Liquid Fuels from Coal: From R&D to an Industry

The technology road is clear but the economic driving force is highly uncertain.

L. E. Swabb, Jr.

Today, there is clearly room for synthetic fuels, including liquid fuels from coal, if they could be made available at a competitive price. This is apparent from the fact that in 1977 just over 45 percent of U.S. liquid fuel needs will be supplied by imported oil.

Summary. On the basis of current U.S. oil imports, room now exists for a U.S. coal liquids industry. Unfortunately, technology is not available which can produce coal liquids at a price competitive with imported oil. Direct liquefaction technology is under development, but the prospects are that the technology will not be economic at the time the pioneer commercial plant should be constructed to provide the foundation for a possible coal liquids industry in the 1990's. Government support of coal liquefaction R & D has created the conditions that make possible the development of the technology, and probably government incentives for pioneer plants will be needed. With the proper incentives pioneer plants will lead to lower costs, and this, plus rising prices, will create the conditions necessary to develop a multiplant industry.

Liquid fuels play a critical role in the U.S. economy. They fill needs for which substitutes simply are not available—in transportation, for example, and peak shaving in electric power generation. Also, there are many homes and commercial buildings heated by oil, for which gas is unavailable and coal is impractical. The only alternative in these cases to liquid fuel is electricity, an expensive alternative. Because of the critical role liquid fuels play, they will continue to be in demand for many years.

Petroleum production in the United States peaked in 1970 and began to decline. There is substantial potential for arresting the decline for a time, depending on government leasing policy and successful exploration offshore. However, eventually even world petroleum production must peak and decline because petroleum is, after all, a nonrenewable resource. Many estimates place the inflection point of the world's crude oil supply before the end of this century (*1*). How the world will adjust to declining supplies of petroleum is a major uncertainty of the long-term energy outlook. Clearly, passing the peak of world oil production will restrict sharply the major tool that the United States is now using to manage its own fuel supply-demand gap—imported oil. Thus, although there is room now for a domestic industry producing liquid fuels from coal, the need for that industry could become acute before the end of the century.

One candidate for supplementing current and future petroleum supplies is synthetic liquid fuels made from the vast reserves of coal in the United States. However, there is no commercial industry in place today for making liquids directly from coal, nor, for that matter, is there technology available for producing liquids from coal at an economically competitive price. Developing this technology is the goal of the large coal liquefaction R&D program now under way sponsored by both industry and government.

Over the years, the petroleum industry has developed and commercialized a variety of new refining processes to produce desired products at the lowest possible cost. In general, the development and commercialization of these processes was relatively straightforward. The research and development costs were moderate. There was a clear market for the products, and the economics of commercial plants gave a satisfactory return on investment. However, in the case of liquid fuels from coal, the picture is quite different. The R&D cost is high, and the timing, conditions, and economics of future commercial applications are not clear. This places added challenges on the development and commercialization process.

In this article, I consider how we, as a nation, might proceed from today's R&D efforts to the creation of a commercial coal liquids industry in the private sector, or at least to ensuring that such an option will be available if national policy or needs dictate its use. After a brief description of the state of the art in coal liquids technology, I discuss the major steps needed to develop and commercialize that technology, and then offer some insights into the conditions that appear necessary for these steps to take place.

Coal Liquids and Coal Liquefaction

Basically, there are three ways to liquefy coal: (i) add hydrogen, (ii) take away carbon, or (iii) break it down to individual carbon atoms and rebuild. The third approach is being used today by the South African Coal, Oil and Gas Corp., Ltd. (SASOL) in Sasolburg, South Africa (*2*). Coal is gasified with steam by the Lurgi technology to produce carbon monoxide and hydrogen, which are then reacted over a catalyst in the Fischer-Tropsch process to produce liquid hydrocarbons. The combination of tearing down and rebuilding results in the highest cost route to liquids from coal. Another indirect approach now under investigation would gasify the coal, convert the gases to methanol, and convert the methanol to gasoline. The economics of this route are uncertain.

