A1F06: Committee on Alternative Transportation Fuels
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Alternative Fuels for U.S. Transportation

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As we enter the new millennium, the U.S. transportation sector is highly dependent on oil. Currently, oil accounts for 97 percent of fuel use in the sector (*1*). While oil has been cheap and plentiful for the past decade, significant security, economic, and environmental concerns are associated with the sector's reliance on petroleum resources (*2–4*). Because conventional oil reserves and oil production are concentrated in the Middle East, there are also concerns about access to crude reserves due to either military or cartel action taken by producers (*5,6*). Past actions of the Organization of Petroleum Exporting Countries have cost the United States an estimated $4 trillion, and oil imports represent a significant portion of the U.S. balance of trade deficit. Oil use raises major environmental concerns regarding local pollution effects and the global climate change potential of carbon dioxide emissions.

Two options for reducing the petroleum dependence problem of the transportation sector exist, other than reducing travel demand: efficiency improvements and use of alternative fuels. Alternative fuels can be considered in two categories: nonpetroleum fossil energy resources and nonfossil energy resources and fuels.

For many, the sustainability of future transportation fuels is a major concern. Whereas many definitions have been applied to the term "sustainability" (*7,8*), in this context sustainable fuels are defined as having two attributes: (*a*) they are long lasting (e.g., resource availability is indefinite), and (*b*) they have low carbon content.

The focus of this paper is on alternative fuels, primarily for highway transportation, not on efficiency of vehicles. It is assumed that battery-electric, fuel cell, and grid-connected hybrid vehicles that will be commercially available in the future will consume some alternative fuels. Limited consideration is given to air transportation.

CRITERIA FOR FUELS THAT DISPLACE PETROLEUM IN THE TRANSPORTATION SECTOR

Any fuel that displaces petroleum in the transportation sector will have to perform well relative to numerous criteria, such as sustainability, contribution to greenhouse gas (GHG) emissions on a life-cycle basis, contribution to emissions of criteria pollutants, toxicity, effect on land use and damage, cost competitiveness, and infrastructure requirements.

A sustainable fuel is long lasting. Richardson developed one definition of sustainability that was discussed during the 1999 Annual Meeting of the Transportation Research Board (*9*). The definition includes the notions that a sustainable transportation system will be in widespread use indefinitely and that the fuel consumption, vehicle emissions, safety, congestion, and social and economic access characteristics do not result in great or irreparable harm to future generations. In the overview given here, a simpler definition is posed: (*a*) the supply of the resource from which a transportation fuel is produced is adequate to last well in excess of a century and (*b*) the fuel has low carbon content. These two attributes are seen as essential to justify the transition from the well-established supply and end use infrastructure surrounding petroleum-based fuels.

The climate change effects of carbon from fossil fuels are seen as a potentially serious environmental problem. To meet the goals of the Kyoto agreement, the United States must reduce GHG emissions to a level 7 percent below 1990 emissions in 2008. Carbon dioxide (CO_2) is the predominant contributor to the increased concentration of GHGs. Combustion of fossil fuels accounts for two-thirds of global anthropogenic CO_2 emissions, with the balance attributed to land use change. Although it makes up only about 5 percent of global population, the United States was responsible for 22 percent of global anthropogenic CO_2 emissions in 1995. Nearly one-third of U.S. emissions are attributable to transportation, including motor vehicles, trains, ships, and aircraft (*10*).

A number of studies have analyzed the cost of meeting the goals of the Kyoto agreement (*11,12*). Many of the studies have assigned a disproportionate share of the responsibility for GHG emission reductions to the electric power utility sector. Such assumptions result in a commensurate underestimate of the reductions necessary from the transportation sector. For example, an Energy Information Administration (EIA) study estimated that, although the United States will need to reduce GHG emissions by 31 percent in 2010, the transportation sector would be required to reduce emissions by only 16 percent (*6*).

Moreover, alternative fuels play virtually no part in reducing GHG emissions in the EIA study. For the transportation sector to "pull its weight," it is increasingly likely that alternative transportation fuels will need to be part of the strategy. Recently, a number of analyses have been published on the life-cycle GHG effects of different fuels (*13*; personal communication, M. Wang, 1998).

