Executive Summary

This Second Interim Report of the Interagency Commission on Alternative Motor Fuels describes progress the commission and government agencies have made in implementing the provisions of the Alternative Motor Fuels Act of 1988 (Public Law 100–494, AMFA), assessing the role of alternative motor fuels in the U.S. transportation sector, and developing policies to promote the use of alternative fuels. Chapter 1 describes the alternative motor-fuels policies proposed in the National Energy Strategy (NES) and shows how they compose an effective long-term plan to encourage the widespread use of alternative motor fuels. Chapter 2 reports the progress to date of the Department of Energy (DOE) and other agencies in implementing the programs required by the AMFA. Chapter 3 describes a detailed scenario of future alternative-fuel use that displaces 2.5 million barrels per day (MMBD) of petroleum and a feasible path of vehicle production and fuel supply leading to that goal. The scenario serves both as a planning tool for policy development and as a context for evaluating the potential benefits and costs of alternative motor fuels. An analytical tool for exploring and quantifying the energy market impacts of alternative fuels, the Alternative Fuels Trade Model (AFTM), is described in Chapter 4. The AFTM provides a means of investigating the impacts of alternative fuels in interrelated world energy markets for petroleum and natural gas. Several major initiatives have recently been enacted that have important ramifications for alternative-fuels policy. These are analyzed in Chapter 5. The Clean Air Act Amendments of 1990 contain provisions mandating the use of nonpetroleum oxygenates in reformulated gasoline. This provision alone could result in hundreds of thousands of barrels per day of oil displacement in the 2000 to 2010 time period. Other provisions for much more stringent emissions standards may affect the ability of manufacturers to make and sell conventional-fuel vehicles or, at the very least, affect their cost-effectiveness in comparison to cleaner alternative-fuel vehicles (AFV's). Programs enacted in California may have the same effect and, in addition, appear to require sales of electric vehicles, beginning in 1998. Finally, Chapter 6 reviews the key areas in which technological advances could substantially improve the competitiveness of AFV technologies in the marketplace.

Alternative-Fuels Policy

In the absence of new initiatives, U.S. oil consumption is expected to increase by more than 20 percent to 20.3 MMBD in 2010. World dependence on Persian Gulf oil supplies, where two-thirds of the world's proved reserves are located, also will continue to grow, making energy security a legitimate national concern. No single policy is fully capable of addressing energy security concerns. A balanced energy security policy includes the acquisition of strategic petroleum reserves, improved coordination with other oil-importing nations, increased domestic oil production, increased energy efficiency, and greater ability to substitute other energy supplies for oil. Because the transportation sector accounts for two-thirds of U.S. oil consumption, alternative motor-fuel use is an essential part of a balanced energy security policy.

The NES includes five initiatives to reduce dependence on imported oil by bringing alternative fuels into the marketplace.

- Eliminate the 1.2-mile-per-gallon cap on corporate average fuel economy (CAFE) credits to manufacturers who produce flexible-fuel alcohol vehicles or dual-fuel natural gas vehicles. With the 1.2-mile-per-gallon cap, there is an incentive to produce only a few hundred thousand AFV's per year. Lifting the cap encourages manufacturers to produce as many AFV's as they can sell, paving the way for a large market for future U.S. alternative-fuel production and distribution.

- Increase the size of the Federal alternative-fuel fleet. To stimulate the early production of AFV's, the Federal Government will purchase as many AFV's as possible. Extent, timing, and quantity will depend on negotiations currently under way with automobile manufacturers.

- Ensure the use of AFV's in clean-fuel fleets. The Clean Air Act Amendments of 1990 contain significant new requirements for the use of clean-fuel vehicles in fleets of ten or more vehicles. These requirements, however, do not mandate the use of alternative fuels. The NES proposes a modification of the clean-fuel-fleet concept to ensure use of alternative transportation fuels (which are not required by the Clean Air Act Amendment's clean-fuel-fleet program) and to expand the program nationwide.