The other two methods of liquefying coal, adding hydrogen and removing carbon, should be more economical. Adding hydrogen, or direct liquefaction as it is usually called, will probably become the major source of liquid fuels from coal. Pyrolysis of coal (removing carbon) may also become significant, but processes of this type must contend with low liquid yields and economical use of high volumes of char.

The author is vice president for Synthetic Fuels Research, Exxon Research and Engineering Company, Florham Park, New Jersey 07932.

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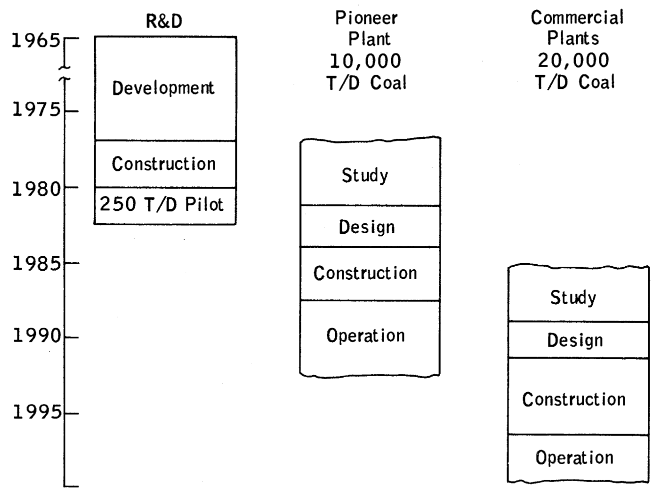

Fig. 1. Timing for the three major steps in the commercialization process. This particular scenario illustrates how the EDS process might be taken to commercialization.

There is no commercially proven technology today for the large-scale, direct liquefaction of coal to produce high yields of distillate liquid products. Several processes for producing yields up to three barrels of liquids per ton of coal are now under large-scale development. Among these are the Exxon Donor Solvent (EDS) process, the HRI H-Coal process, and the Gulf SRC-II process. Small-scale coal liquefaction R&D on other processes is also being done by Pittsburgh Energy Research Center (Department of Energy, DOE), Dow Chemical, Conoco, Lummus, and others.

In general, all direct liquefaction processes now under development involve slurrying the coal in a recycle coal liquids stream and then heating the slurry in the presence of hydrogen or hydrogen donor molecules (or both) to cause the organic molecules in coal to break down and pick up hydrogen. This process of molecular weight reduction and increased saturation with hydrogen converts organic solids in the coal into liquids. The various processes differ in the reactor configuration and conditions, the way catalysts are used, and the way the products are separated from unreacted coal and mineral matter (*3*).

Steps for Commercialization

From industrial experience, we know that commercialization of new process technology involves three major steps. The first step is R&D. This is basically a process of reducing technical uncertainty to the point where a full-sized commercial plant can be designed and built at some reasonable and acceptable level of technical risk. The second major step is the transition from the experimental technical activity to the reduction of the uncertainty concerning the commercial aspects of the technology. The third step is the construction of multiple commercial plants in accord with commercial needs and opportunities.

There are two principal routes for passing through the transition step from R&D to a full-fledged industry; one is through a pioneer commercial plant and the other is through a demonstration plant. On the basis of our experience with developing and commercializing new petroleum and petrochemical process technology, we believe that the pioneer plant approach is preferred. I describe this route to commercialization and then discuss how the demonstration plant approach differs.

Starting with the first step, R&D is progressed to the point where there is sufficient data to design a full-scale commercial plant with acceptable technical risk. How and when this point is reached depends on factors such as the nature and complexity of the new technology; the cost and time required for alternative development routes; the capabilities of the organization that will design, build, and operate the pioneer commercial plant; the level of technical and economic risk that is acceptable to the investor; and whether there is some special value for an earlier commercialization date.

