# 1. INTRODUCTION

An assured long-term supply of energy is essential for the growth and maintenance of a modern industrial nation such as the United States. The current energy crisis this country is facing is well documented, but it may be well to summarize again since the ingredients strongly relate to the subject of this panel report.

1. The growing demand for petroleum and natural gas, coupled with a decline in domestic production, has forced the U.S. to depend more heavily on foreign imports. Curtailment of some uses for natural gas is already in effect and shortages of fuel oil have occured in some states.
2. The increased public awareness of the environmental impact of our current energy generation and use patterns has caused delays in scheduling new facilities to meet the growing demands and has increased the demand for the more scarce "clean" fuels.
3. Substantial increases in the costs of energy have resulted from the above factors coupled with higher labor costs and interest rates.
4. Of longer range concern is the finite lifetime or the ultimate exhaustion of all fossil fuels, including the non-U.S. resources.

These factors work toward a growing dependency on uncertain, distant fuel supplies which in turn may imply serious national security and balance of payments problems. Therefore it seems highly appropriate to investigate alternative energy systems which could provide the U.S. with the means of overcoming these problems. The magnitude of these problems can be seen in Figs. 1 and 2, which show the projected increase[1] in petroleum and natural gas use according to the demand sector. By 1985, the U.S. would be importing over one-half its petroleum and would have a shortfall in natural gas supply of about one-half of demand. In terms of foreign exchange this represents a dollar outflow of about $44 billion (oil at $3.50/bbl and natural gas at $\$1.00/10^3\ ft^3$ as liquefied

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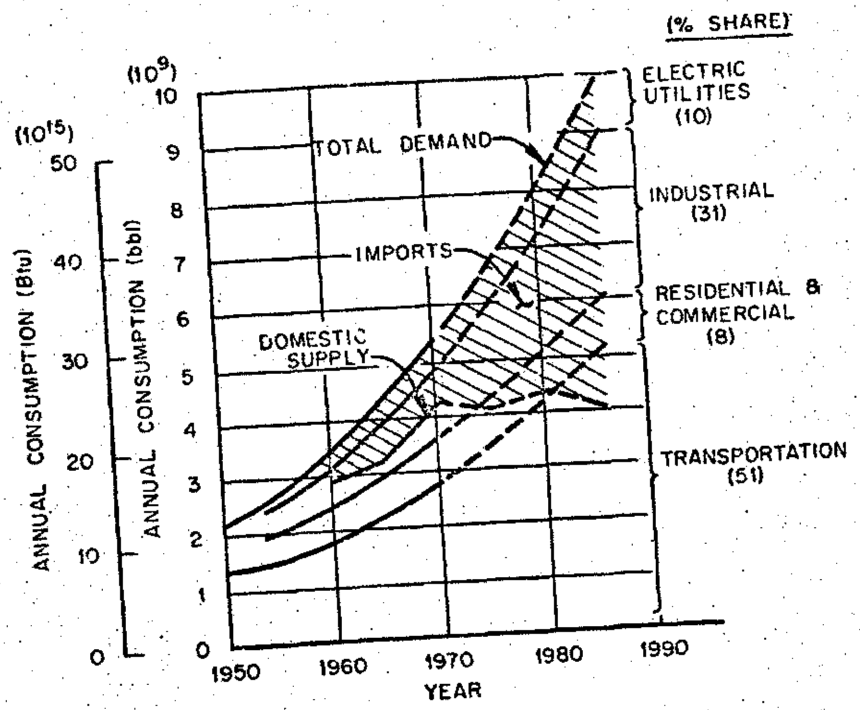


