sources and therefore result in less net oil displacement. Approximately two-thirds of LP Gas is now coproduced with natural gas. We estimate that the incremental supply we are assuming will also be approximately two-thirds from natural-gas-associated sources (about 9.2 billion gallons per year). This is consistent with the underlying assumptions in Table 4. Based on the Myers presentation (and the underlying Purvin and Gertz analysis) and conversations with L. Os-good, we estimate that one-half of the LP Gas generated by the displacement of low-value uses (1.5 billion gallons per year) is likely to be replaced by petroleum or petroleum products (for example, naphtha) (Shiblom, 1990). All of the LP Gas from increased refinery production (3.9 billion gallons per year) will be replaced by petroleum. The net effect is that 5.4 of the 17.7 billion gallons (or 31 percent) is oil based, leaving the remainder from natural-gas-associated sources.

Electric- and Hybrid-Vehicle Production. Maximum electric-hybrid vehicle (EHV) production by 2010 will be constrained by the rapidity with which battery technology evolves from the current lead-acid batteries to more advanced batteries that allow greater range and thus greater market penetration. Further, it will be constrained by the rate at which EHV production facilities, largely battery, can be built and put into operation. Battery evolution and its effect on the emergence of volume manufacturing of EHV's has been considered in an EHV-only scenario developed by Argonne National Laboratory for DOE (Bernard, 1990). Lead-Acid batteries are expected to be used in limited numbers in the early years of the scenario, followed by the introduction of nickel-iron battery-powered electric vehicles in the late 1990's. The first volume production of nickel-iron hybrids occurs in 2001. Volume production of advanced-battery cars (with a possible range of up to 200 miles) is not expected until 2005. No assumption about the specific advanced battery-type is made, because a variety of battery-types may be able to achieve this range. Even then, the buildup in production of these vehicles is gradual. The total or maximum number of EHV's projected to be in operation in 2010 in this EHV-only scenario is 12 million. Table 5 reproduces EHV sales and fleet assumptions used in the EHV scenario.

Other Fuel and Vehicle Constraints. Vehicle-production constraints are not expected for any of the other AFV types, though the necessary levels of AFV market share will be difficult to achieve for many vehicle types. Details of a plausible production schedule are presented in the following chapter. The scenario assumes that once the maximum displacement possible with ethanol, LP Gas, and EHV's is determined, CNG and methanol will split the remaining displacement to be achieved by vehicles.

Table 5. 101-City Electric- and Hybrid-Vehicle Sales and Fleet
(thousands of EHV's)

	EV (dc)		EV (ac)			HV					
Year	Pb.A. Van	NiFe. Van	NiFe. Van	NiFe. Truck	NiFe. Car	NiFe. Van	NiFe. Truck	NiFe. Car	EV Car Adv. Bat.	Net New EHV's	EHV Fleet Total
1992	0.1	—	—	—	—	—	—	—	—	0.1	0.1
1993	1	—	—	—	—	—	—	—	—	1	1.1
1994	1	—	—	—	—	—	—	—	—	1	2.1
1995	1	0.1	—	—	—	—	—	—	—	1.1	3.2
1996	1	1	—	—	—	—	—	—	—	2	5.2
1997	—	10	1	—	—	—	—	—	—	11	16.2
1998	—	10	50	—	—	—	—	—	—	60	76.2
1999	—	—	50	100	—	1	—	—	—	151	227.2
2000	—	—	50	100	100	10	—	—	—	260	487.2
2001	-0.5	—	50	100	100	100	—	—	—	349.5	836.7
2002	-0.5	—	50	100	100	100	100	—	—	449.5	1,286.2
2003	-0.5	-5	50	100	100	100	100	100	—	544.5	1,830.7
2004	-0.5	-5	50	100	200	100	100	200	—	744.5	2,575.2
2005	-0.5	-5	50	100	200	100	100	400	100	1,044.5	3,619.7
2006	-0.5	-5	50	50	200	100	100	400	200	1,094.5	4,714.2
2007	-0.5	-1.1	0	0	200	100	100	400	400	1,198.4	5,912.6
2008	-0.3	—	-50	-50	400	100	200	600	600	1,799.7	7,712.3
2009	-0.3	—	-50	-100	400	200	200	699	800	2,049.7	9,762
2010	—	—	-50	-200	200	200	200	800	1,000	2,150	11,912
Total	**0**	**0**	**301**	**400**	**2,200**	**1,211**	**1,200**	**3,500**	**3,100**	**11,912**	**—**

CNG and methanol were not judged to be production-limited fuels in the volumes and timeframe required for this scenario. As will be discussed below, the scenario requires the use of 0.9 trillion cubic feet of natural gas per year in vehicles in 2010. This volume represents approximately 4 percent of total natural gas use projected in the United States for 2010 in EIA's reference case (EIA, 1991, Table A9). The scenario also requires the use of approximately 1.1-MMBD methanol. According to one estimate, if there were a sufficiently rapid expansion in demand, and if the construction of large methanol plants begins in 1995, methanol production capacity could be expanded to exceed 3 MMBD by 2010 (Difiglio, 1989).

3.1.4 Alternative-Fuel Vehicles: Vehicle Types and Markets

The scenario developed here is one of widespread and large-scale alternative-fuel use to achieve the scenario goals. AFV's, both dedicated and flexible-fuel (or dual-fuel), will have to be used in both the fleet and personal-use markets. Alternative fuel will have to be used in cars, light trucks, heavy trucks, and buses. The specific assumptions regarding the vehicle markets for each alternative-fuel type are detailed below.