In the case of the EDS technology, the R&D will include the operation of a large pilot plant of the minimum size needed to provide the critical design and the mechanical and process data for scale-up to full commercial size. This minimum size was determined to be 250 tons of coal feed per day, based on a technical analysis of the chemical and physical phenomena occurring in each of the process steps. The EDS project illustrates the timing and costs involved. Exploratory R&D started in 1966. By 1971, a promising process sequence was defined and was under development in the laboratory and in small pilot plants of roughly ¼ to ½ ton of coal feed per day. Further development is being carried out in a 1-ton-per-day pilot plant to confirm the design of the 250-tons-per-day pilot plant, and to define quantitatively the effects of process variables. Construction of the large pilot plant will begin in 1978. Operation will start in late 1979 and is scheduled to be completed by mid-1982. Laboratory and small pilot plant R&D will continue throughout this period. This is the R&D step illustrated in Fig. 1. The estimated cost of the total program to reach the point of designing a commercial scale plant is in the range of $275 million to $300 million.

In addition to having an adequate technical data base for commercial plant design, a new coal liquefaction process must also meet certain other criteria. It must be operable and reliable on a commercial scale and produce products of desired quantity and quality. It must meet current and projected future standards for impact on the environment, and on the health and safety of workers and users of the products. Finally, it must meet the cost criteria which will make commercial viability possible.

Confirmation that these criteria will be met is best achieved in a pioneer commercial plant. A pioneer plant is defined as a commercial-scale, stand-alone facility intended to operate as a commercial venture for a normal plant life of 20 to 30 years. It is a first of its kind. Its location and size are based on commercial and technical considerations. By definition, it is constructed, operated, and managed by the private sector. It might be designed in modules to permit later expansion. However, each module would be to full commercial scale.

The definitive planning and the initial design work for the pioneer plant can be started before the total process development program is completed. The definitive planning for a large commercial project, such as a coal liquefaction plant, is a major undertaking, and it must be started early. Significant areas to be defined are the plant site; the necessary permits; the feed, water, and utility supplies; customers for the products; waste disposal; and economics and financing.

If it is deemed urgent to do so, definitive design work can be completed as soon as the data base for scale-up is available from the large pilot plant. If the overall development program is well planned, this should be available after 1 to 2 years of large pilot plant operation. Thus, the design phase of a pioneer plant for EDS could start sometime in 1981.

Assuming a 3-year design effort, construction of the pioneer plant could start in 1984 and the start-up operations could begin in 1987 (Fig. 1). Current estimates place the cost of a pioneer plant capable of processing 10,000 tons of coal per day at around $75 million (1976 dollars). Such a plant would be one train of a commercial plant and would produce 25,000 to 30,000 barrels of coal liquids per day. It would be designed for possible expansion later, to twice the size by the addition of a second process train, if and when justified.

The specific goals of the pioneer plant, as we see them, are to establish the cost and value of the products, to reduce the business risk, and to reduce the cost of future plants. In meeting these goals, the pioneer plant confirms solutions to whatever community and social effects are encountered. It charts a path through the regulatory and environmental requirements. It sets the basis for the development and growth of a supporting infrastructure and logistics system for feed and products. It provides the opportunity to train a cadre of operating and maintenance people. Especially important, the pioneer plant starts the "learning curve." Experience with a variety of industrial processes has shown that investment and operating costs fall as experience is accumulated in commercial-sized plants. Cost reductions as great as 30 or 40 percent (in constant dollar terms) have been experienced for commercial plants built about 10 years after the start-up of the pioneer plant provided that R&D is continued and plant tests of potential improvements are conducted. Achieving significant cost reductions as a result of the pioneer plant step will be an important factor in establishing a viable coal liquids industry.

