Chapter 1
Introduction

Substituting alternative fuels for gasoline in highway vehicles is being promoted by the U.S. Environmental Protection Agency, the California Energy Commission, and others as a way to combat urban air pollution as well as a means of slowing the growth of oil imports to the United States and—for some of the longer term alternatives---of delaying global climate change. The primary suggested alternative fuels include the alcohols ethanol and methanol, either 'neat' (alone) or as blends with gasoline; compressed or liquefied natural gas (CNG or LNG); liquefied petroleum gas (LPG), which is largely propane; hydrogen; and electricity. Each of the suggested liquid and gaseous fuels has one or more features-high octane, wide flammability limits, and so forth-that imply some important advantage over gasoline in powering highway vehicles. Electric vehicles (EVs) may be particularly attractive to urban areas because they operate virtually without air emissions. (However, the emissions from the powerplants providing the electricity are an important concern, even though these plants may be separated geographically from the area of vehicular use.) Similarly, hydrogen-fueled vehicles would emit only NO_x in significant quantities, and even the NO_x emissions could be eliminated if the hydrogen was used in a fuel-cell-powered EV.[1]

Not surprisingly, each of the suggested fuels has disadvantageous as well as advantageous features. Methanol is more toxic than gasoline, for example, and natural gas engines may have difficulty in achieving hoped-for large reductions in vehicular nitrogen oxides emissions; ethanol production may require crop expansion onto vulnerable, erosive lands; and so forth. Decisions about promoting the introduction of alternative fuels should carefully consider the full range of effects likely to accompany such an action.

Some experience has already been gained with each of the fuels. Hundreds of thousands of CNG-fueled vehicles operate worldwide, particularly in Italy, Australia, and New Zealand; about 30,000 CNG vehicles operate in the United States. Over 300,000 vehicles in the United States, primarily in fleets, are fueled by LPG. Nearly a billion gallons/year of ethanol are used in the U.S. fleet today in ''gasohol, ' a 10 percent blend with gasoline. Methanol serves as the feedstock for methyl tertiary butyl ether (MTBE), a widely used octane-enhancing agent for gasoline. Currently, about 25 percent of the United States' total annual methanol use of 1.7 billion gallons is devoted to MTBE manufacture, and about a billion gallons/year of ethanol are blended with gasoline. Brazil (and related auto manufacturers, including the U.S. "Big Three") has extensive experience with ethanol-fueled vehicles. And experience has been and continues to be gained with several small fleets of methanol-powered vehicles built for test purposes. Commercial (as well as experimental) electricity-driven light-duty vehicles exist today, both in the United States and overseas, and experimental hydrogen-fueled vehicles have been developed in Germany and Japan. Table 1-1 displays the volumes of alternative fuels used in several countries.

Other than fuel cost, the major barrier that most alternative fuels must overcome is the need to compete with the highly developed technology and massive infrastructure' that exists to support the production, distribution, and use of gasoline as the primary fleet fuel. Any new fuel must compete with the ready availability of gasoline throughout the country, the massive amounts of capital and engineering time that have been invested in continuing engine modifications to optimize performance for gasoline, and consumers' lifetime acceptance of gasoline. This competition will be an especially formidable problem if the fuel requires a totally new production and/or distribution network or if it significantly reduces vehicle performance and/or range.

In particular, the introduction of vehicles using alternative fuels creates a difficult transition problem because fuel availability is likely to be limited geographically during the first years following introduction of the fuel. This problem will likely be

[1]The magnitude of air emissions and other environmental impacts of *producing* the hydrogen depend on the technology used. At one limit, coal gasification would generate relatively large impacts; at the other, electrolytic production from water using solar energy as a power source would generate relatively low impacts aside from land coverage.