- Increase research and development (R&D) on AFV's. The Federal Government is taking several steps to accelerate R&D on AFV's. A consortium of vehicle manufacturers, battery developers, and utilities, along with DOE, is being formed to carry out an aggressive R&D program to make major advances in battery technology, the major hurdle to market acceptance of electric vehicles. The Government is continuing R&D on gas turbine engines, which can be 30 to 40 percent more efficient than conventional gasoline engines and can operate well on a variety of alternative fuels. Research efforts will be stepped up on the heavy-duty low-heat-rejection diesel, which has the potential to be 22 percent more efficient than conventional diesels. Fuel-cell-powered vehicle research is continuing. Fuel cells, a potentially ultraclean technology, can be 70 to 80 percent more efficient than conventional engines and can operate on a variety of alternative fuels.

- Accelerate development of advanced biofuels technology. The Federal Government will accelerate R&D in the areas of new feedstocks and conversion technologies to achieve commercial readiness of cost-competitive alcohol fuels from biomass by the year 2000. Domestically produced liquid fuels from nonfood biomass can provide significant energy security benefits, are a renewable and sustainable source of energy, and have important potential emissions benefits. Research efforts over the past decade have cut the costs of producing alcohol fuels from biomass in half. Further reductions to the price range of conventional petroleum-based fuels are possible through improvements in crop yields and conversion processes.

These five measures, if enacted, will make a significant contribution to reducing petroleum use in the U.S. transportation sector, by substituting alternative motor fuels for gasoline and diesel fuel. The NES projections indicate a potential to replace 2.2 MMBD of gasoline and diesel by 2010. Thus, the NES meets the requirements of the AMFA for the development of a long-term plan to encourage the widespread use of alternative transportation fuels.

Progress Report on AMFA Implementation Programs

The AMFA directs DOE to undertake a number of actions in collaboration with the General Services Administration (GSA), the Department of Transportation (DOT), the Environmental Protection Agency (EPA), and other agencies to encourage the development and widespread use of methanol, ethanol, and natural gas as transportation fuels. Three major programs have been established to fulfill the AMFA's requirements. In addition, the Interagency Commission on Alternative Motor Fuels has been formed to coordinate and develop policy, and the Alternative Fuels Council has been constituted to advise the commission. Finally, six studies required by the AMFA have been completed or are near completion.

DOE established three major programs with the assistance of other Federal agencies:

- The Alternative-Fuel Federal Light-Duty Vehicle Program
- The Truck Commercial Application Program
- The Alternative-Fuels Bus Testing Program

The objective of the Light-Duty Vehicle Demonstration Program is to ensure that the maximum practicable number of automobiles and light trucks (LT's) purchased annually by the Federal

Government be AFV's. An interagency agreement between DOE and GSA has been negotiated and signed, and a total of $2.9 million transferred to GSA for the purchase of vehicles. Thus far, 65 General Motors and Ford methanol fuel-flexible vehicles were placed in the Federal fleet by March 1991. These vehicles are operating in Los Angeles; San Diego; Washington, D.C.; and Detroit. A contract for 50 compressed natural gas (CNG) Chrysler vans has been placed, and funding has been provided for additional vehicles, including ethanol vehicles, as well.

The Truck Commercial Application Program will establish and conduct one or more truck or other heavy-duty vehicle commercial application projects in real-world operating environments. The Trucking Research Institute of the American Trucking Associations Foundation is under contract to manage a program demonstrating and evaluating alternative-fuel heavy trucks. To date, the project has surveyed alternative-fuel truck demonstrations in progress.

The objective of the Alternative-Fuels Bus Testing Program is to assist State and local government agencies in the testing of alcohol- or natural gas-powered buses in urban areas. The Urban Mass Transit Administration has the lead role and has integrated the project with its existing Clean Air Program. The Clean Air Program currently includes an alternative-fuels initiative, with 300 buses in 50 locations nationwide; a methanol bus demonstration program, including 60 buses in seven locations; and a clean-diesel-system program, involving 400 buses in the testing of diesel particulate traps. In fiscal year 1991, $800,000 was provided by DOE to the Urban Mass Transit Administration in support of these programs.

Four of the six studies mandated by the AMFA have been completed and reports submitted to Congress. The status of each of the six reports is shown in Table E–1. The environmental study report is in draft form and undergoing review. The Light-Duty Vehicle Operations progress report is scheduled to be released in March 1992.