Figure 1 provides a comparison of the life-cycle GHG effects of a number of alternative fuels and advanced vehicle technologies. The savings indicated include both end use and fuel production emissions.

In the past 30 years, the United States has made major efforts to limit criteria pollutant emissions from the transportation sector (*1,14*). Although great gains have been made in reducing emissions on a per mile basis, increasing travel due to population growth and rising income threatens the benefits achieved in the past 20 years (*15,16*). As a result, federal and California regulatory authorities plan to impose increasingly stringent emissions standards. It was once thought that only alternative fuel vehicles would be able to meet such stringent standards, but technological advances have made it possible for vehicles burning conventional fuels to meet some of these standards, dimming the prospects for widespread, commercial alternative fuels use for environmental purposes.

Besides criteria pollutants, alternative fuels will be evaluated on their toxicity. The U.S. Environmental Protection Agency defines toxic air pollutants as "those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or to cause adverse environmental effects" (*17*). The 1990 Clean Air Act Amendments list 188 toxic air pollutants; four of these compounds are constituents of gasoline: butadiene, formaldehyde, acetaldehyde, and polynuclear aromatics.

Land use is a concern for many of the renewable fuels (e.g., ethanol from biomass resources such as switch grass, and electricity from wind and photovoltaics). For example, the current level of corn ethanol production of approximately 800 million gallons requires about 1.2 millions acres (personal communication, T. Nguyen, 1998). However, some ethanol can be produced from resources with minimal land use effects, including municipal waste, agricultural waste, and forest waste.

To be successful, alternative fuels will require the key characteristics of cost-competitiveness and infrastructure availability (*18*). No matter how attractive the end use benefits, consumers will not buy an alternative fuel in large quantities if it costs more than gasoline. Even if it is cost-competitive with gasoline, consumers must be able to easily refuel their vehicles (*19*,*20*).

Costs and benefits associated with converting to various sustainable alternative fuels are summarized in Table 1. The network of existing service stations must be converted to allow the on-site storage and delivery of any alternative fuels. The table values are based on the assumption that each existing gasoline service station dispenses approximately 150,000 gallons per month. Converting the station to allow it to accommodate a new fuel in addition to gasoline decreases the gasoline capacity to 100,000 gallons per month with the new fuel distribution capacity accounting for 50,000 gallons on a gasoline equivalent-energy basis. New or modified equipment and components required for the conversion include underground storage tanks, fueling stations, dispensing pumps, and hoses.

As with any product, a gradual increase of market share is expected for the new fuels. This phasing in of alternative fuels would spread the capital costs of production, storage, distribution, and delivery over time. Table 1 shows the estimated annual capital cost for the studied fuels in 2030 using a “high market penetration scenario” addressed by Wang et al. (*18*). This scenario assumes favorable conditions for every factor that was determined to influence consumer acceptance of vehicles with a fuel economy three times that of conventional vehicles. Wang et al. (*18*) evaluated another scenario in which some factors were assumed to be less favorable, resulting in lower market penetration.

The unit costs indicated in Table 1 were calculated to reflect possible market prices after assigning to each fuel those costs associated with its raw material, production, distribution, service station conversion as described above, and taxes. This analysis assigned a fuel cost to hydrogen that is more than twice as high as any of the alternatives indicated. However, Thomas et al. (*21*) have proposed an alternative means of producing hydrogen for highway vehicles that involves on-site reforming of natural gas at refueling stations. They project a retail cost for hydrogen (including federal and average state taxes) of $0.77 per gasoline equivalent gallon.

Substitution of these alternative fuels for gasoline often has favorable effects on criteria pollutant and carbon dioxide emissions and is forecast to maintain and in most cases decrease the atmospheric levels of GHG, CO, SO_X, NO_X, volatile organic compounds (VOCs), and PM_{10}. However, Fischer-Tropsch diesel is an exception since its use has been estimated to increase emissions of PM_{10}. Table 1 shows the predicted reductions in GHG emissions in 2030. Ethanol, methanol, and compressed natural gas (CNG) use has practically no effect on VOC, CO, and NO_X emissions, whereas hydrogen use produces the greatest decrease in these pollutants.

