I

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

The growing divergence between the demand for liquid fuels in the United States and domestic supply makes desirable the development of technically and economically feasible means for converting coal to environmentally acceptable liquid fuels. The United States consumed about 17.5 million barrels of oil per day in 1976 and imported about 7.2 million barrels of oil per day. Furthermore, imports are expected to increase substantially in future years. The problem is greatly aggravated by the accompanying decrease in the availability of natural gas, which will be replaced in part by oil. Of equal or greater significance is the limited nature of world oil reserves; by the year 2000, it is estimated that significant curtailment of oil use may be necessary for the world as a whole.

Fortunately, U.S. coal reserves are estimated to amount to more than 80 percent of the total of coal, oil, and gas that is available and are sufficient to support production of a large amount of liquid fuel. Approximately 230 billion tons of coal are considered to be minable by existing methods on a reasonably economic basis, a sufficient amount to supply the country's estimated requirements for solid and additional liquid fuels for decades.

The rapid decline of the nation's oil and gas resources emphasizes the need for a strong, balanced energy program involving the direct utilization of coal, the conversion of coal to liquid and gas fuels, oil shale, unconventional gas sources, nuclear power, and, in the longer term, solar and geothermal power. In addition, conservation must be practiced to the highest degree.

A considerable number of alternative technologies are being developed to convert coal to environmentally acceptable fuels including synthetic crude oil, and, as of 1976, a few technologies were approaching the commercialization stage. The reasonably well-developed coal-liquefaction technologies are expected to yield the equivalent of a synthetic crude oil at from $20 to $30 per barrel, about twice the current price of imported oil. (Process improvements may reduce these costs.) These estimates are based on 1976 costs, and the rate of escalation in these costs as compared to the rate of escalation in the price of imported oil will determine when coal liquefaction becomes economically attractive. Economic considerations, however, may not be the ultimate criterion, and national well-being could be the overriding factor.

At least 15 years will be required to construct a synthetic liquid fuels industry to produce 3 to 4 million barrels of oil per day (about 15 percent of the post-1990 demand projected by the Energy Research and Development Administration [ERDA]). This is the period required for the construction of commercial plants for those conversion processes that are now fully understood. In essence, then, it appears that the United States has reached the time when the design of coal liquefaction "pioneer plants" must be initiated.

The production of synthetic crude oil from coal at significantly lower costs might be possible if radically different conversion techniques are developed. Several such techniques have been studied but only in limited bench-scale programs. Within the next several years, these processes need to be evaluated to the fullest possible extent to determine their potential significance in the construction program that the United States must soon plan for coal conversion.

The Panel's conclusions and recommendations are directed toward the most efficient use of the limited time still available for the country to develop coal liquefaction processes that offer the lowest possible costs for the plants producing synthetic crude oil or low-sulfur fuel oil.

B. CONCLUSIONS

1. Of the four general methods of coal liquefaction, only indirect liquefaction (Fischer-Tropsch and methanol synthesis) currently is practiced on a commercial scale. Indirect liquefaction requires complex plants, and the capital costs equal or exceed those of coal hydrogenation plants. Furthermore, since the thermal efficiency of existing indirect liquefaction plants is 40 to 45 percent, coal consumption is very high. Thus, indirect liquefaction does not appear promising for meeting the large liquid fuel requirements of the United States; however, it may be economical for producing chemical feedstocks.

2. Pyrolysis processes for coal liquefaction produce gas, heavy liquids, and char; the heavy liquids require hydrogenation and the char requires gasification if clean fuels are to be produced. Char is the major product, but it does not have a ready market primarily because of handling and combustion problems. Although the thermal efficiency of pyrolysis can exceed 80 percent, further conversion of the char to a marketable product will significantly reduce the overall thermal efficiency. In the final analysis, pyrolysis does not appear promising for meeting the large liquid fuel requirements of the United States.

3. Pyrolysis at short residence times or in a fluidized bed in the presence of pressurized hydrogen improves liquid yields somewhat but may require additional processing to reduce the sulfur in the products to environmentally acceptable levels. Common problems also involve the feeding of dry coal into a pressurized reactor and the handling of caking coals at high temperature without agglomeration.