Potential Alternative-Fuels Use Scenario

The potential alternative-fuels use scenario is based on a goal established by the Alternative Fuels Council of using alternative fuels in 25 percent of vehicle travel in the United States by 2010 (about 2.5 MMBD). The exercise of describing this goal and a path by which it can be reached is a valuable planning tool for formulating policy. First, it provides a specific fuel-use future within which the potential effects of alternative-fuel use can be investigated in detail. Second, it forces one to be specific about what is required to achieve the goal, in terms of the quantities and timing of key factors (vehicles

Table E–1. Status of AMFA Studies and Reports

Study	Lead Agency	Supporting Agency	Status
Light-Duty Vehicle Operations*	DOE	EPA/DOT	In Progress
Light-Duty Vehicle Disposal*	GSA/DOE	—	Complete
Electric Vehicles	DOT	DOE/EPA	Complete
Residential Energy Prices	DOE	DOT	Complete
Natural Gas-to-Methanol Plants	DOE	—	Complete
Environmental Study	EPA	DOE/DOT	Draft

* These studies are part of the Federal Light-Duty Vehicle Project.

sales, fuel supplies, and distribution infrastructure). Many scenarios of future fuel use can be postulated. The one reported here was developed in collaboration with the Alternative Fuels Council and was approved by the council on May 17, 1991. It is not intended to be a projection of the most likely, most efficient, or most desirable scenario. Rather, it is intended as an analytical context in which to examine the costs and benefits of all the alternative fuels.

In this scenario, alternative fuels replace 2.5 MMBD of petroleum equivalent energy with roughly equal shares of ethanol, methanol, natural gas, LP Gas, and electricity. Substitution is achieved by the use of alcohol-based oxygenates in gasoline as well as direct alternative-fuels use. Dedicated, as well as flexible- and dual-fuel vehicles, are included, as are electric and hybrid electric vehicles. AFV's penetrate the household market, as well as fleet vehicles. All major vehicle types are included: passenger cars, LT's, heavy trucks, and buses. In general, vehicles are distributed to markets in which it appears presently that they are most likely to be successful, but other patterns of market penetration are certainly possible and may even be more likely.

Oxygenates blended in gasoline displace 0.5 MMBD of the 2.5 MMBD total. Liquid fuels containing oxygen will be required in certain areas to reduce emissions of carbon monoxide in cold weather. These oxygenates will also comprise a significant fraction of low emission reformulated gasoline. Those most likely to be used are methyl tertiary-butyl ether (MTBE), ethyl tertiary-butyl ether (ETBE), and ethanol. MTBE and ethanol are already in widespread use as oxygenates. Both MTBE and ETBE require butane or isobutane, some of which is derived from petroleum. Current ethanol production also requires petroleum, although future production will likely require less. As a result, oxygenates do not replace petroleum on a Btu-for-Btu basis. If all 120 billion gallons of projected gasoline use in 2010 were oxygenated and no other alternative fuels were used, oxygenates in 2010 would displace 700,000 barrels per day. Including about 40 billion gallons of gasoline equivalent alternative-fuel use, the maximum petroleum displacement with oxygenates is estimated to be 0.5 MMBD. One-half of the displacement is from MTBE, one-third from ETBE, and the remaining one-sixth from ethanol.

The scenario postulates that AFV's displace 2 MMBD of petroleum in 2010 with a combination of E-85 (85 percent ethanol, 15 percent gasoline), M-85 (85 percent methanol, 15 percent gasoline), CNG, LP Gas, and electricity. Battery electric and electric hybrid vehicles displace 0.37 MMBD, LP Gas vehicles, 0.46 MMBD, CNG vehicles, 0.49 MMBD, and alcohol-fueled vehicles, 0.67 MMBD. In all, approximately 70 million AFV's must be in use in 2010 to achieve these goals. Ninety-five percent of these vehicles are cars and LT's. Approximately one-fourth are fleet vehicles, but this varies considerably by fuel type (Table E-2). For example, more than one-half of the CNG vehicles are fleet vehicles, taking advantage of centralized refueling facilities. Only 10 percent of the alcohol vehicles are in fleets, reflecting their close resemblance to conventional-fuel vehicles owned by households. About one-third of the AFV's are dedicated (use an alternative fuel exclusively), while the rest have flexible- or dual-fuel capability (Table E-3). This varies considerably by fuel and vehicle type. Three-quarters of CNG vehicles are assumed to be dedicated, while 96 percent of the alcohol-fuel vehicles are fuel-flexible.