ALTERNATIVES TO CONSIDER

As we enter the next millennium, world demand for oil is projected to grow substantially. For transportation, there are a number of alternative fuels to consider as replacements to conventional oil. These fuels include other fossil fuel resources (heavy oil, oil shale, and tar sands); natural gas–based fuels and resources such as CNG, liquefied natural gas

(LNG), and synthetic liquids; methane hydrates; and electricity. Nonfossil fuels such as ethanol or methanol from biomass, hydrogen, and electricity from renewable sources also are substitute candidates. Both other fossil fuel resources and nonfossil substitutes are considered below.

Other Fossil Fuels

Numerous analysts have estimated total and remaining resources to produce fossil fuels (*22–26*). Table 2 gives one estimate of global reserves, resources, and additional occurrences of fossil fuels based on work performed for a joint study by the International Institute for Applied Systems Analysis (IIASA) and the World Energy Council. The term “reserves” includes occurrences that have been measured in known reservoirs and can be economically extracted. “Resources” are occurrences that have not been measured with the same level of accuracy as reserves and may not be economically recoverable with today’s level of technology and fuel prices. “Additional occurrences” refers to additional quantities that have unknown degrees of assurance and with unknown or speculative economic significance. It can be seen that an assessment of fossil fuel quantities depends on technical and economic assumptions and that the classification of quantities is a dynamic process because the terms change to reflect technological and economic conditions. It is important to note that some people use the term “ultimate resources” to refer to the total amount of a fossil fuel that has been consumed plus the amount remaining. Table 2 does not account for the amount of fossil fuel already consumed.

Viable alternative transportation fuels will likely resemble gasoline for some time into the future. Whereas it is foreseeable that the world could deplete much of its cheap conventional oil resources within a century (*28–32*), Table 2 indicates that there are far more unconventional oil sources such as heavy oil, shale, and tar sands that could replace conventional oil. Currently, crude oil is being produced from oilsands, tar sands, and bitumen in Canada and Venezuela (*33,34*).

Natural gas–based fuels are another potential class of alternative fuels. Natural gas could be used directly as a fuel in the transportation sector as CNG or LNG. CNG is enjoying limited but increasing success as an alternative fuel in niche light vehicle applications, and a number of manufacturers offer CNG-fueled vehicles in the United States (*35*). In 1997, there were 71,665 CNG vehicles in the United States (*36*). The major disadvantages of CNG are the incremental cost of the vehicle, fuel availability, and reduced vehicle range attributable to storage limitations. However, incremental costs, currently about $2,500, have declined and are expected to reach $800 (*20,37*). Research is also under way to develop storage systems that are more compact, thus enabling greater range.

LNG has seen limited application as a fuel for heavy vehicles (*38*). LNG has the advantage over CNG of higher energy density, although a gallon of LNG contains only 70 percent of the energy content of a gallon of diesel fuel (*39*). However, the cryogenic requirement of LNG necessitates specialized storage and handling.

Natural gas also can be used as a feedstock to manufacture synthetic liquids such as Fischer-Tropsch diesel fuel and methanol. Chemical conversion of natural gas to synthetic diesel fuels offers a fundamental advantage by allowing the use of existing distribution systems. As a consequence, dedicated (and duplicative) shipping and receiving terminals are not required. The downside is the greater capital intensity of conversion to distillates per ton of gas processed as compared with LNG. On balance, however, chemical gas conversion is of strategic importance for gas/oil companies since it complements LNG in the overall portfolio for commercializing natural gas as a transportation fuel.

As Table 2 indicates, methane gas hydrates are potentially an enormous energy source. Global methane hydrate accumulation is estimated to be about 137 trillion barrels of oil equivalent (*27*). Methane hydrates form when methane gas (excreted by sea bacteria that primarily consume phytoplankton as well as the flesh of dead organisms) dissolves and forms crystals in icy cold waters under the substantial hydrostatic pressures at the bottom of the sea. This process, which has occurred during a span of millions of years, has left huge deposits of the gas. When exposed to warm temperatures and atmospheric pressure, 1 cubic meter of methane hydrates expands to 164 cubic meters of methane and 0.8 cubic meters of water. Methane hydrates also form below permafrost lands. The Japanese are currently conducting methane hydrate recovery research. The Japanese government has planned a demonstration project of hydrate harvesting in the Nankai. In the United States, improved assessment of hydrate abundance and geological stability is in progress. Hydrate rigs must be able to reach deposits at depths of .5 mi (about 2,500 ft) or more.