The last step in the commercialization process involves the construction and operation of a number of commercial plants. Again, definitive planning for such plants would have to start several years in advance of the design stage. Design of commercial plants might start after the pioneer plant operates for a year. In the case of the illustrated development schedule for the EDS coal liquefaction process, this would mean 1988, and construction could begin in 1991 with start-up in 1996. Present estimates are that a commercial coal liquids plant capable of processing 20,000 tons of coal per day into 50,000 to 60,000 barrels of liquids per day will cost between $1 billion and $1.5 billion (1976 dollars). This estimate incorporates the cost reduction benefits from the pioneer plant.

Pioneer Contrasted with Demonstration Concept

A significant portion of the DOE fossil energy R&D budget provides for demonstration plants. There are some major differences between the pioneer plant route and the concepts underlying the DOE demonstration program.

Demonstration plants are usually intermediate in size between pilot and full-scale commercial plants. Their primary purpose is to reduce technical risk associated with scale-up, plus providing an improved definition of operability, reliability, costs, and environmental acceptability. This contrasts with the pioneer plant concept, which is based on the premise, supported by extensive experience, that scaling directly to commercial capacity from a pilot plant involves acceptable technical risk and does not justify an intermediate step if the pilot plant is properly sized and appropriate supporting data and scale-up correlations are developed in the R&D stage. Further, an intermediate-sized demonstration plant is unlikely to be economic and therefore will not provide adequate answers to questions about commercial viability. Its high cost and short life are likely to lead to shortcuts that result in omitting some of the facilities that would be included in a commercial plant and limiting some of the activites required to develop and implement a commercial venture.

A significant difference between the DOE demonstration plant program and the pioneer plant approach that we favor is related to the degree of responsibility assumed by the private sector and the federal government. In the DOE demonstration program, there is a significant federal role including a strong voice in and the right to control such matters as selection of technology to be employed, project scope, site location, technical involvement by the National Laboratories and the Corps of Engineers, and cost-sharing arrangements. Usually demonstration projects are developed in response to a request for proposal and then awarded as a result of competition on the basis of criteria established by DOE.

Our concept of the pioneer approach contemplates a predominant private sector responsibility with respect to project initiation, selection of technology, scope, location, project planning, development, and implementation. This includes negotiation of all commercial agreements, securing of all permits, arrangements with regulatory and local authorities, and the long-term operation of the pioneer facilities. In this concept, the primary role of the government is to establish the climate and broad framework that will provide appropriate encouragement and adequate incentives for the private sector to undertake pioneer projects. The private sector has the responsibility to advise the government with respect to the adequacy of available or possible incentives for undertaking pioneer projects.

A strong, dominant role of the private sector in the pioneer plant step is necessary to ensure successful commercialization. In the business world, research, development, and commercialization are a combination of closely entwined technical and business activities geared to the market. They involve considerable knowledge and judgments about market acceptance and economics for new technology. Federal agencies, on the other hand, have limited access to experience and judgments honed by competitive markets. Also, in government activities political considerations sometimes overshadow economic factors in the decision-making process. These significantly inhibit the government's ability to transfer its R&D results into commercial ventures.

Conditions Required

The process of creating and commercializing new technology is driven by economic considerations. As the private-sector investor proceeds through the various steps, he is continually reassessing the economics. His willingness to go ahead is based on his expectation of benefits in view of the apparent costs and risks involved.

During the 1960's, the early stages of research on coal liquids were pursued largely on the conviction that eventually they would be needed to supplement petroleum. While no accurate assessment of costs was really possible early in the research, a strong driving force was the hope that small-scale, applied research would result in a liquefaction process with acceptable costs. Also, the business environment appeared reasonably predictable in terms of the overall economy, the mechanism for establishing prices, and the applicable government regulations. While there was uncertainty, it was at a level which industry felt competent to handle.

The events of the early 1970's introduced a great deal more uncertainty. Prices began to be set by political forces.