Penetration in Fleets. The scenario assumes maximum use of AFV's in the fleet market. This assumption is consistent with Federal and State efforts under way to promote the use of alternative fuels in fleets, with the requirements of the CAAA and the NES, and with the goals of many alternative-fuel proponents who view fleet vehicles as a desirable market niche.

The fleet-vehicle penetration assumptions for fuels other than electricity are presented in Table 6. Table 7 presents our estimates of the number of fleet vehicles in fleets of the specified minimum size in 2010. We assume that AFV's will generally penetrate larger rather than smaller fleets, because of economies of scale that can be achieved in refueling larger numbers of vehicles. This assumption is based on the expectation that central refueling at private facilities may be required initially as more economic. It also is consistent with the CAAA which mandate the use of clean-fuel vehicles in centrally fueled fleets of 10 or more in selected nonattainment cities and with the NES fleet proposal described in Chapter 1. Use of alternative fuels in fleets to displace all use of gasoline and diesel fuel may not be possible; therefore, we have assumed that the maximum penetration in fleets will be, in most cases, 90 percent.

Given the current state of technology development and projected vehicle characteristics, including costs, range, and fuel-storage space needs, the most likely markets for CNG and LP Gas vehicles are fleets, both light- and heavy-duty. This is consistent also with the current market for CNG and LP Gas conversions. In contrast, flexible-fuel vehicles capable of using methanol, ethanol, or both are being developed predominantly for the household, personal-use market, though flexible-fuel cars are currently being used in fleet demonstrations. For these reasons, we believe that CNG and LP Gas are more likely than ethanol or methanol to be used

Table 6. Assumptions Regarding Use of AFV's in Fleets
(percent of the AFV's)

Fleet Type (Size of Vehicle Fleet)	% AFV	As % of AFV's: CNG	LPG	EtOH	MeOH
Autos (10+)	90	25	25	25	25
Light Trucks (6+)	90	50	50	0	0
HDT's (6+)	90	50	50	0	0
School Buses	90	50	50	0	0
Transit Buses	100	50	0	0	50

Table 7. Total Vehicles in Fleets

Fleet Type (Size of Vehicle Fleet)	Vehicle Total (millions)
Autos (10+)	6.891
Light Trucks (6+)	3.589
HDT's (6+)	2.684
School Buses	0.994
Transit Buses	0.085

in fleet trucks (both light and heavy) and school buses. Reflecting this, we have split these markets between CNG and LP Gas. All four fuels are likely to compete to some degree for the passenger-fleet market. because of its relative size. We assume that they will share the larger auto-fleet market equally. Substantial effort has been expended to date to develop CNG and methanol transit buses. Assuming continued success of these efforts, this scenario assumes that this market will be shared equally between CNG and methanol.

The EHV-only scenario discussed above assumed that all EHV vans and light trucks would be fleet vehicles. While there may in fact be some use of EHV light trucks in fleets of six or more, we have assumed here that they will penetrate the smallest fleets (less than six vehicles). While that same analysis assumed that EHV autos would be virtually all (98 percent) personal autos, there are a few fleet autos. They are assumed here to be used in fleets of less than 10.

Alternative-fuel light trucks and autos in fleets will eventually make their way into the personal auto and light truck market through resale as used vehicles. It is assumed that by 2010 an equivalent number of fleet autos and light trucks are in operation as second-owner personal vehicles. This assumption does not apply to the EHV fleet trucks, which are assumed to be used their full useful life in fleets.

Personal-Vehicle Markets. In the personal-vehicle market, it is assumed that methanol and ethanol vehicles will be purchased in the same approximate proportions as gasoline-fueled vehicles: 70 percent will be cars and 30 percent will be trucks. Purchase of personal-use CNG cars is not as likely as with these two fuels because of their limited range on two CNG cylinders. In the scenario, we assume that all personal-use CNG vehicles, other than the ones that were once fleet vehicles, will be light trucks. The vehicle markets for LP Gas are similar to those for CNG, but with LP Gas's greater range, there may be greater likelihood of its use in personal cars. Therefore, we assume that 30 percent of the personal LP Gas vehicles bought new are cars, while 70 percent are light trucks. All personal-use EHV's are assumed to be cars. The general focus of EHV development efforts has been on light trucks for fleet use and cars for household use (for example, as the household second car).

Dedicated Versus Flexible-Fuel Vehicles. For fuels other than electricity, dedicated vehicles are assumed to be first purchased only in fleets. The potential for central private refueling of these vehicles is the primary reason behind this assumption. Additionally, individuals will be reluctant to purchase a limited-range dedicated vehicle that can be refueled at a relatively limited number of public refueling outlets.

Because of the substantial performance improvements that can be obtained with dedicated gaseous-fuel vehicles (as opposed to dual-fuel/gaseous-fuel vehicles), 80 percent of the CNG and LP Gas fleet autos and light trucks are assumed to be dedicated. Performance improvements are not expected to be as dramatic with dedicated ethanol and methanol vehicles. Therefore, we project that just 20 percent of the ethanol and methanol fleet autos will be dedicated. All heavy-duty trucks and buses are assumed to be dedicated AFV's.