The levels of fuel use described in this scenario will require substantial increases in the production of ethanol, methanol, and LP Gas, and relatively smaller increases in natural gas and electricity output (Table E-4). There are likely to be constraints on battery production, however, and these are reflected in a gradual buildup of electric-hybrid vehicle (EHV) production to nearly 2.5 million vehicles per year in 2010. Methanol production is unlikely to be constrained, given the time available for plant construction and the quantities of undeveloped natural gas available around the world as a feedstock. Ethanol is expected to be produced from both grain (corn) and cellulosic material in 2010. Production from grain at levels above 3 billion gallons would exert strong upward pressure on corn prices. DOE estimates that about 3 billion gallons could be produced from woody biomass by 2010, for a potential total of 6 billion gallons. The 8 billion gallons assumed here stretches these estimates by a bit. Almost 14 billion gallons per year of LP

Table E-2. 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
LP Gas	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**

Gas is assumed to be available to the transportation sector by 2010, taking into account potential supplies, growth in demand by other uses, and some substitution of other fuels for LP Gas in lower value uses. About two-thirds of LP Gas production is currently from natural gas, and this proportion is assumed to hold in 2010. While 0.9 trillion cubic feet of natural gas is required by natural gas vehicles, another 1.1 trillion cubic feet is required to support this scenario, because of the substitution of natural gas for LP Gas in some markets, and additional natural gas needed to produce electricity and ethanol.

Just as there are any number of possible scenarios for future alternative-fuel use, there are any number of paths by which a given scenario can be reached. The purpose of developing a specific path is to demonstrate the feasibility of the scenario in terms of the expansion of capacity and demand, and to provide a means of relating specific policies to the desired end result. The assumed introduction dates of AFV's are consistent with the availability of vehicle technology in the 1995-to-2000 period, as reflected in provisions of the AMFA, the Clean Air Act Amendments of 1990, and California's Low-Emission Vehicles and Clean-Fuel Programs. Initial sales of vehicles are consistent with the volumes required by existing legislation. Expansion of AFV sales is assumed to be gradual, with a slowing of growth in shares in the 2005 to 2010 period. Most projections suggest a very gradual expan-

Table E-3. 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
LP Gas	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**

Table E-4. 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 ethanol; 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**	

sion of vehicle sales through 2010, implying that AFV's must take significant market shares away from conventional vehicles to reach the scenario goals.

Production of flexible-fuel alcohol vehicles begins in 1996 with fleet sales at 150,000. By 2010, flexible-fuel vehicle sales to fleets reach 250,000, while sales to households amount to 2.5 million vehicles. LT flexible-fuel vehicle sales are more modest, starting at 35,000 units in 1996 and reaching 750,000 by 2010. Production of dedicated alcohol-fuel vehicles also begins in 1996, with combined sales of 80,000 to fleets and households. By the year 2000, sales reach 160,000, where they remain through 2010. No alcohol-fuel heavy trucks are sold, but alcohol-powered bus sales grow from 1,000 in 1997 to 5,000 by 2010, mostly for urban applications.

Gaseous-fueled vehicle production commences at a modest level in 1996, with dual-fuel CNG and LP Gas light-truck sales to fleets at 10,000 each. In 2010, gaseous-powered LT sales to fleets amount to 80,000 units, and sales to households, 300,000 units, both evenly split between CNG and LP Gas. Dual-fuel auto sales grow from 100,000 units in 1998 to nearly 750,000 by 2010. Dedicated gaseous-vehicle sales begin in 1998-99 at a level of 160,000 vehicles per year. Bus production begins in 1996 and truck production in 1999. Gaseous-fuel buses replace mostly those previously fueled by gasoline, nearly all of which are school buses. By 2010, 90 percent of gasoline bus sales are replaced by alternative-fuel buses, and nearly one-half of diesel sales have also been displaced.