Electrical energy from fossil resources is another alternative fuel resource candidate for the new millennium. Present-day electric vehicle technology offers highly efficient point-of-use energy conversion, but on-board energy storage is limited because of battery energy storage density constraints.

While the point-of-use conversion efficiency of electric vehicles is very high, the high efficiency is partially offset by the energy losses that occur at the power plant and in the transmission system as well as frequent use of a high carbon fuel, coal. This results in the electric power industry producing high levels of carbon emissions. However, the electric power utility industry is on the threshold of significant restructuring. The changes are largely in response to the Energy Policy Act of 1992 (EPACT), which enabled competition for customers. Since the passage of EPACT, numerous corporate sales, acquisitions, and mergers have occurred within the energy industry; they are resulting in the creation of more multifuel providers.

The deregulation of the electric power industry is occurring on a state-by-state basis as state legislatures and public utility commissions enact the required enabling laws, regulations, and service tariffs. The emerging competitive environment within the industry is expected to result in improved efficiency in the energy conversion and distribution system. On the basis of EIA assumptions for advanced power generation technology characteristics, the Department of Energy (DOE) Office of Transportation Technologies analyses have indicated a potential improvement from a nominal 30 percent delivered energy efficiency to in excess of 50 percent by 2050 (personal communication, J. Moore, 1998). Much of the efficiency gain will occur through waste heat utilization and implementation of combined cycle–natural gas power plants.

Nonfossil Fuels

There are a number of potential renewable alternative fuels. Table 3 summarizes current world renewable energy use. In contrast to the resource availabilities shown earlier for fossil energy resources, the values indicated in Table 3 are annual quantities. It has been estimated by EIA that the current values shown in the table will grow to 20 billion barrels per year in the United States and 110 billion barrels per year worldwide by 2020. A comprehensive analysis in 1992 indicated that the potential could be much greater (*40*).

Fuels that can be produced from the renewable resources given in the table include ethanol or methanol from biomass, hydrogen, and electricity. Ethanol from biomass is an attractive alternative because of its low life-cycle GHG emissions and its sustainability. Ethanol from biomass has nearly no GHG emissions on a full fuel-cycle basis because the carbon emitted by the combustion of ethanol is about equal to the carbon absorbed by the biomass used to make the fuel (*8*). Since biomass ethanol is also a renewable fuel, it meets the sustainability criteria used here. Large-scale production of biomass ethanol above that available from waste—estimated to be 225 million barrels of oil equivalent per year—would require dedicated crops (*41*).

Historically, only about 460 million acres have been used for agriculture in the United States. If one-tenth of the available crop land were used, the production of up to 38 billion gallons (gasoline equivalent) of ethanol a year, or 1.2 mbpd, could be supported. This estimate assumes land use yields of 6.5 tons of biomass per acre and a production yield of 127 gallons per ton of biomass. As an additional comparison, in 1997, U.S. highway vehicles consumed 2.62 million barrels of gasoline (*1*).

Ethanol can easily be blended into gasoline, reducing the infrastructure requirements associated with an alternative fuel. The primary disadvantages of ethanol are its current price and its energy density.

Hydrogen can be produced from biomass, fossil fuels, or electrolysis of water via a range of process options. Potential resources and production paths contributing to nonfossil hydrogen production include the following:

- Biomass and other high-moisture-content materials,
- Biological production using marine microorganisms,
- Photolysis using electrochemical systems to split water,
- Renewable resources to produce electricity for electrolysis, and
- Thermocatalytic conversion.

The DOE goal is to produce hydrogen for as little as $6/million Btu (for thermal processes) (personal communication, J. Moore, 1999). This is more than double present-day natural gas prices.