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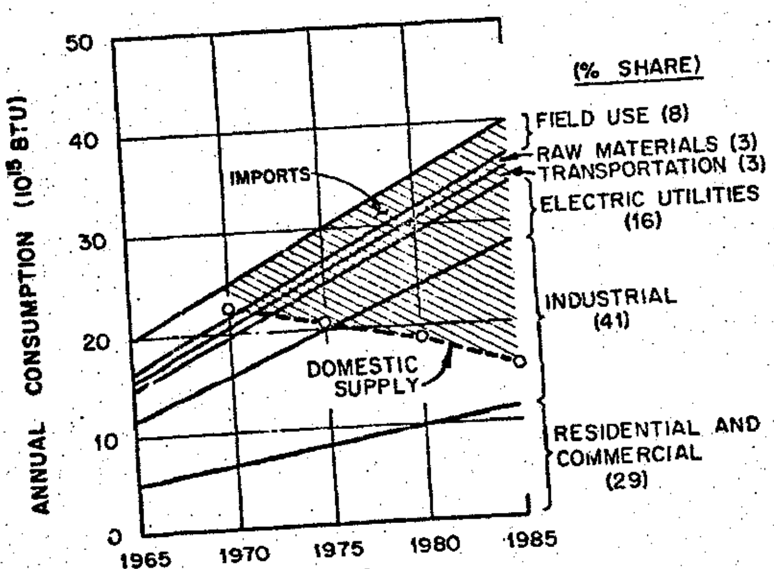


U.S. Gas Demand and Supply.

natural gas) for 1985 and would continue to increase with time.

It should be recognized that today's energy needs are served primarily by direct use of fossil fuels and secondarily by electricity. Near-term electricity needs will continue to be satisfied from economic domestic resources such as coal and uranium and near-term portable fuels from domestic petroleum reserves and imports. For the longer term, all energy will have to come from solar, geothermal, nuclear (breeder), or thermonuclear sources. Satisfying the long-term need for gaseous and liquid fuels appears to be a more complex problem than that posed by electricity.

Synthetic fuels from nonfossil sources appear to be the most likely alternative for supplying the long-term needs for gaseous and liquid fuels. These fuels, as considered in this study, consist of hydrogen obtained from water and synthetic fuels containing hydrogen, namely, ammonia, hydrazine, methanol, and related substances. It should be recognized that in the near term these fuels can, and most likely will, be made more economically from fossil sources such as coal and oil shale or possibly from urban and agricultural waste products.

While production of synthetic fuels requires thermal or electrical energy and thus may appear to complicate an already difficult problem, these fuels can be obtained from domestic and, for the most part, clean sources, for example, nuclear or solar. In addition, because of low transport costs, synthetic fuels can be produced at remote, well-regulated plants and thus would not contribute to the primary pollution problems that exist in our urban centers. An additional advantage of such a system is in conservation of our limited fossil fuel resources, particularly petroleum, so that they may be used as valuable chemical product feedstocks and in metallurgical processes. The synthetic fuels, especially hydrogen, may be consumed with very little or no air pollution as well as with higher conversion efficiencies and thus could be more attractive for urban uses than the fossil fuels in current use.

This report represents about a six-month effort of a panel of representatives from four AEC laboratories, industrial firms, and consultants as tabulated in the Appendix. It is one of 11 panels performing similar studies of various technologies that could potentially contribute to solving the future energy probl&ms facing our country. These panels have been formed by various interested agencies of the federal government and are being coordinated by the Federal Council on Science and Technology's Committee on Energy Research and Development (R&D) Goals. While many of these panels interface with some of the topics considered in this study, a few that seem to be particularly closely related are: Energy from Urban Wastes, Transportation, Total Energy Systems, and Solar Energy.

The specific purpose of this panel's work may be summarized as follows:

1. to assess the potential of an energy system based on nonfossil synthetic fuels, mainly hydrogen;
2. to give special attention to the use of synthetic fuels for the dispersed, stationary generation of electricity;
3. to examine all segments of a synthetic fuel system and make recommendations for performing any required research and development.

This report covers all aspects of an energy system based on nonfossil synthetic fuels and includes discussions on the production of the fuels; their storage, transmission, and end uses; and an overall systems analysis illustrating the role these fuels might assume in the future. A section on the use of coal to produce hydrogen and methanol is also included to help define the interim time period before our dependency on nonfossil fuels occurs. This summary report is based on individual detailed reports which were prepared in support of the panel's effort.