Table I-I—Major Users of Alternative Fuels (thousands of barrels/day of gasoline equivalent-estimated)

Country	Total	LPG	Ethanol	CNG	Synthetic gasoline	Methanol	Electricity
Brazil	110	—	110	—	—	—	—
Japan	79	79	—	—	—	—	—
United States	62	18	34	1	—	9	—
Italy	57	42	—	15	—	—	—
New Zealand	45	3	—	9	33	—	—
Holland	27	27	—	—	—	—	—
Europe	18	9	—	—	—	9	—
Canada	8	7	—	1	—	—	—
U. K.	2	—	—	—	—	—	2
Australia	2	2	—	—	—	—	—
All others	37	15	8	14	—	—	—
Total	447	202	152	40	33	18	2

World gasoline -15,700 thousand bbl/day (for comparison)
U.S. gasoline -6,800 thousand bbl/day (for comparison)
Ethanol and Methanol estimates are based on fuel production data. All others are based on the simplified assumption that vehicles use the equivalent of 800 gallons of gasoline per year.

SOURCE: U.S. Department of Energy, *Assessment of Costs & Benefits of Flexible and Alternative Fuel Use in the US Transportation Sector Progress Report Two:* The International *Experience,* DOWPE-0085, August 1988.

aggravated by the limited range of alternative fuel vehicles, caused by the low volumetric energy density (compared to gasoline) of the alternative fuels (or of the batteries in EVs). To counter this problem, some plans for the introduction of alternative fuels call for vehicles capable of using both gasoline and alternative fuels either one-at-a-time ("dual-fueled vehicles") or mixed together in varying proportions (flexible-fueled vehicles, or FFVs); for EVs, the equivalent is a so-called hybrid vehicle combining electric motors with small internal combustion engines or fuel cells to allow extended range. Unfortunately, the multifuel vehicles generally will be more costly than dedicated vehicles and inferior to them in fuel efficiency, emission characteristics, and performance,[2] reducing the benefits for which the alternative fuels are being vigorously promoted. Other measures for coping with range problems include a strong emphasis on vehicle fuel efficiency;[3] introduction of higher pressure storage tanks and cryogenic or hydride storage for gaseous fuels; and accepting the weight and space penalties associated with larger storage tanks.

The barriers to introduction and acceptance are not identical for the different, competing alternative fuels. For ethanol and methanol, the major barriers are potentially high fuel costs and the lack of pipelines, filling stations, and other pieces of a supply infrastructure; some nagging problems with vehicle performance need to be solved, but these seem likely to be of lesser importance than the cost and infrastructure problems. In contrast, aside from the need to establish large numbers of home charging stations, fuel cost and the fuel supply infrastructure do not appear to represent major barriers to electric vehicles; instead, the primary barriers are the high first costs, short battery life (of current batteries) and inferior range, performance, and refueling capabilities of EVs compared to existing gasoline-powered vehicles (though hybrid vehicles combining electric and gasoline propulsion and energy storage systems can overcome the range and performance barriers, at additional cost).

For vehicles powered by compressed natural gas, range is an important barrier, as is the lack of a retail sales infrastructure; on the other hand, long-range distribution, a problem for ethanol and methanol, is not a problem for gas because gas services currently can reach 90 percent of the U.S. population through its extensive pipeline network.[4] (Given the extensive

[2] In particular, the need to operate on gasoline compromises the ability to redesign engines to take advantage of the favorable properties of the alternative fuels.

[3] For example, General Motors' prototype "Impact" electric vehicle has an unusually low aerodynamic drag coefficient of 0.19 and high pressure tires that cut rolling resistance in half. SOURCE: General Motors Technical Center, "Impact Technical HighLights, press release of Jan. 3,1990, Warren, Mr.

[4] U.S. Department of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the US. Transportation Sector, Technical Report Five, Vehicle and Fuel Distribution Requirements,* January 1990, Draft.

Photo cmo'it: Ford Motor Co.

This Ford Flexible Fuel vehicle, an adaptation from a regular production Taurus, will operate on methanol, ethanol, gasoline, or any combination of those fuels. Similar prototypes or limited production vehicles have been introduced by a number of other vehicle manufacturers.

use of gas in residential applications, use of home compressors might help overcome the retail infrastructure barrier-though at considerable cost.) In addition, CNG/gasoline dual-fueled vehicles are expensive and of somewhat lower power than competing gasoline vehicles, which may make the transition to dedicated vehicles somewhat harder than for some competing fuels. For hydrogen-powered vehicles, the comparative lack of technology development, high fuel costs, lack of a supply infrastructure, and high vehicle cost, low range, and high fuel storage space requirements are major barriers. For natural gas, use of liquefied rather than compressed gas would help to overcome range problems, although at the loss of the option for home refueling and with losses in thermal efficiency during liquefaction.