Electric vehicle sales begin in 1993 with very modest numbers of lead-acid battery powered vans (1,000 units per year). Electric and hybrid vehicles powered by nickel-iron batteries appear just before the year 2005. By the year 2000, total EHV sales exceed 1 million units, most of which are still LT's for fleet use. Passenger car sales steadily increase through 2010, however, and eventually come to dominate the market, with 1.8 million of 2.4 million total sales in that year.

To achieve the target levels of petroleum displacement, AFV's are assumed to capture the majority of light- and heavy-duty vehicle sales by 2010. Alternative-fuel passenger cars capture 20 percent of sales in 2000, 40 percent in 2005, and reach almost 60 percent by 2010. AFV's comprise 40 percent of the LT market in 2010, and dominate heavy truck and bus sales, as well (Figures E-1 and E-2). These sales projections produce a fleet of 49 million alternative-fuel and 133 million conventional-fuel passenger cars in 2010. There are approximately 28 million alcohol cars, almost 3 million CNG cars, and 5 million LP Gas-powered autos. The total LT stock amounts to 67 million units, of which 47 million use conventional fuels, 15 million use gaseous or alcohol fuels, and 4 million are EHV's. The heavy-truck stock consists of 4.9 million conventional-fuel trucks and 1.5 million AFV's. One-third of the 1.5 million buses on the road use alternative fuels. In all, 27 percent of passenger cars, 28 percent of LTs, 23 percent of heavy trucks, and 33 percent of buses are powered by alternative fuels in 2010.

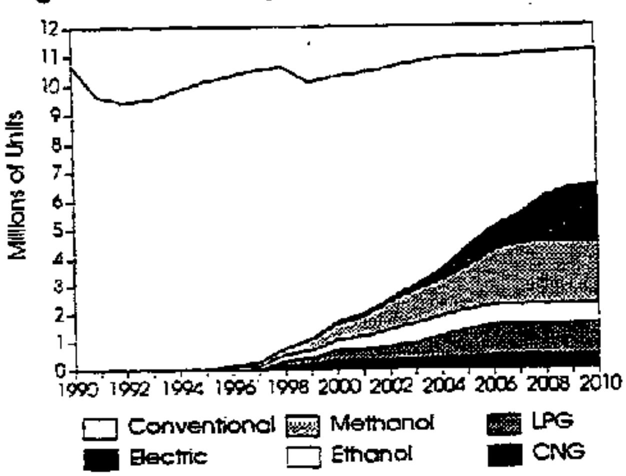
The sales and vehicle stock projections described above result in fuel demands matching the target levels of alternative-fuel use almost exactly. Clearly, the target scenario is technically feasible but requires aggressive market penetration, and, in most cases, market dominance by AFV's by the year 2010.

Potential Impact of Alternative Fuels

The Department of Energy has developed the AFTM as a tool for integrating the various factors influencing the impact of alternative fuels on world energy markets and for quantifying those impacts. This model, developed by Alan Manne (Stanford University) and modified by Paul Leiby (Oak Ridge National Laboratory), represents the world market for fossil fuels by means of an optimization model. The AFTM determines prices and quantities that balance demand and supply in the interrelated world oil and gas markets. Although gas is not today an internationally traded commodity like oil, extensive use of methanol derived from gas and increased trade in liquefied natural gas may make it an international market in the future. A key aspect of the AFTM is its consideration of substitution of gas for oil in transportation and boiler-fuel markets. The AFTM provides a long-run, comparative statics analysis for the year 2010. There are no explicit dynamics governing the response of consumers and producers to changes in energy-market forces over time. The results are best viewed as long-run balances or tendencies—balances that would occur if market conditions were stable long enough for all adjustments to be completed.

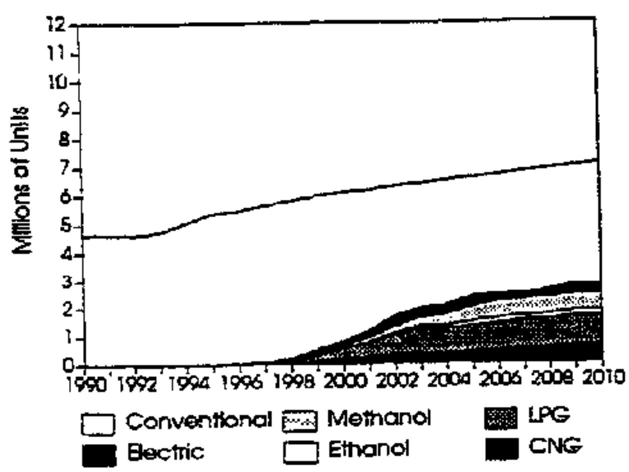
A key feature of the AFTM is its ability to represent regional demand and supply. There are six

Figure E-1. Passenger Car Sales by Fuel Type



Note: Sales are represented by distance between lines.