## 2. SUMMARY AND CONCLUSIONS

The primary sectors of an energy system based on nonfossil synthetic fuels have been examined on the basis of readily available information. The main overall conclusion reached is that these fuels can have a significant beneficial long-term impact on the energy problems facing the U.S. Hydrogen is a particularly attractive synthetic fuel for the following reasons:

1. It is essentially clean burning, the main combustion product being water.
2. It may be substituted for nearly all fuel uses.
3. It can be produced from domestic resources.
4. It is available from a renewable and universal raw material—water.
5. Nearly all primary energy sources, nuclear, solar, etc., may be used in its production.

The main obstacles to the use of hydrogen as a universal fuel are its high cost relative to the current low prices for fossil fuels and, for some applications, the unresolved problems of handling a low-density or a cryogenic fluid. Safety considerations, while important, are not believed to present a serious technical obstacle to its widespread use.

The panel believes that most of these economic problems could be resolved by appropriate research and development programs and, even though some applications are of a long-term nature, that it would be prudent to begin the required research at once. The solutions to research and development problems cannot often be rigorously scheduled, and, particularly in this case where a serious national problem exists, it would be far better to have technology ready in advance than to be late. Attaining the technical and economic goals of such a program could allow the U.S. to be independent of foreign energy sources while essentially eliminating the pollution problems related to energy use.

Of the other synthetic fuels considered by the panel, methanol (provided a low-cost source of carbon such as coal or lignite is available) appeared to offer the most potential, particularly as a fuel for ground transport. A comparison of selected characteristics of the synthetic fuels considered in this study is given in Table 1.

## 2.1 Major Findings

The long-term need for synthetic gaseous and liquid fuels is believed to be incontrovertible when one considers the potential alternatives. Although the applications of electricity, the most likely alternative, are increasing, there are several energy use sectors which do not appear capable of adapting to this energy form, for example, transportation, particularly air and sea. Also, many chemical and metallurgical uses for hydrogen cannot be replaced directly by electricity. The need for a portable, storable, and readily deliverable form of energy seems to be an essential ingredient of an advanced society as far into the future as can be visualized today, certainly beyond the time when the earth's fossil fuels have been exhausted.

The panel concluded that hydrogen has outstanding potential as a fuel for the transportation sector because of its unique, nonpolluting character. The applications would initially be to fleet-operated trucks and buses, high-speed trains, and aircraft and may later extend to private automobiles. The key to realizing the potential of hydrogen as applied to the transportation sector is the development of practical on-board storage and logistics systems. Methanol was identified as an attractive near-term automotive fuel. While not as clean burning as hydrogen, it appears to be superior to gasoline and would more readily fit into existing vehicle designs and fuel logistics systems, although its relatively low heating value and boiling point imply changes in on-board storage concepts.

The panel also found that conversion of agricultural and urban wastes to synthetic fuels is worthy of serious consideration. This source could supply a significant fraction of the 1985 shortage of pipeline gas, probably at costs competitive with imports. However, a substantial program of research, development, and demonstration is

Table 1. Comparative characteristics of synthetic fuels

| Fuel | Heat of combustion, low heating value (Btu/lb) | Heat of vaporization at b.p. (Btu/lb) | Relative fuel required to equal $H_2$ heat content | | Density | | | Boiling point (°F) | Ease of storage[b] | Toxicity[b] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | By wt | By vol | Liquid ($lb/ft^3$) | $H_2$[a] ($lb/ft^3$) | Gas, STP ($lb/ft^3$) | | | |
| Hydrogen ($H_2$) | 51,600 | 194 | 1.0 | 1.0 (liq.) | 4.4 | 4.4 | 0.005 | −423 | 6 (liq.) | 1 |
| Ammonia ($NH_3$) | 8,000 | 590 | 6.4 | 0.6 | 42.6 | 7.8 | 0.043 | −28 | 4 | 5 |
| Hydrazine ($N_2H_4$) | 7,200 | 540 | 7.2 | 0.5 | 62.4 | 8.9 | | 236 | 3 | 6 |
| Methanol ($CH_3OH$) | 8,600 | 474 | 6.0 | 0.5 | 49.7 | 7.1 | | 149 | 2 | 4 |
| Methane ($CH_4$) | 21,500 | 220 | 2.4 | 0.4 | 25.9 | 6.5 | 0.041 | −259 | 5 (liq.) | 2 |
| Ethanol ($C_2H_5OH$) | 11,600 | 360 | 4.4 | 0.4 | 49.7 | 6.5 | | 173 | 1 | 3 |
| Gasoline[c] ($C_8H_{18}$) | 19,100 | 140 | 2.7 | 0.3 | 43.8 | 7.0 | | 257 | (1) | (4) |