Introducing alternative fuels will likely require large capital investments, government interference in markets, increased consumer expenditures on transportation, and, for most fuels, some decrease in consumer satisfaction. Undertaking such an introduction is justified only if the rewards, in terms of reduced pollution or increased energy security, are valued very highly and if other, less expensive measures are not available to achieve the same ends. Given the substantial differences in the importance that various policymakers attach to the potential benefits, and differences in their willingness to impose monetary and convenience costs, there would be substantial disagreement about the urgency of introducing alternative fuels, the appropriate policy measures to accomplish this introduction, and the appropriate ranking of fuels *even if the many uncertainties about fuel costs, pollution effects, and other characteristics were resolved.*

This report makes it clear that there are substantial uncertainties and remaining concerns about all aspects of the fuels; that costs will be high, especially during the transition from gasoline to the alternatives; and, for most of the fuels, that consumers would have to make substantial adjustments to allow successful entry of the fuels into the marketplace. The report also makes clear that alternative fuels can provide substantial levels of transportation service at costs to consumers that are similar to or lower than costs already being paid in Europe,[5] that some of the fuels have *long-term* potential to drastically reduce greenhouse gas emissions, and that there are ample supplies of natural gas and other nonrenewable feedstocks to provide at least several additional decades of fuel supply as a bridge to renewable sources of transportation fuel.

Existing analyses of the costs and benefits of the alternative fuels are based on a variety of evidence. As noted above, many of the fuels have been used in vehicles for years, and much of this experience is relevant to projections of future, wider use. Also, aside from their vehicular use, most of the fuels have been in commerce for decades, and the experience with producing and handling the fuels will also aid the projections. Finally, unlike gasoline, which is a complex *and nonuniform* blend of hydrocarbons, most of the suggested alternative fuels have simple chemical structures and are relatively uniform in quality-which should improve the accuracy of extrapolations of their performance in vehicles.

Nevertheless, evaluation of the costs and benefits of the various alternative fuels relative to gasoline and to each other is an exercise handicapped by four primary areas of uncertainty. First, *the technology for producing and using alternative fuels is still developing and changing.* Ongoing research programs are attempting to overcome or ameliorate the technical problems listed above and reduce the overall system costs for the competing alternative fuels. The *short-term* problems associating with bringing the *first generation* of alternative fuel vehicles to market are, for most of the fuels, relatively minor, and solving the remaining problems for these vehicles introduces only moderate uncertainty into projections of cost, performance, and system characteristics. For the longer term, though, bringing to market advanced technology, optimized vehicles, perhaps dedicated to a single fuel (and perhaps with a neat fuel rather than a blend), with a fuel supply obtained from large-scale, advanced-technology production plants, involves major uncertainties. The outcome of development programs for these technologies is essentially unpredictable, but the fact that most of the fuels are in an early stage of development for transportation use[6] makes it likely that at least some of the characteristics of future technologies available for supply and vehicle systems—and conclusions about their relative costs and benefits-will be considerably different from the characteristics of the technologies available today. For example, ethanol currently is one of the most expensive of the alternative highway fuels, and the fact that its primary source of feedstock materials in the United States is corn (it is sugar cane in Brazil) creates some potential problems for any attempt to greatly increase ethanol production. Ongoing research on manufacturing ethanol cheaply from wood conceivably could drastically improve ethanol's attractiveness as a transportation fuel, by lowering costs and by reducing or eliminating the potential for competition between society's food and fuel requirements. Similar "technological breakthrough" potential exists for the other fuels. Analysts and policymakers should be wary, however, of confident predictions that the potential benefits of such breakthroughs will actually occur-there are few guarantees in the research and development process.

Second, *uncertainty is introduced by the vagaries of the transition from successful research project to real world system. The* process of moving from promising laboratory experiments and technology prototypes to establishment of large vehicle fleets and an elaborate supply infrastructure involves

[5] Although today's fuel-cost differential between the United States and Europe is in the form of taxes, which benefits government services, as opposed to differential costs in raw materials, processing, and the other factors of production.