Inflation caused plant construction costs to soar. Environmental, health, and safety regulations began to change rapidly. Overall, changes in the business environment became less predictable. Also, the coal liquefaction processes under development began showing estimated costs that were much higher than prices for petroleum fuels. In the face of increased uncertainty and poor process economics, private sector investors hesitated to commit all of the large sums of money required for the large pilot plant stage of development of coal liquefaction.

Coal liquids technology is proceeding now into the large pilot plant stage because of government support of the R&D. All the coal liquids processes now in the large pilot plant phase involve at least 50 percent government cost sharing, and, for many, the government share is higher. At the present level of uncertainty, the high program costs, and the relatively poor economics, such government support is an essential condition for proceeding.

Turning to the next stage, that of the pioneer plant, again the private investor's decision to proceed will hinge on economic considerations. Economic studies, based on detailed conceptual designs of a pioneer plant in the mid-1980's, yield estimates of discounted cash flow (DCF) returns ranging from none at all to 10 percent, depending on the assumptions made. The most critical assumption is the rate of increase of the price of coal liquids relative to the rate of inflation of plant construction costs. In our studies, coal liquids are assumed to command a price equivalent to the marginal supply of liquid fuel, that is, imported oil. If coal liquids price and plant construction costs are assumed to escalate at the same rate, estimated DCF returns on a pioneer plant are in the 0 to 5 percent range. If coal liquids price is assumed to escalate faster than construction costs, DCF returns up to 10 percent can be estimated. Even this level, however, is too low to attract the private investor, and thus incentives of some sort appear to be needed to encourage the private sector to proceed with a pioneer plant.

The most preferred incentives would be single plant incentives designed to have their greatest impact early in the project life. Such incentives could include (i) allowing coal liquids to be priced competitively with the marginal supply, (ii) providing a higher investment tax credit, (iii) providing for more rapid depreciation, and (iv) providing a cash grant that would be convertible to a loan at a later date. The precise combination and level of these incentives that will be needed cannot be predicted today. When the time comes to build the pioneer plant, the company developing the project will need to define the necessary incentives in cooperation with the responsible agency of the government.

Loan guarantees have been suggested as an aid for pioneer plants. Loan guarantees may be useful where part of the plant investment is to be borrowed. However, a loan guarantee cannot raise the DCF return on a project; it cannot make an uneconomic project economic. Thus loan guarantees may supplement but not replace the incentives mentioned above.

While the outlook is that incentives will be needed to encourage pioneer plants in the mid-1980's, the longer term prospects for the formation of a multiplant industry are not clear. The private sector will invest in coal liquids plants if there is an expectation of a reasonable return on the investment. The essential conditions for such an expectation appear to be some combination of lower costs and higher prices. Pioneer plant experience plus continuing R&D, if pursued, will undoubtedly result in lower costs to some extent. Thus, pioneer plants appear to be essential to eventual commercialization. However, based on current cost estimates and estimates of learning curve benefits, the cost of the technology now under development is not likely to fall enough to make coal liquids economic at the price coal liquids might command today (that of imported oil). Thus, barring an unexpected breakthrough in liquefaction technology, the second essential condition for commercialization is that the real price coal liquids command will have to rise.

This is not to suggest the subsidization of a commercial coal liquids industry. Commercialization will occur if the technology has been proved workable and acceptable through the pioneer plant phase and if coal liquids command a sufficient price. If coal liquids do not command such a price it means that less expensive alternatives are available and coal liquids are not needed or desired.

Despite the uncertainties of future economic conditions, it is in the national interest to pursue the development of several coal liquefaction processes through R&D and the pioneer plant stage. Multiple technologies are needed because it is probable that no one process will be best in all circumstances. These developments will provide increased options for the nation and insurance against economic disruption caused by severe limitations in supplies of liquid fuels. Since the United States may have a compelling need for a supplemental source of liquid fuel before the end of the century, these developments should proceed now, as rapidly as possible.

References and Notes

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