Some dedicated vehicles will be used in the personal car and light-truck market as they are resold after use as fleet vehicles. Otherwise, all personal-use vehicles are flexible-fuel. The same dedicated vehicle percentages that are assumed for fleet vehicles apply to personal-use vehicles purchased secondhand after use as fleet vehicles.

For vehicles fueled by electricity, one-half are postulated to be all electric (dedicated) vehicles by 2010. The other half are postulated to be hybrid, with an internal combustion engine (ICE) to provide range extension. (Other hybrids are possible, but are not included in the scenario.) This is a direct result of assumptions underlying the EHV-only scenario regarding the various stages in development and production of alternative battery- and vehicle-types (Bernard, 1990). The electric-vehicle share is as high as it is because of the assumed development of an advanced battery with a potential range of 200 miles. Without it, the electric/hybrid split would be one-third/two-thirds.

3.1.5 Alternative-Fuel Vehicles: Vehicle Operation

The operating characteristics of AFV's (specifically, fuel economy and annual miles of travel), are presented in Tables 8 and 9. Table 8 presents the assumptions we made regarding vehicle miles traveled (VMT) and fuel economy for conventional vehicles (CV's) and all the AFV's, except EHV's. The assumptions for VMT and fuel economy for CV's are consistent with those used in the development of the NES. AFV's, except EHV's, are assumed to have the same annual VMT as CV's. Flexible-fuel- and dual-fuel vehicles are assumed to operate 75 percent of the time on the alternative fuel.

Flexible-fuel- and dual-fuel vehicles are assumed to be 5 percent more energy efficient, and dedicated vehicles 10 percent more efficient, than their gasoline counterparts (on a British-thermal-unit basis). No improvement in the energy efficiency of AFV's is expected relative to diesel-fuel vehicles. (Note that FFV and dedicated AFV efficiencies are scenario-specific generic assumptions. As *actual* efficiency data become more available, they will be integrated into future analyses.)

Table 8. Vehicle Operating Assumptions
(CV's and all AFV's except EHV's)

Vehicle Type	Fuel Economy (miles per gallon)			Annual Travel (miles)
	CV	FFV	Dedicated	
Fleet				
Auto	23	24.2	25.3	21,670
Light Truck	17	17.8	18.7	12,140
HDT	7	—	7.3*	12,200
School Bus	8	—	8.2*	8,200
Transit Bus	3.3	—	3.3*	32,800
Personal				
Auto	23	24.2	25.3	12,400
Light Truck	17	17.8	17.8	10,000

* Weighted by AFV replacement of diesel and gasoline vehicles.

Table 9. EHV Operating Assumptions.

Vehicle Type	Annual Travel		HV Fuel Economy
	EV	HV	
Fleet Auto	6,898	12,994	36
Fleet Light Truck	6,752	13,250	21
Personal Auto	12,775	10,220	36

The EHV's in this scenario have somewhat different operating characteristics than are assumed for other fleet vehicles and personal-use cars. These characteristics are presented in Table 9. They were derived from work by W. Hamilton, who limited EHV penetration to specific potential applications (Hamilton, 1989). For example, potential applications in fleets were limited only to vehicles parked overnight on company premises and, for electric vehicles, to trucks, vans, and cars never driven beyond 75 to 80 miles per day. Potential household applications were limited to passenger cars in multicar-households in single-family residences with offstreet parking. Thus, travel in EHV's should not be compared directly with the average travel of all fleet or all personal vehicles.

The hybrid vehicles are assumed to operate approximately 80 percent of the time on electricity using the ICE on board for range extension. The small ICE will be more efficient than other vehicles when operating on gasoline.

3.1.6 Alternative-Fuel Vehicles: Vehicle-Specific Fuels

The energy content (lower heating values) of fuels used in this analysis is shown in Table 10. Both ethanol and methanol, when used as a vehicle fuel, are mixed with 15 percent gasoline by volume. This is true even with dedicated vehicles. Seven percent of the electricity generated for EHV's is assumed to be from petroleum.

3.2 The Scenario

3.2.1 Summary

Table 11 presents an overview of the scenario. As discussed in Sec 3.1.2, the oxygenates are estimated to displace approximately 0.5 MMBD (0.52 MMBD). One-half of their displacement is from MTBE, one-third from ETBE, and the rest from ethanol's use in gasohol.

Table 10. Energy Content
(Btu per gallon)

Fuel	Content
Gasoline	115,400
Ethanol	75,670
E–85	81,630
Methanol	56,560
M–85	65,386
LP Gas*	83,975
CNG (on a gallon-equivalent basis)	115,400

Note: Lower heating values

* 95% propane and 5% butane

AFV's are expected to displace approximately 2 MMBD. EHV's will displace 0.37 MMBD; LP Gas vehicles, 0.46 MMBD; CNG vehicles, 0.49 MMBD; and alcohol-fueled vehicles, 0.67 MMBD. The latter vehicles are predominantly flexible-fuel-vehicles that will be able to use both ethanol and methanol blends (E–85 and M–85). Approximately 70 million AFV's will be needed to achieve this displacement.

3.2.2 Vehicle Totals

Table 12 presents the total number of vehicles by vehicle type. Ninety-five percent of the AFV's are cars and light trucks.