Many researchers are pursuing large, industrial-scale facilities to produce hydrogen and distribute the energy through a dedicated hydrogen transportation system that might be analogous to the natural gas transportation system. However, such a distribution system would be extremely expensive to build and operate. As noted previously, other analysts have proposed the use of small-scale steam reformers or electrolyzers to avoid the massive investment in infrastructure that the centralized concepts require (*21*).

Another important issue that may affect the future commercialization of hydrogen as a sustainable fuel is the cost of sequestering CO_2, which may be necessary to achieve GHG reductions. Table 4 presents the results of a recent analysis of the sequestration costs associated with various production and distribution options for hydrogen performed on behalf of DOE's Office of Power Technologies (*46*).

The assumptions used to generate Table 4 reflect cost and performance parameters that are expected to be achieved in the 2020 to 2030 time frame. The table indicates that the cost of sequestration for distributed systems is greater than that for centralized options and that sequestration could represent more than one-third of the cost to produce and deliver the fuel. (Sequestration also is being explored for fossil fuels.)

Many analysts consider hydrogen the ultimate energy carrier because of its nonpolluting characteristics (*21,47–49*). Hydrogen can be used in an internal combustion engine, a combustion turbine, or a fuel cell. Hydrogen is particularly attractive when it is used in a fuel cell because of the fuel cell's high energy conversion efficiency (*47*). Whereas hydrogen has great potential as a replacement fuel in the next millennium, it must overcome many barriers. First and foremost is cost. One of hydrogen's most promising attributes is the environmental benefit. If hydrogen is produced from renewable resources, its use will result in low criteria emissions and greenhouse gases.

In addition to automotive applications, hydrogen has been identified as a candidate future fuel for air transportation. Currently, a joint German-Russian team headed by Daimler-Chrysler, Airbus, and Tupolev (the former Soviet Union plane manufacturer) is developing a liquid hydrogen airplane called "Cryoplane." The project involves modifying an Airbus 310 and a Dornier 328 to use hydrogen. The partnership hopes to have Cryoplane serving European routes by 2010. Although the team investigated LNG, it appears to be continuing only the hydrogen work (*47*). Hadaller and Momenthy (*50*) also developed a concept for a hydrogen-fueled airplane that involves on-board cryogenic storage of the fuel.

Electricity from renewable sources also shows promise in the next millennium. As noted above, electricity can be used in electric vehicles or hybrid-electric vehicles that can recharge from the electrical grid (*51*).

Electricity can be generated from a number of renewable sources including wind power, photovoltaics, biomass combustion, hydro power, and geothermal power (*52*). Each of these resources has advantages and disadvantages relating to cost, environmental impact, and maximum potential generating capacity. Electricity generated by nuclear fission also satisfies the sustainability criterion used here. As discussed earlier, significant resources of solar and wind energy are available, although the costs of wind turbines, photovoltaic panels, and solar thermal steam generators have suppressed the development of these technologies as major resources for electrical energy generation. However, both wind and photovoltaics are being used in niche applications worldwide. Renewable technologies lend themselves well to distributed generation applications, which is typically an advantage in less developed areas where central station power generators would require investment in extensive power distribution grids.

DEMAND PROJECTIONS

Various projections for U.S. transportation sector and world oil demand are summarized in Figure 2. The figure indicates significant continued growth in world oil demand. Growth in U.S. transportation demand also continues but represents a decreasing share of total world consumption. Various future carbon emissions scenarios are indicated in Figure 3. The IIASA scenario assumes the implementation of aggressive measures to control carbon emissions.

OBSERVATIONS AND SUMMARY

Not surprisingly, the view of the future transportation energy picture is unclear, with circumstances that await unanticipated technological, policy, and market developments.

World transportation sector and total demand for oil will grow dramatically during the 21st century. Absent the availability of alternatives, oil will continue to be the transportation fuel of choice. Carbon emissions associated with world transportation oil use will grow at about the same rate as oil use. Recent estimates project that between 1997 and 2020, carbon emissions from U.S. transportation will grow by 47 percent (*41*). The use of other fossil-based fuels in transportation would result in about the same growth in carbon emissions unless the vehicles using these fuels are highly efficient. Non-fossil-based fuels would reduce carbon emissions regardless of vehicle technology. Electric drive vehicles such as EVs, HEVs, and fuel-cell-powered vehicles are candidates.