4. The other two methods of coal liquefaction, solvent extraction and catalytic liquefaction, have been studied in a number of process configurations. These process schemes have resulted in thermal efficiencies of 60 to 65 percent and have produced 2 to 2.7 barrels of oil per ton of coal feed. At their present stage of development, there are difficult filtration requirements and, therefore, only those schemes yielding a product that can be recovered by vacuum distillation seem to be practical. A simple, economic method of separating unconverted coal and ash from non-distillate coal liquids remains to be demonstrated.

5. Solvent extraction processes using donor solvents to produce a synthetic crude have been developed through the pilot-plant scale, and at least one process is ready for testing in a plant processing 200 to 600 tons per day. In these processes, hydrogenation of products and recycled solvents is carried out after solids removal and it may be possible to develop methods to use a fixed bed of catalyst without rapid deactivation.

6. A solvent extraction process that produces a solid combustible material with a relatively low sulfur and ash content has been demonstrated in units up to 50 tons per day, and the product is referred to as solvent refined coal (SRC). Because SRC is a solid, handling is complicated by dusting or sticking problems that depend on the temperature at which the solid is handled. Problems of greater significance arise in the filtration operation used to remove unconverted coal and ash, and improved separation techniques need to be developed. This process must compete with direct combustion of coal followed by stack-gas cleaning, with fluid-bed combustion, or with the production of low-Btu gas followed by a combined cycle for electric power generation.

7. Of the processes for producing synthetic crude or low-sulfur heavy fuel oil by hydrogenation of a slurry of heavy oil and coal in the presence of a solid catalyst, only those in which the catalyst is kept in motion have been developed through the pilot-plant stage. One such process is ready for testing at the 250- to 600-tons-per-day level. Existing problems with this process are the separation of ash and unreacted coal from heavy oil and rapid catalyst deactivation.

8. Rapid catalyst deactivation is experienced in processes in which the catalyst and coal-oil slurry come into direct contact, and catalysts that resist such deactivation need to be developed. The regeneration of deactivated catalysts has not yet been achieved. From available deactivation data, it is estimated that a 2 million barrels per day liquefaction operation utilizing these processes would require from 5 to 20 times the

amount of hydrotreating catalyst currently produced in the United States.

9. General experience in process development, verified in recent coal liquefaction programs, has shown that pilot plants as large as those built by ERDA and its predecessors are not required. Even allowing for coal-handling problems, plants processing 1 to 5 tons per day can usually provide the data needed to design demonstration-scale plants.

10. Demonstration of a process to obtain data for the design of a commercial plant can be carried out in a properly designed and operated unit utilizing 250 to 600 tons per day. The first commercial (pioneer) plants can then be designed from the information obtained.

11. Based on the information available on coal conversion processes developed at least through the pilot-plant scale, it is estimated that the capital cost of establishing a capacity of 3.4 million barrels per calendar day of synthetic crude oil (approximately 15 percent of estimated U.S. requirements after 1990) would be $92.5 billion (in 1976 dollars) or $74 billion for heavy fuel oil.* Full production would not be achieved until about 15 years after construction was started.

12. The cost of synthetic crude oil from processes currently developed at least through the pilot-plant scale is estimated to be $20 to $30 per barrel (based on 1976 costs) or about twice the present cost of imported oil.

13. During the past 10 to 15 years, it has been shown that hydrogen in a gas phase can be added to solid coal in the presence of a catalyst to produce liquids. If the coal is heated rapidly enough and intimate contact is maintained between the coal, the catalyst, and the hydrogen under pressure, the conversion to liquids can be completed in seconds; therefore, it may be possible to develop a process that can produce a synthetic crude in a closed pressure cycle without recycle oil. Such a process may be significantly more economical than coal conversion processes now under development.

14. Although understanding of the conversion of coal to liquids has improved greatly, more knowledge is required if uniquely new processes are to be developed.