Table 11. Vehicles, Oil Displacement, and Alternative-Fuel Use by Fuel Type

Fuel Type	Number of Vehicles (million)	Oil Displaced (million barrels per day)	Alternative Fuel Used
9% Ethanol in Gasoline	N/A	0.08	2.0 bil gal per year
17.1% ETBE	N/A	0.16	1.6 bil gal per year 2.2 bil gal per year isobutylene
15% MTBE in Gasoline	N/A	0.27	2.3 bil gal per year methanol; 4.5 bil gal per year isobutylene
Electricity	11.9	0.37	220 gigawatthours per day
LP Gas	17.1	0.46	13.7 bil gal per year
CNG	8.8	0.49	0.9 trillion cubic feet per year
Alcohol (E–85, M–85, M–100)	29.8	0.67	4.4 bil gal per year ethanol; 14.5 bil gal per year methanol
Total	**67.6**	**2.50**	

Table 12. Total Vehicles by Type
(millions)

Cars	40.4
Light Trucks	23.8
Heavy-Duty Trucks	2.4
School Buses	0.89
Transit Buses	0.08
Total	**67.6**

Table 13 and Figure 1 present the fleet- versus personal-vehicle split. Approximately one-quarter of the AFV's are fleet vehicles, but this proportion varies by fuel type. For example, more than one-half of the CNG vehicles are fleet vehicles, while only 10 percent of the alcohol-fuel vehicles are fleet vehicles.

Table 14 and Figure 2 present the dedicated versus dual-fuel/flexible-fuel vehicle split. Approximately one-third are dedicated. Again, this percent varies by fuel type. Three-quarters of the

Table 13. Total Vehicles: Fleet versus Personal
(millions)

Fuel Type	Total	School Buses	Transit Buses	Heavy-Duty Trucks	Fleet LTs	Fleet Cars	Personal LTs	Personal Cars	Total LTs	Total Cars	Total Fleet	Total Personal
EHV's	11.9	0	0	0	3.1	0.1	0	8.7	3.1	8.8	3.2	8.7
LPG	17.1	0.45	0	1.2	1.6	1.6	8.0	4.3	9.6	5.8	4.8	12.3
CNG	8.8	0.45	0.04	1.2	1.6	1.6	2.3	1.6	4.0	3.1	4.9	3.9
Ethanol	7.9	0	0	0	0	1.6	1.4	4.9	1.4	6.5	1.6	6.3
Methanol	21.9	0	0.04	0	0	1.6	5.6	14.7	5.6	16.3	1.6	20.4
Total	**67.6**	**0.89**	**0.08**	**2.4**	**6.3**	**6.3**	**17.4**	**34.1**	**23.8**	**40.5**	**16.1**	**51.6**

Figure 1. Alternative-Fuel Vehicles by Fuel Type (Fleet Versus Personal)

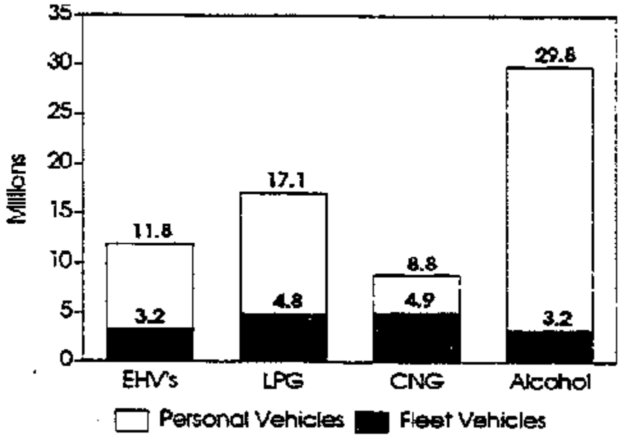


Figure 2. Alternative-Fuel Vehicles by Fuel Type (Dedicated Versus Flexible Fuel)

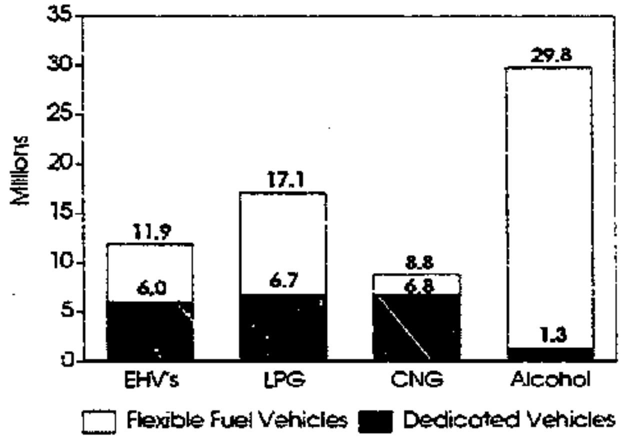


Table 14. Total Vehicles: Dedicated Versus Dual Fuel
(millions)

Fuel Type	Total	Dedicated School Buses	Dedicated Transit Buses	Dedicated Heavy-Duty Trucks	Dedicated Light Trucks	Dual-Fuel Light Trucks	Dedicated Autos	Dual-Fuel Autos	Total Light Trucks	Total Cars	Total Dedicated	Total Dual Fuel
EHV's	11.9	0	0	0	0.7	2.4	5.3	3.5	3.1	8.8	6.0	5.9
LPG	17.1	0.45	0	1.2	2.6	7.0	2.5	3.4	9.6	5.8	6.7	10.4
CNG	8.8	0.45	0.04	1.2	2.6	1.4	2.5	0.6	4.0	3.1	6.8	2.0
Ethanol	7.9	0	0	0	0	1.4	0.6	5.8	1.4	6.5	0.6	7.3
Methanol	21.9	0	0.04	0	0	5.6	0.6	15.6	5.6	16.3	0.7	21.3
Total	**67.6**	**0.89**	**0.08**	**2.4**	**5.9**	**17.9**	**11.5**	**29.0**	**23.8**	**40.5**	**20.8**	**46.9**

CNG vehicles are dedicated, while just 4 percent of the alcohol-fuel vehicles are dedicated.