The U.S. share of world transportation energy use will continue to diminish. The fossil fuels supply potential in the 21st century is very large. Meanwhile, the prospects for commercial availability of large volumes of sustainable alternative fuels appear highly unlikely. Sustainable alternatives that have been addressed here include ethanol from biomass and hydrogen and electricity from sustainable sources. While each offers significant reductions in carbon emissions, each also is faced with serious barriers to large-scale 21st century commercialization, though some niche commercialization at economically competitive costs is likely. The data on the cost and availability of renewable fuels for transportation require further development and critique to ensure the most effective use of these often costly and generally scarce (compared with fossil fuels) resources.

In the near term, ethanol and electricity offer potential as niche alternative fuels. Ethanol, as a liquid fuel that is largely compatible with the present infrastructure, offers potential paths for immediate increased use via blending with petroleum products. The electricity sector, because of the effects of U.S. deregulation, has high incentives to pursue growth energy markets such as transportation. Although hydrogen has the potential in the long term for significant carbon reduction benefits and widespread application, its delivered cost is expected to be the highest of the sustainable alternatives for the next several decades.

If carbon sequestration in the production of hydrogen from natural gas is required, the sequestration costs will be included in the delivered cost of the fuel. Recent analysis has shown that this element could represent more than one-third of the cost to produce and deliver hydrogen. Even more extreme cost effects can be anticipated for the fossil fuel alternatives because they contain carbon as consumed in the vehicle. If sequestration is required because of major (certainly not present) concerns over 21st century CO_2 emissions, the economic balance would move toward hydrogen.

An emerging expectation is that concerns for carbon emissions effects will provide the greatest incentive for the widespread use of sustainable fuels. However, this scenario is highly uncertain. Present estimates indicate that costs far exceed CO_2 reduction benefits for hydrogen fuels. Given the availability of large quantities of low-cost fossil fuels, powerful policies will be needed to induce massive transitions to low-carbon fuels such as hydrogen or renewables. Without effective policies to induce transitions to low-carbon products, it appears likely that natural-gas–derived fuels—such as CNG, LNG, hydrogen, methanol, and Fischer-Tropsch diesel—will see a steady but gradual increase in use and probably will play a significant role in the transportation sector in the 21st century.

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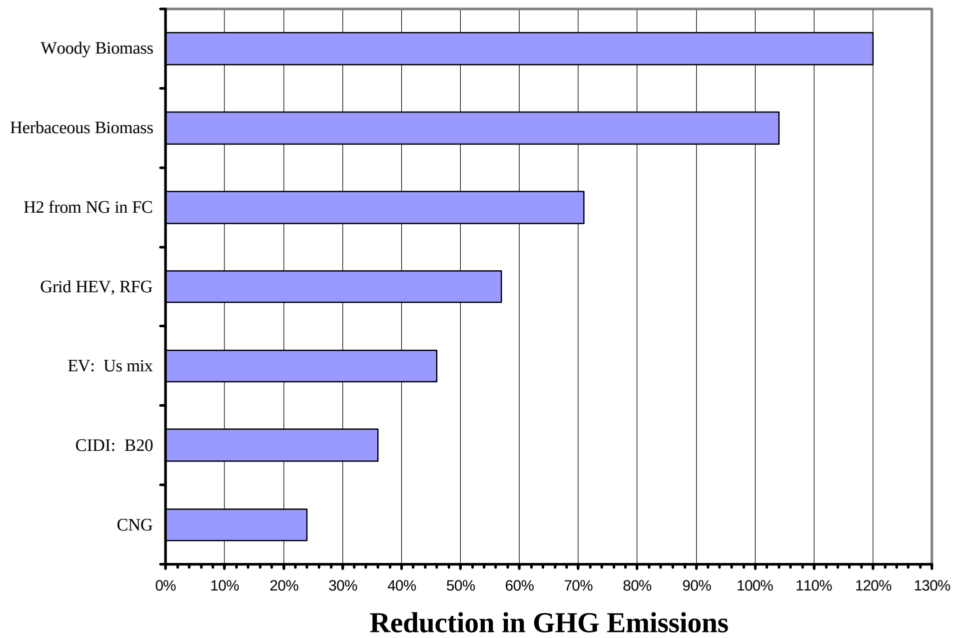

FIGURE 1 GHG reductions relative to gasoline in 2010 (personal communication, M. Wang, 1998).