Figure E-2. Light Truck Sales by Fuel Type



Note: Sales are represented by distance between lines.

main supply-demand regions: the United States. Canada. Japan. Western Europe. the Organization of Petroleum Exporting Countries (OPEC). and the rest of the world. OPEC is further divided into OPEC-Core and OPEC-NonCore, recognizing the key role of certain OPEC members. The supplies of petroleum and natural gas are represented in the model by upward-sloping, price-responsive curves. An important feature of the modified AFTM is the inclusion of country-specific supply curves for natural gas, including estimated costs of supply from undeveloped and remote reserves that might be particularly important sources of gas as a feedstock for methanol production. The model also includes relationships representing the costs of fuel transportation among regions. Also included are processes for converting crude oil or natural gas to industrial and consumer fuels. Final demands for each fuel are represented by downward-sloping, constant-elasticity demand curves. The model also provides equations for long-run fuel substitution in vehicles and boilers, depending on the relative prices of fuels. Fuel switching by flexible-fuel vehicles and substitution of gas for oil industrial boilers provide key linkages between oil and gas markets.

The purpose of the AFTM is to integrate information on oil and gas supplies and demands, accounting for the potentials for fuel switching in various sectors, and to estimate the net impacts of alternative fuels on the world oil market. This impact will strongly depend on assumptions about OPEC behavior. The AFTM is flexible enough to accommodate various models of OPEC behavior, so that the sensitivity of impacts to them can be determined. A major advance over previous world energy modeling efforts is the inclusion of detailed, country-specific natural gas supply curves. These data permit the evaluation of potential sources of natural gas supply by country. It is hoped that this capability will help in evaluating the likely competitiveness of a future world market in natural gas. Thus, the AFTM should be viewed as a tool for investigating and developing insights into how a major substitution of alternative fuels (such as that described in Chapter 3) might affect world energy supply and demand, rather than as a tool for evaluating the desirability of particular policies for promoting alternative-fuel use.

AMFA, Clean Air Act Amendments, and California's Low-Emission Vehicles and Clean-Fuels Programs

The goal of the AMFA is to encourage the development and use of alternative transportation fuels in order to address national energy security and air quality concerns. The Clean Air Act Amendments of 1990 (CAAA), together with alternative-fuels programs of the State of California, may also have significant impacts on these goals. This chapter assesses the implications of the CAAA and the California requirements for the achievement of AMFA's primary goals. It reviews the pertinent provisions of the initiatives, discusses the alternative technologies available for meeting their goals, and discusses the levels of alternative-fuel use that might be expected as a result of them.

The CAAA contain provisions requiring the use of reformulated and oxygenated gasoline, a clean-fuel-fleet program, the California Pilot Program, a low-polluting fuel requirement for urban buses, and Phase II emission standards for conventional vehicles. In the 41 carbon monoxide nonattainment areas, use of fuels containing 2.7 percent oxygen is required for a minimum of the four coldest months. In addition, all gasoline sold throughout the year in the nine worst ozone nonattainment areas must contain at least 2.0 percent oxygen. Since petroleum fuels are hydrocarbons and contain essentially no oxygen, alternative liquid fuels containing oxygen must be added. The most likely sources are alcohols or alcohol-derived ethers. These oxygen requirements alone will result in oil displacement on the order of 200,000 barrels per day by 2010. The CAAA also require that in 21 nonattainment areas, vehicles in fleets of 10 or more that are capable of being centrally refueled must be "clean fuel" vehicles. Vehicles capable of meeting the standards for clean-fuel vehicles using reformulated gasoline are permitted. Because it appears likely that conventional vehicles will be able to meet these standards using a combination of more stringent controls and reformulated gasoline, it is not clear what the impact of this provision will be. The low-polluting fuel requirement for urban buses requires that, beginning in 1994, all new urban buses meet a stringent new standard for particulate emissions. If this standard cannot be met using conventional fuels, buses will be required to operate exclusively on methanol, CNG, ethanol, LP Gas, or other low-polluting fuel. Finally, Phase II CAAA standards for conventional vehicles are sufficiently strict that it may not be possible to cost effectively meet them using conventional fuels. If Phase II standards are implemented, AFV's may become necessary.