3.2.3 Fuel Totals

Table 15 summarizes the alternative-fuel volumes required for the scenario. The ethanol and LP Gas volumes are those that we assumed to be a reasonable upper limit as discussed in section 3.1.3. At this point, we do not anticipate any additional constraints on production of the fuel volumes shown in the table. The ethanol and methanol totals are for the alternative fuel itself: they do not include the gasoline required to blend these fuels to E-85 and M-85. While 0.9 trillion cubic feet (tcf) of natural gas is projected to be used in CNG vehicles, an additional 1.1-tcf-per-year domestic natural gas will be required to support this scenario. Natural gas will be used to replace LP Gas drawn out of other markets, to generate electricity for EHVs, and to produce ethanol. The rationale for our estimate is described below. The estimate will be reexamined in subsequent analyses.

Table 16 presents the LP Gas totals we assumed for this scenario and discussed in Section 3.1.3. It also presents our estimates of the amount of LP Gas that will be replaced by new sources of domestic natural gas. Various estimates exist regarding projected increases in natural gas use by 2010. For purposes of this analysis only, we assume that approximately 2-tcf-per-year additional natural gas will be consumed in that year, independent of the scenario and its substantial increases in CNG-vehicle use. Approximately 1.6-billion-gallons LP Gas will be coproduced with this 2-tcf natural gas, thereby reducing to 3 billion gallons per year (from the 4.6-billion-gallon total from increased plant recovery) the LP Gas that must be generated by new sources of natural gas. We believe the increased refinery recovery of LP Gas (1.5 billion gallons per year) can all be replaced by natural gas, as well as one-half of the displacement of low-value uses of LP Gas (3.1 billion gallons per year). LP Gas from Canada and Mexico is not going to be replaced by U.S. natural gas. In total, approximately 0.83 tcf per year will be required to generate or replace these 6-billion-gallons-per-year LP Gas.

The Amoco analysis referred to earlier indicates that natural gas to produce fertilizer accounts for approximately 21 percent of the energy content of a gallon of ethanol (Ho, 1989). Applying this percentage to the ethanol volume in the scenario results in an additional 0.23-tcf-per-year natural gas demand.

Table 15. Total Alternative-Fuel Volumes Required for Scenario

Fuel Type	Alternative-Fuel Volumes
Ethanol	8 billion gal per year
Methanol	16.8 billion gal per year
Natural Gas	2.0 tcf per year*
LP Gas	13.7 billion gal per year
Electricity	220 gigawatthours per day
Isobutylene	6.7 billion gal per year

* 0.9 tcf per year of natural gas from domestic sources will be used in natural gas vehicles. We estimate that another 1.1 tcf per year will be used (1) to replace the LPG drawn out of other markets, (2) to generate electricity for EHVs, and (3) to produce ethanol (for example, in fertilizer manufacture). Thus, a total of 2.0-tcf-per-year domestic natural gas will be used in this alternative-transportation-fuels scenario. See text for further discussion.

Table 16. LP Gas Volume To Be Replaced by Domestic Natural Gas: 2010
(billion gals per year)

Sources	Increased LP Gas Available for Transportation and Other Uses from U.S. Sources	LP Gas to be Replaced by Additional Domestic Natural Gas
Increased Gas Plant Recovery	4.6	3.0
Increased Refinery Recovery	1.5	1.5
Increased Refinery Production	3.9	0
Displacement of Low Value Uses	3.1	1.65
Total	**13.1**	**6.15**

Natural gas will also be used in the generation of electricity for EHV's. Hamilton assumed it would be 7 percent, which leads to an additional 0.06 tcf per year. In sum, an additional 1.1 tcf per year of natural-gas production may be required to support the scenario.

3.2.4 Concluding Note

This scenario was developed to achieve a target displacement of 2.5 MMBD in 2010. The transition required to reach the target levels is particularly important in view of the number of vehicles assumed to be on the road. In the scenario, all vehicles are assumed to have average use and performance characteristics. Consideration was not given to minimum vehicle-production requirements for mass-production of specific vehicle fuel types, vehicle survival and utilization rates (the VMT and fuel economy of vehicles by age), and actual rates of fleet vehicle turnover to the personal market. In the following chapter, this scenario has been revised to take account of these factors, while attempting to match the alternative-fuel use and oil-displacement totals presented above. Vehicle-use characteristics and the number of vehicles of the various types have been adjusted to reflect these phase-in and production constraints. The results of this refinement are presented in Section 3.3. The vehicle totals and displacements achieved in the revised scenario and presented in Section 3.3 will be used as the basis for subsequent cost/benefit analyses.