[a] Density of hydrogen in the fuel.

[b] Relative ranking.

[c] Included for reference only.

clearly indicated; another panel is believed to be developing the details of such a program.

In the long term the panel envisions an energy economy based on nonfossil sources, with electricity and hydrogen being the staple forms of energy distributed to cities and industries. The transition from fossil fuels to synthetic fuels will occur when the total cost of producing and using fuels from nonfossil energy sources intersects the rising costs, including environmental effects, of coal and imported oil and gas. In the interim, hydrogen will be produced from fossil sources such as coal and from off-peak electricity via water electrolysis.

The research, development, and demonstration program outlined below is recommended for federal government sponsorship. While some of the important goals can be identified now, a more detailed analysis of the alternative development paths should be undertaken before commitment to a major effort in order to arrive at the most effective program from a standpoint of cost.

## 2.2 Critical Related Issues

To better define the priority and urgency of such a program, several other evaluations should be made and a number of policy issues should be resolved. The real cost of environmental effects should be determined so that the environmentally beneficial characteristics of synthetic fuels can be evaluated and compared with other alternative and with the environmental effects of their production processes. Other critical policy issues to be resolved are mainly related to our increased dependency on foreign energy sources, that is, dependability of supply, the impact on national security and balance of payments, and the possibility of arbitrary pricing by foreign interests. There are also serious policy issues related to the need for, or the desirability of, imposing controls on the rate of growth of energy demand.

The future use of coal as a source of gaseous and liquid fuels was also identified as an important factor in determining the urgency and the level of effort to be placed on developing fuels from nonfossil sources. Since a time constraint, plus originally a basic ground rule for this panel's study, prevented detailed examination of the use of coal, answers to many highly relevant questions were not available; for example, questions of the ultimate costs and total environmental impact of producing hydrogen, methane, or methanol from coal and questions relating to the extent of our economic resources relative to their possible future use in supplying gaseous and liquid fuels.

A related problem, also somewhat beyond the primary scope of this panel's work, is concerned with the siting and construction (including capital allocation) of sufficient nuclear, solar, etc., plants to provide the primary energy required to produce the synthetic fuels. Just to meet one-half of the projected transportation fuel needs for year 2000* with electrolytically produced hydrogen would require an additional electrical generating capacity of nearly 1,000,000 MW (equivalent to ~$350 billion) or about 2 1/2 times the currently expected nuclear generating capacity at that time. Making full use of the available off-peak nuclear power in the year 2000 could reduce the required generating capacity by about 20%. To use coal in a gasification plant to produce this same transportation fuel need, would require about 1.3 billion tons of coal or more than double the current production rate.

Another possible strategy for relieving the demand for imported fuels, but also not considered to be within the scope of this panel's work, would be to substitute electricity for some selected fuel uses. As an example, if the residential and commercial space heating load projected to be met by gas and oil in 2000 were to be met by electricity, additional electrical generating capacity of 300,000 MW would be required. This alone would represent a 35% increase in the nuclear generating plant capacity planned for this time period but would release sufficient oil and gas to provide about 30% of the total transportation energy need.

It is further important to recognize that keeping up with energy demands without introducing new alternatives is in itself costly. It has been estimated, for example, that the cost of developing additional

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*Thus decreasing projected petroleum imports by about one-half and realizing a savings in foreign exchange of $\$12 \times 10^9$/yr at the 1972 price level.