The State of California adopted a low-emission vehicle and clean-fuels program that could have a substantial impact on alternative-fuel use. It is possible that conventional-fuel vehicles using reformulated gasoline, heated catalysts, and heated fuel-preparation systems could meet all but the most stringent requirements of the program. Alternatively, the vehicle manufacturers may sell AFV's. Manufacturers must sell 2 percent zero-emission vehicles (ZEV's) beginning in 1998 and 10 percent by 2001. The only known ZEV's are battery-powered electric vehicles. Based on the required ZEV sales volumes, we estimate the oil displacement potential of this program at nearly 50,000 barrels per day by 2010.

Based on a review of available emissions control technologies and of the potential to formulate low-emission gasoline and diesel fuels, it appears that the various CAAA and California program requirements generally can be met by conventional-fuel-vehicle technologies. What is not clear is whether these technologies will be more or less economical than AFV's. Thus, except for California's ZEV requirement, none of these programs *require* AFV's.

Research Needs for Alternative-Fuel Vehicles

Conventional-fuel vehicles have the benefit of a century of refinements in technology and production methods. It should not be surprising, therefore, that each AFV technology has one or more shortcomings relative to conventional gasoline- or diesel-powered vehicles. As a result, there continues to be a need for AFV research and development.

One of the more challenging technical issues facing AFV's is the inherent technical difficulty in the use of fuels in a gaseous, rather than in a liquid state. To a large extent, this stems from the underdeveloped state of gaseous-fuel vehicle technology. For example, much of the emissions technology developed over the last two decades is designed for use with liquid petroleum systems operating under stoichiometric conditions. Until recently, relatively little attention has been paid to systems that would operate under lean-burn conditions with excess oxygen and little unburned hydrocarbon in the exhaust stream. Natural gas and alcohol fuels are particularly well suited for lean-burn operation and, thus, have not had the benefit of major research on appropriate emission control technologies. The inherently lower energy density of gaseous fuels is also a major challenge for the design of vehicles and fuel-storage systems. Finally, nearly all vehicles currently operating on gaseous fuels are of the dual-fuel variety. Major compromises in design have been made to accommodate the two fuels with very different properties. In general, performance on the gaseous fuel in a dual-fuel vehicle is far worse than could be achieved in a vehicle optimized for gaseous fuel alone. This is also true of dedicated fuel-alcohol vehicles. Adapting engine and vehicle designs to make optimal use of the properties of alternative fuels is an important area requiring further research. Key research needs for AFV's can be grouped in six categories:

- Research on *basic engine and combustion phenomena* is needed for all fuel types, but especially alternative fuels where the knowledge base is relatively small. Such research can help improve thermodynamic efficiency and reduce emissions.
- *Gaseous-fuel storage* requires substantial improvement to be comparable to conventional-fuel systems. Present techniques, even if optimized, fall far short of conventional-fuel systems in terms of energy quantity, energy density, and cost. A technological breakthrough is needed.
- *Alternative additives for alcohol fuels* might be found that maintain their full environmental and oil displacement benefits.

- Additional research on *emissions and environmental quality* is needed to identify the specific roles of specific emissions (especially hydrocarbon species) in the formation of ambient pollutants. This knowledge can help to focus attention on developing control technologies and fuels that most effectively reduce the formation of harmful pollutants.

- Reducing the uncertainty surrounding the issues of *global climate change* would help to determine the relative desirability of various fuel alternatives. In particular, it would help decide the relative importance of R&D on hydrogen and photovoltaically produced electricity as vehicle fuels.

- Finally, there is a need to expand the number of scientists and engineers trained to conduct research on alternative fuels through support of *educational programs in alternative fuels.* Such support is not expensive, but in view of the technical challenges facing alternative fuels, can have an enormous payoff.