[6] Natural gas is an exception, since hundreds of thousands of vehicles are in use worldwide. These vehicles are retrofit from gasoline vehicles, however, and do not attain the performance likely to be required to break out of niche markets in the United States. Similarly, ethanol is widely used in Brazil, but the Brazilian experience is not encouraging for U.S. ethanol use.

massive scaleups, design trade-offs (and, often, acceptance of lower performance in exchange for cost reductions or improved marketability) to allow for mass production and practical vehicle maintenance, improvements in design as information is gained, and other factors that diminish the value of preliminary estimates of costs and performance. At the current time, without much actual experience to temper judgments, analysts with optimistic views see primarily the numerous potential opportunities for reducing emissions, increasing efficiency and power, and lowering costs associated with the alternative fuels; and analysts with pessimistic views instead see primarily the numerous problems—higher emissions of aldehydes with alcohol fuels, materials problems, and so forth-associated with the same fuels. Although the growing experience with small fleets of alternative fuel vehicles-for example, the highway fleet of several hundred methanol-fueled vehicles—will settle some of the ongoing controversies, others may remain until mass production places many thousands of such vehicles on the road and several years of driving experience are amassed.

Third, *it is difficult to predict in advance what the scale of alternative fuels development will be* (though the scale of development will, of course, depend strongly on government policy), *and whether such development in the United States would stimulate similar development in other countries . . . yet the scale of development of the fuels will affect the costs and characteristics of their supply systems.* For example, a moderate-sized shift to natural gas vehicles[7] could readily be supplied by domestic gas sources or pipeline imports from North America, but larger scale development would require LNG imports from overseas, at different costs and implications for national security. Similarly, vehicular methanol development, especially if it were confined to the United States, might first be accommodated by methanol produced from gas found in remote areas, which may be cheap and, by providing some additional diversity to transportation fuel supply sources, could be beneficial to national security concerns about OPEC dominance of the liquid fuels market. A large worldwide shift to methanol might, however, have distinctly different costs and security implications, because the geographical preponderance of world gas reserves and resources in the Middle East and Eastern Bloc nations could become important in such a scenario. The security implications of a major Eastern Bloc role in methanol production—and, indeed, the overall significance of energy security concerns—may, of course, need to be rethought in light of recent political developments in that part of the world.

The scale of a U.S. Government-backed alternative fuels program will depend on whether the program is principally an air quality control measure aimed at the few nonattainment areas that cannot satisfy ozone standards by conventional means, or instead is an energy security measure, which would demand a much larger market share for the fuels. The Federal Government might also envision the program as two-phased, with the first phase a smaller program aimed principally at air quality and designed as well to work out ‘‘bugs’ in the system, with a follow-on phase designed more for energy security and aimed at spreading fuel use throughout the country.

Fourth, *the gasoline-based system that alternative fuels will be judged against is a moving and movable target. The* prospects for conversion to alternative fuels are putting enormous pressure on the petroleum industry to devise *petroleum-based* solutions to the problems alternative fuels are designed to address. Although revisions to gasoline composition and modifications to gasoline-fueled vehicles are unlikely to address the problem of growing oil imports, it is air pollution more than oil import growth that is driving the current push towards alternative fuels--and further changes to fuels and vehicles *can* reduce air pollution. ARCO’s August 1989 announcement of a reformulated, pollution-reducing gasoline as an alternative to leaded gasoline in the California market[8] is likely only the opening salvo in an industry effort to defuse current interest in alternative fuels. Furthermore, State and Federal recognition of the potential for improving air quality by changing gasoline composition—stimulated by the ARCO announcement-is likely to lead to increased *regulatory* pressures towards reformulation. Similarly, Federal and some State governments are likely to exert continuing pressure

[7]The U.S. light-duty highway fleet consumed nearly 7 million barrels per day (mmbd) of gasoline in 1989 (U.S. Energy Information Administration data). If 5 percent of this demand were shifted to natural gas, this would add about 0.7 trillion cubic feet per year to U.S. gas consumption.