TABLE 1 Infrastructure Costs and Estimated Benefits for Various Alternative Fuels (*18*)

ITEM	ETHANOL	METHANOL	CNG	HYDROGEN	FISCHER-TROPSCH	COMMENTS
STATION COST FOR CONVERSION (1000 $)	170	182	928	1423	N/A	VALUES ARE COST PER STATION
2030 HIGH CASE ANNUAL CAPITAL COST (billion $)	10.44	9.16	2.33	59.56	1.22	
2030 FUEL COST ($/gallon)	1.95	1.60	1.70	4.84	1.02	CONSUMPTION 50,000 GAL./MO. GASOLINE EQUIVALENT.
2030 REDUCTION IN GHG EMISSIONS (MMT CO_2)	678	374	427	498	343	

TABLE 2 Remaining Fossil Fuel Quantities (*27*)
(All Values in Billion Barrels of Oil Equivalent)

Fossil Resource	Reserves	Resources	Additional Occurrences	Total
Oil				
Conventional	1,100	1,063		2,163
Unconventional	1,340	2,460	13,370	17,170
Natural Gas				
Conventional	1,030	2,050		3,080
Unconventional	1,410	1,890	2,840	6,140
Hydrates			137,500	137,500
Coal	7,350	17,570	20,860	45,780
Totals	12,230	25,033	174,570	211,833

TABLE 3 Current Renewable Energy Resource Use (*42–45*)
(All Values in Billion Barrels of Oil Equivalent)

Renewable Resource	United States	Non-United States	World
Hyrdo-electric	0.60	2.02	2.62
Biomass	0.51	1.86	2.36
Geothermal	0.06	0.08	0.14
Photovoltaic	0.00	0.00	0.00
Solar Thermal	0.01	0.04	0.05
Wind	0.01	0.01	0.02
Total	1.18	4.01	5.19

TABLE 4 Cost To Produce Hydrogen and Sequester CO_2, 2020 to 2030 Time Frame

COST ELEMENT	DISTRIBUTED PEM ELECTRO-LYZER	BIOMASS PYROLYSIS	DISTRIBUTED NG REFORMER	LARGE-SCALE BIOMASS	LARGE-SCALE NG REFORMER
PRODUCTION, TRANSPORT AND DISTRIBUTION COST, $/MMBTU	18.4	9.1	13.0	18.0	12.9
CO2 SEQUESTRATON, $/MMBTU	0.0	5.8	4.4	1.9	0.8
TOTAL, $/MMBTU	18.4	14.9	17.4	19.9	13.7