Evolution of the Vehicle and Fuel-Distribution Infrastructure

The purpose of this section is to describe a feasible path for the timing of AFV's introduction and sales that could lead to the quantities of alternative-fuels use envisioned in the scenario described in the preceding section of this chapter. In addition, we develop rough estimates of the costs of fuel distribution and retailing infrastructure required to support such levels of fuel use. The point of this exercise is not to precisely match the numbers of vehicles by type and usage pattern in 2010, but rather to achieve the fuel-use volumes of the scenario presented in the preceding section, with the same pattern of vehicle and fuel types by specifying a plausible path of vehicle and fuel sales that could lead up to the desired result.

The first part of this section describes the key assumptions we used to develop guidelines for the scenario evolution. We assumed introduction dates of AFV's that were consistent with the likely timing of availability of the required technology as reflected in provisions of the Alternative Motor Fuels Act of 1988, the CAAA, and California's Low Emission Vehicles and Clean-Fuels Program. We assume that production of AFV's begins in a manner consistent with the startup of conventional-vehicle assembly lines, in blocks of 200,000-to-300,000 similar vehicles. We use a vehicle stock model (described below) to perform stock evolution and fuel-use calculations. We used 1991 EIA assumptions for fuel prices and consistent projections for total automobile, light-truck, and heavy-truck sales. Clearly, there are any number of ways of reaching the alternative-fuel use goals of the 2010 scenario. The particular course of evolution we provide here is merely intended to illustrate one possible path by which the goals can be reached.

The second part of this section describes rough estimates of the magnitudes of investments in vehicles and infrastructure required to make this scenario possible. We explain the nature of the additional infrastructure and vehicle costs and describe the resulting costs over time to present very approximate estimates of the financial outlay required.

3.3 Scenario Description

To develop a feasible scenario for the timing of AFV's introduction and sales, we assumed that the introduction dates would be consistent with the dates presented in the Clean Air Act Amendments, the Alternative Motor Fuels Act, and the California Clean Fuels Initiative. All of these suggest that large-scale production of such vehicles can begin between 1995 and 2000. For this scenario, we assumed that production of flexible-fuel vehicles will begin around 1996, with dedicated-fuel vehicle production beginning at low levels in 1998. The assumption that the technology required for these AFV's will be available at these times is critical (see Chapter 6).

In the vehicle stock model we use, the Alternative Motor Fuel Use (AMFU) model, fuel use depends on the size of the vehicle stock and on its use (Greene and Rathi, 1990). Fuel prices affect vehicle usage rates. Fuel-price projections are based on EIA's 1991 Annual Energy Outlook, Reference Oil Price projections (EIA, 1991, Table A3). Figure 3 shows fuel prices converted to a common base of price-per-gallon-of-gasoline-equivalent energy content. Vehicle sales projections for cars, light trucks, and heavy trucks were taken from the Data Resources Inc. 30-year trend projection for July 1990, a projection fairly consistent with the EIA 1991 Annual Energy Outlook. This forecast anticipates sluggish sales for the next five years, followed by very slight increases in passenger car sales and steady, but still modest growth in light-truck sales (Figure 4). The fact that the motor-vehicle market is not growing rapidly implies that AFV's must capture major market shares to achieve the fuel-use goals of the 2010 scenario.

Light-duty vehicles are introduced in stages, phased in blocks of approximately 250,000. We assumed that an assembly line operating at full capacity manufactures from 200,000 to 300,000 vehicles each year, and that the startup pattern for vehicle production would be approximately 50,000 vehicles in the first year, increasing to 150,000 in the second year, and 250,000 vehicles at full capacity. AFV's can be produced economically in smaller numbers especially when, as with flexible-fuel ethanol and methanol vehicles, the technologies are essentially identical. We are assuming, however, that original equipment manufacturers' AFV's will embody significant design changes to take advantage of, or accommodate, fuel properties. For heavy trucks we assumed a smaller production level, because assembly lines for heavy trucks operate at a lower full capacity than light-duty assembly lines. Electric-vehicle production was directly based on the production scenario illustrated in Table 5.

We then used the AMFU model to integrate production of vehicles, perform stock evolution, and calculate expected fuel use. The AMFU model is a computer-based model that forecasts fuel use, vehicle use, and vehicle stock for 1 to 40 years into the future. It allows the user to define several different vehicle types, as well as defining different technology types within each vehicle type. This allowed us to define dedicated as well as dual- or flexible-fuel vehicles and also to indicate fleet versus personal-use vehicles.