[8]M.L. Wald, ‘‘ARCO Offers New Gasoline to Cut Up to 15% of Old Cars’ Pollution,’’ New *York* Times, Aug. 16, 1989.

on vehicle manufacturers to improve gasoline-based emissions control systems.

The remaining questions about performance and costs of the alternative fuels create a policy dilemma for Congress. First and foremost, Congress must decide whether or not to support alternative fuels in the face of substantial uncertainty and controversy. Although alternative fuels are likely to have some important advantages over gasoline, these advantages are not easily quantified and must be balanced against significant but similarly uncertain costs (as well as some disadvantages).

Second, if Congress does wish to promote alternative fuels, it must choose between selecting one or two fuels and providing specific incentives for these, or providing more general market and/or regulatory incentives that do not favor one fuel but rather focus on air quality or other goals. Selecting one or two fuels-or selecting particular fuels for different market niches—may provide higher market certainty and larger scale, both of which are important cost determinants.[9] On the other hand, early selection of "winners" increases technological risk and opens up the very real possibility that the "best" fuel will not be selected. Providing a more general incentive reduces some of these risks, but may force higher costs because market uncertainty will lead to higher required capital return rates and higher markups, and smaller volumes of each fuel will tend to lower the economies of scale otherwise available.

A critical corollary to this decision is the need to consider whether to incorporate longer term goals into any alternative fuel program designed initially to meet short-term problems. In making decisions about alternative fuels, Congress must recognize that it maybe launching this Nation down a path that will have long-term consequences for the U.S. energy system—including, by building a new and expensive infrastructure, the enhancement or discouragement of the future adoption of certain energy technologies or fuels not currently economic or practical. Those concerned about global warming are concerned, in particular, about the likelihood that a turn to fuels such as methanol might lead inexorably to a dependence on coal as a feedstock—with potentially strong negative consequences for attempts to reduce emissions of CO_2 and other greenhouse gases (since gasoline can itself be made from coal, a *no change* strategy may have the same consequences). Others believe that even methanol produced only from natural gas is harmful to greenhouse control strategies because its use—by reducing stress on oil markets, keeping oil prices lower, and reducing strategic concerns—will reduce pressures on the industrial nations to move away from fossil fuels. And some scientists believe that a turn to natural gas could have the effect of paving the way for hydrogen produced from renewable sources. Because the short-term options for alternative fuels—methanol, ethanol, and natural gas—are unlikely to have a strong effect on greenhouse emissions, there may be a temptation for policymakers to ignore greenhouse problems in dealing with these fuels.

Third, Congress must choose a timetable for a program that finds an appropriate balance between testing and experimentation, and moving forward with mass production of vehicles and fuels. In deciding to act now or wait, Congress must judge whether the new information likely from a test program will add sufficiently to the selection process to offset the benefits lost by waiting.

In this report, OTA reviews the major factors affecting the commercial and societal acceptability of methanol, ethanol, CNG and LNG, electricity, and hydrogen,[10] as compared to gasoline and to each other (see box 1-A for a brief discussion of a key problem involved in making the alternative fuels/gasoline comparison). In many of the discussions, especially in those involving energy security, we focus on the issues and effects of alternative fuel programs of a large-scale, nationwide nature. Programs restricted to helping solve the air quality problems of a limited group of ozone nonattainment areas would create much lesser impacts and have different costs. Where feasible, we try to separate the effects of the two program scales. We identify key

[9] Higher market certainty reduces the capital return rates demanded by developers, and larger scale allows scale economies to be realized. On the other hand, artificially stimulating higher demand for a single fuel can raise some costs by forcing reliance on more expensive sources of feedstock material, or by eliminating some incentives for cost reduction that would come with competition from other fuels.

[10] Propane and LPG were not addressed in this study. Use of these fuels should have air quality benefits similar to those obtainable with natural gas; in particular, effective hydrocarbon emissions (taking into account both changes in mass rates and changes in the reactivity of the emissions) should be cut substantially, providing ozone reductions in areas where hydrocarbon emissions area controlling factor in ozone concentrations. Enough supply of these fuels should be available for gasoline replacement in a few million vehicles, sufficient for an air-quality-based strategy aimed at critical ozone non-attainment areas.