15. In many respects the processing of coal-derived liquids will be similar to the processing of petroleum crude; however, coal-derived products present some unique problems and opportunities. When upgraded, the coal-derived products can yield high-grade gasoline blending stock and desirable chemical feedstocks. The presence of high polynuclear aromatic levels is a potential carcinogenic hazard especially in the fractions boiling above 600 °F. Precautions will be required in handling and containment operations to protect personnel from fume inhalation and prolonged cutaneous contact. The nitrogen present may result in pollution control problems in combustion.

*Synthetic crude oil is of higher quality and more expensive to produce than heavy fuel oil because of its higher hydrogen content.

16. Commercial coal liquefaction plants that incorporate appropriate pollution control and industrial hygiene practices and facilities will pose no unusual threat to employees, the public, or the environment. Most of the pollution-control technology required is already commercially available or can be developed when needed.

17. The primary role of the universities is in basic research that requires long-term efforts. Problems requiring short-term solutions can best be handled in industrial laboratories.

C. RECOMMENDATIONS

1. Scale-up of the most promising solvent extraction process (Exxon) and the most promising direct catalytic coal-oil-slurry hydrogenation process (H-Coal) should be carried forward expeditiously at a scale of 250 to 600 tons per day. The construction of demonstration plants for other liquefaction processes should not be considered until small scale and pilot plant results have demonstrated substantial advantages over the Exxon and H-Coal processes.

2. A vigorous effort should be made to reduce the size of the equipment for process development. As much work as possible should be carried out on the bench scale. Pilot plants should not be larger than 1 to 5 tons per day. Process demonstration should be carried out on units not larger than 250 to 600 tons per day.

3. Solid separation techniques including improved filtration, distillation and solvent precipitation should be vigorously investigated to identify the best approach.

4. Present research on, and operation of, existing units for the solvent refined coal process should be continued until complete technologic and economic data are available. The economics of this process then should be compared with alternatives such as the combustion of coal followed by stack-gas cleaning, the use of coal-derived fuel oil, the use of low-Btu gas in a combined cycle, and the use of fluidized-bed combustion.

5. Small-scale research on synthetic crude oil production, including solid-gas catalytic coal hydrogenation, should be increased and broadened in scope as rapidly as possible. Major emphasis should be given to the study of methods for feeding dry pulverized coal and hydrogen gas to pressurized reactors.

6. A long-range environmental research and hazard assessment program should be effectively integrated with evolving coal liquefaction technologies so that the ultimate commercialization of these technologies can be carried out on a sound basis. Particular emphasis should be placed on identification of possible carcinogenic effects of higher polynuclear aromatic materials contained in coal-derived liquids. Effective integration of industry, EPA, and ERDA efforts is essential to the success of the program; coordination of effort should be assigned to an impartial body.

7. If the private sector is to undertake a vigorous program for coal conversion, it is essential that the nation establish a firm, positive energy policy that includes financial incentives to compensate for the risks involved. These incentives should be established in such a way that responsibility for the program is in the hands of private industry. A possible incentive is the establishment of an agreed-upon price for the product; as an alternative, the government could provide the capital for construction and industry could be permitted to sell the product at operating cost plus a fixed profit.

8. The development of catalysts resistant to rapid deactivation in the presence of coal slurries should be vigorously pursued. The urgency of this problem dictates that it be assigned to groups with a broad background and established past performance in hydroprocessing catalyst development.

9. Strong support should be given broadly ranging fundamental research aimed at improving understanding of:

a. The structure and composition of coal

b. The kinetics of the pyrolysis and dissolution of coal

c. The important reaction paths and the rates of hydrogen transfer from the donor solvent to coal molecules

d. The rates and reaction paths by which gaseous hydrogen reacts with coal with and without added catalyst

e. The role of mineral matter in catalytic coal liquefaction by hydrogenation

f. The catalytic chemistry involved in the conversion of coal to liquids having low nitrogen content

g. NO_x abatement in flue and exhaust gases by thermal and catalytic reduction.

10. U.S. universities represent a major source of fundamental knowledge and highly skilled personnel, and efforts to support and broaden their involvement in coal conversion research and manpower training should be undertaken. Further, development of active programs of university, not for profit institutions, industry, and government cooperation and interaction should be given high priority.