Figure 3. Retail Fuel Price Projections

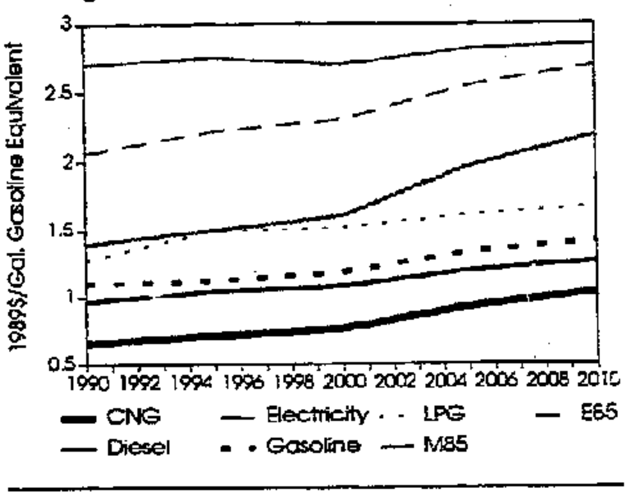
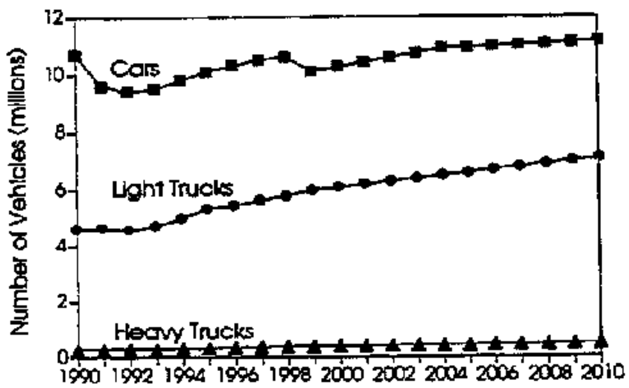


Figure 4. Vehicle Sales Projections to 2010



Source: Data Resources, Inc.

The AMFU model allows us to treat fleet and personal household vehicles differently in terms of use, scrappage, and efficiency. In addition, we can specify when a particular type of fleet vehicle is resold to the household sector as a second-hand vehicle. For this scenario, we assumed that fleet automobiles reverted to the household sector after being in a fleet for 3 years, while light trucks move into the household sector after 5 years. After that period of time, 80 percent of previous fleet automobiles and 50 percent of light trucks become personal or household vehicles.

Using the production patterns described above, we "built up" projections of vehicle sales by vehicle type and year by adding blocks of 250,000 at different times. For alcohol-fuel vehicles, we anticipated that production of flexible-fuel fleet automobiles would start in 1996, with personal flexible-fuel vehicle production beginning in 1997. The production of flexible-fuel methanol and ethanol automobiles begins in 1996 with fleet sales at 75,000 each, and in 2010 reaches peak sales of 250,000 fleet automobiles and 2 million methanol and 500,000 ethanol personal-use flexible-fuel vehicles. Production of flexible-fuel ethanol light trucks begins in 1996 with sales at 10,000 and sales in 2010 of 150,000. Flexible-fuel methanol light-truck production begins in 1998, with sales at 25,000 and sales in 2010 of 600,000. The distinction between ethanol and methanol flexible-fuel vehicles is merely intended to ensure the desired proportions of fuel use. In actuality, it is likely that the vehicles will be identical and capable of using either fuel.

Dedicated methanol- and ethanol-vehicle production begins in 1996, with combined sales of 80,000 for both methanol and ethanol fleet and household passenger cars. Sales are evenly divided between methanol and ethanol, household and fleet vehicles. By the year 2000, sales reach 160,000, where they remain through 2010. In 1997, 1,000 dedicated methanol buses replace buses previously fueled by diesel fuel. Dedicated methanol bus sales reach 5,000 by 2010.

Gaseous-vehicle production commences in 1996 with dual-fuel CNG and LP Gas light trucks sold to fleets. Initial sales are 10,000 each. In 2010, 40,000 dual-fueled CNG fleet light trucks are sold with 150,000 dual-fuel CNG trucks sold to the personal market. In 2010, 40,000 fleet LP Gas light trucks are sold, with sales of personal-use LP Gas light trucks at 150,000. Production of gaseous dual-fuel passenger cars begins in 1998, with 50,000 each of LP Gas and CNG autos. Both types are sold in equal numbers in both the fleet and household markets. In 2010, dual-fuel LP Gas fleet sales reach 50,000, and dual-fuel LP Gas personal autos have reached 600,000. In 2010, dual-fuel CNG fleet and household auto sales total 40,000 each. Production of dedicated gaseous-fueled automobiles also begins in 1998, with total sales at 80,000 units, and light-truck production begins in 1999, also with 80,000 units. Dedicated CNG and LP Gas buses first appear in 1996, with heavy-truck production beginning in 1999. The CNG buses produced replace those buses previously fueled by gasoline, and CNG transit buses replace those fueled by diesel. LP Gas buses replace those previously fueled by gasoline, nearly all of which are school buses. By 2010, more than 90 percent of gasoline bus sales have been replaced by alternative-fuel buses, and about one-half of diesel buses have switched, as well.

As stated above, electric-vehicle production follows the scenario outlined in Table 5. Production of fleet vans and light trucks begins in 1992, with a mere 100 vehicles, and increases to sales of 2,400,000 in 2010.

Alternative-fuel passenger cars capture almost 20 percent of the car market in the year 2000, increasing to 40 percent by 2005 and almost 60 percent by 2010 (Figure 5). Alcohol-fuel cars make up the largest component of the passenger car AFV's followed by electric cars, both hybrids and battery-electrics, LP Gas, and then CNG vehicles. AFV's capture 40 percent of the light-truck market in 2010, with gaseous (LP Gas and CNG) fuels dominating and electric trucks and vans capturing a relatively minor fraction (Figure 6).