Box I-A-Comparing Vehicles Fueled With Gasoline and Alternative Fuels

A source of confusion in examining the results of various studies of alternative fuels is a divergence in the nature of the gasoline/alternative fuels comparisons that are made. In particular, different studies may choose different baseline vehicles from which to compare vehicles fueled with alternative fuels.

It has been our experience that many studies choose a kind of "average" gasoline vehicle from which to compare vehicles powered by alternative fuels. This vehicle will have range, performance, and efficiency characteristics that are representative of the automobile fleet as a whole, or the new car fleet, during the time period in question-for example, 350 mile range, 2,500 to 3,000 pound curb weight, 30 to 35 mpg fuel economy, O to 60 mph time of 11 seconds, and so forth. Generally, these studies demand that the alternatively fueled vehicles satisfy minimum performance requirements, e.g. 200 mile range, though these requirements may be inferior to the baseline characteristics.

Using a baseline vehicle of this sort is the same as asking the question, "Is it possible to market an alternatively fueled vehicle that can compete economically (or in another critical characteristic) with a gasoline-fueled vehicle, even if it may be inferior in one or more other characteristics?" From a policy standpoint, framing the question this way implicitly assumes that the policymakers will be ready to force the market entry of alternative fuel vehicles as long as they are an effective way of achieving a policy goal (e.g., improving air quality), don't cost too much, and don't perform insufferably badly.

A manufacturing organization that is not counting on a government-mandated market will compare gasoline and alternative fuels differently. They will either demand that the alternative fuel vehicle perform up to the standards of the gasoline vehicle--e.g., by using very large fuel tanks to increase range--or they will select a baseline gasoline vehicle that matches some of the performance inferiority of the alternative fuel vehicle, trading off this loss by lowering costs and/or improving fuel economy. For example, the organization may consider that, if there is a market (e.g., as a commuter car) for an electric vehicle with limited cargo space, range, and performance, there may also be a market for a competing gasoline vehicle with similar characteristics but with the low cost and extremely high fuel economy made possible by accepting these characteristics. If such a vehicle could undercut the market for EVs, then it maybe too risky to build an EV even if the EV could compete *economically with an* "average" car.

Selecting different baselines will drastically alter the results of a "side-by-side comparison" of gasoline and alternative fuel vehicles. Properly interpreting the results of such comparisons demands an understandingof what baselines were chosen, and thus, what policy question is being addressed.

SOURCE: Office of Technology Assessment, 1990.

uncertainties and place the fuels in a time context, that is, identify how long they might take to become practical alternatives to gasoline. We also discuss the option of reformulating gasoline to reduce emissions, because reformulation is a likely strategy to be adopted by the oil industry to hold market share in the transportation fuels supply market.

Because available studies of the costs and benefits of the alternative fuels often have widely diverging results and conclusions, we have attempted to present and explain the source of the more important of these differences. In several instances, we could not resolve conflicting conclusions or even narrow significantly the range of appropriate views, partly because further testing and development is required, and partly because we could not evaluate each issue to the extent necessary to accomplish this. And because methanol has attracted the most policy interest, we discuss it in more detail than the other fuels. The discussions are not strictly parallel in structure because the issues affecting the acceptability of the fuels are different for each fuel, and because the states of knowledge for each fuel are not identical.

A **final note:** Although this report focuses on alternative fuel use in light-duty vehicles, readers should be aware that these fuels are suitable for heavy-duty vehicles, and in some cases their benefits are greater and liabilities less in these applications. In particular, heavy-duty vehicles have fewer space constraints than light-duty vehicles, and generally can accommodate more fuel storage, reducing the range constraint of alternative fuels. Also, many heavy-duty vehicle fleets, particularly bus fleets, are centrally fueled and maintained, greatly reducing infrastructure constraints. Finally, heavy-duty vehicles often use diesel engines that create difficult pollution problems in urban areas. These engines can be adapted to run on methanol, ethanol, or natural gas instead of diesel, with a corresponding improvement in emissions of particulate and other harmful pollutants.