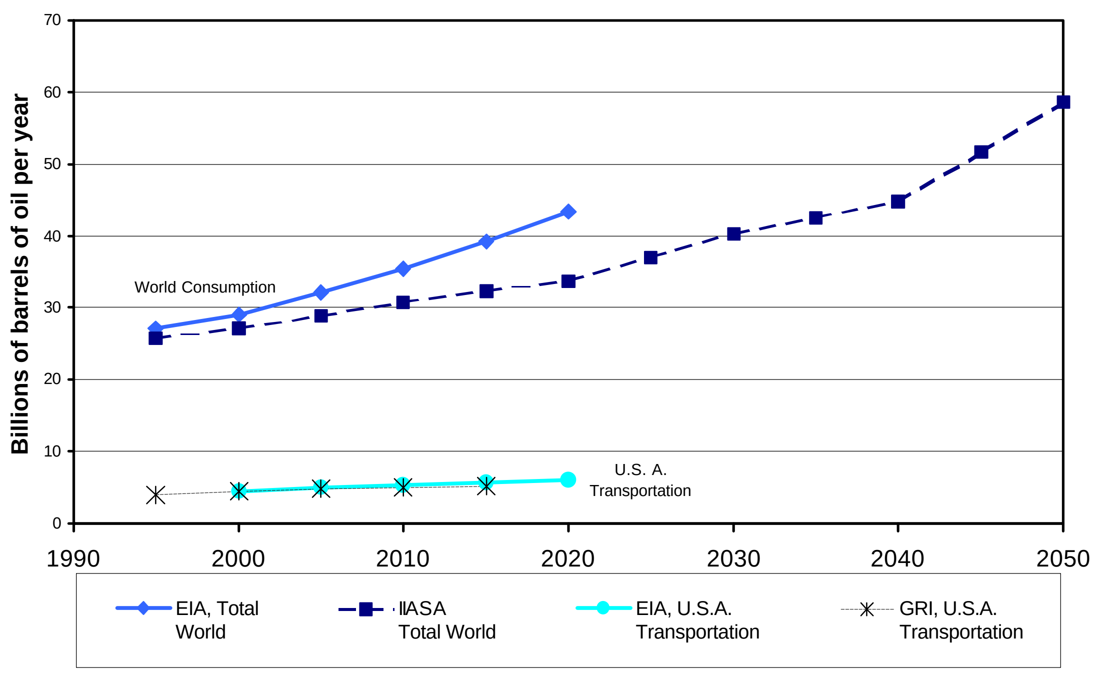

FIGURE 2 Projections of U.S. and world transportation demand for oil.

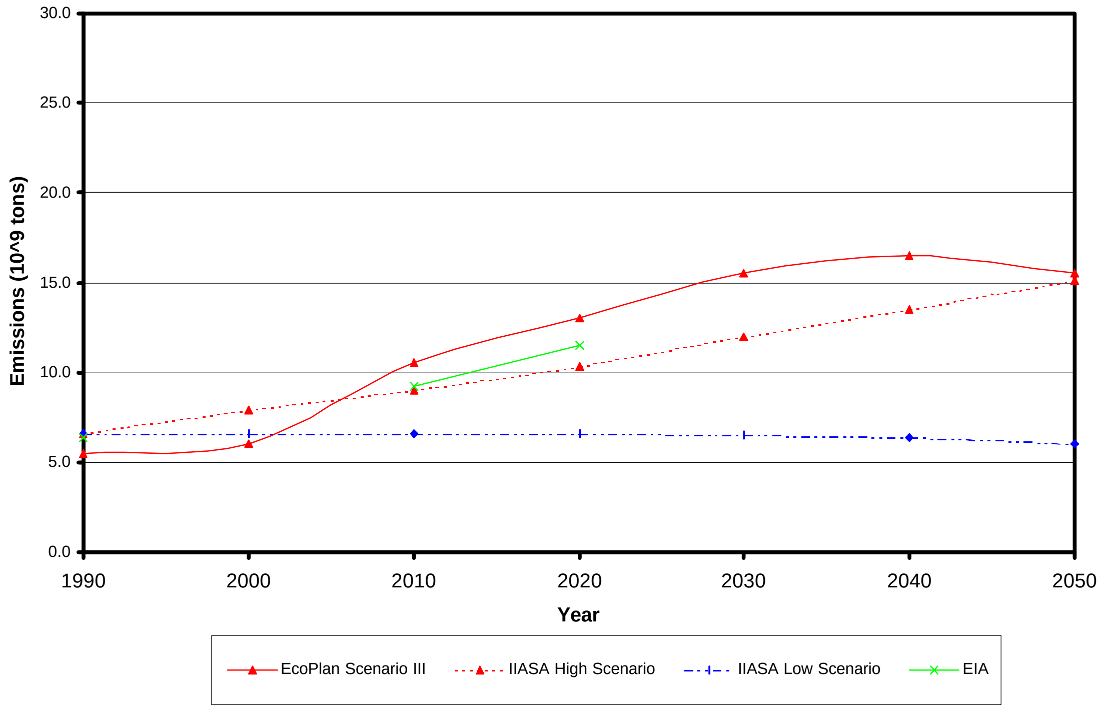

FIGURE 3 Projections of world carbon emissions