Using the sales projections indicated above, we estimated the vehicle stock and fuel use by vehicle type. The total stock of automobiles in 2010 is estimated to be approximately 170 million liquid or gaseous fueled, and 12 million electric vehicles and EHV's. Of these, conventional-fuel vehicles number approximately 133 million, the remaining 37 million automobiles being fueled by methanol, ethanol, CNG, or LP Gas. There are approximately 20 million methanol automobiles, 8 million ethanol automobiles, 2.8 million CNG automobiles, and 5.2 million LP Gas automobiles. Gaseous- and alcohol-fuel passenger cars thus account for more than 20 percent of automobile stock in 2010.

The total light-truck stock amounts to approximately 67 million units in 2010. Of these, 47 million are conventional petroleum-fuel light trucks; 15 million use alternative gaseous or alcohol fuels; and there are 4 million electric-vehicle and EHV trucks and vans.

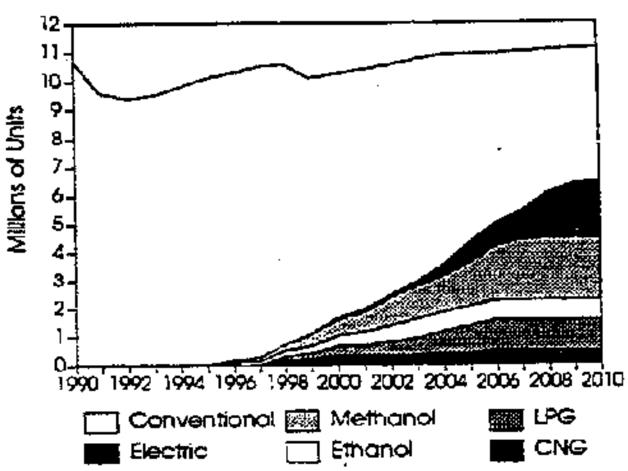
Total heavy-truck stock in 2010 is 6.4 million, of which 4.9 million are gasoline and diesel heavy trucks, with the remaining 1.5 million being alternative-fuel (LP Gas and CNG) trucks. Bus stock in 2010 is approximately 1.5 million. Of these, 1 million are gasoline and diesel-fuel buses, and 500,000 are alternative-fuel buses.

The above indicates that 27 percent of passenger cars, 28 percent of light trucks, 23 percent of heavy trucks, and 33 percent of buses need to be AFV's by 2010. Because these vehicles are newer than the average vehicle, they tend to receive greater use and are just slightly more energy efficient.

The above projections generate levels of fuel use that match the 2010 scenario almost exactly. The numbers of AFV's using methanol displace 0.51 MMBD. Those using ethanol displace an additional 0.16 MMBD. Gaseous AFV's using LP Gas displace 0.465 MMBD, while those fueled by CNG displace 0.51 MMBD. Electric vehicles and EHV's and could displace 0.3 MMBD, for a total displacement of 2 MMBD through the use of alternative motor fuels.

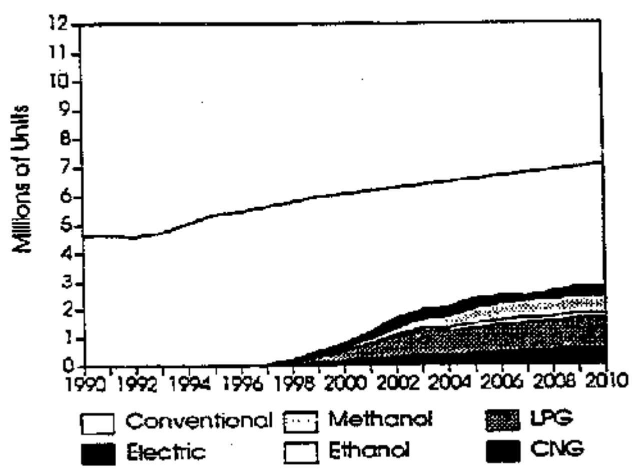
In addition, substantial oil displacement is achieved through the use of oxygenated or reformulated gasoline. By adding products derived from methanol and ethanol to gasoline, a displacement of 0.51 MMBD can be achieved with the number of gasoline-powered vehicles described above. Ethanol in gasoline accounts for 0.8 MMBD. ETBE accounts for a displacement of 0.16 MMBD and MTBE, a displacement of 0.27 MMBD.

Figure 5. Passenger Car Sales by Fuel Type



Note: Sales are represented by distance between lines.

Figure 6. Light Truck Sales by Fuel Type



Note: Sales are represented by distance between lines.

3.4 Conclusions

The 2010 scenario for alternative motor-fuels use requires aggressive introduction of the AFV's and simultaneous market penetration by several new-vehicle technologies to reach the target numbers outlined in the scenario. While it appears to be technically possible to reach the fleet and fuel-use configuration outlined in the scenario, several key uncertainties remain.

One key uncertainty is consumer acceptance of AFV's. The operating characteristics of AFV's are somewhat different than those of CV's, especially with respect to the additional cost of purchasing an AFV and to the necessity of adapting to different refueling patterns to achieve the same usage as a CV.

Another key uncertainty relates to the reliability and durability of the technology required to produce and run AFV's. The scenario introduces AFV's at an early date and in large numbers. For technologies that are not yet fully market ready, it is likely that unforeseen problems may arise after the vehicles are introduced. These may be minor and easily resolved. If not, they could seriously impact vehicle sales and scrappage.

Fuel costs and fuel-supply buildup are another important uncertainty. Fuel supply would need to be expanded rapidly and regularly, without major cost runups to allow individuals with AFV's access to economically priced fuel.

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