Coal Research (II): Gasification Faces an Uncertain Future

Gasification of coal is an old art. In the 1920's, more than 150 companies worldwide manufactured coal gasification equipment. As first oil and then natural gas replaced coal gas in most applications, however, the technology base for gasification eroded to the point where only a few processes are now commercially available. A 12-year U.S. research program to remedy that lack appears to have failed, however, and the Energy Research and Development Administration (ERDA) is now planning to test designs based on British research. Even so, the commercial future of coal gasification seems uncertain.

Preeminent among the surviving processes is the German Lurgi gasifier, for use with applications that require gas at pressure such as pipeline distribution or gas turbine power plants. Also still in use is the Koppers-Totzek process—a German design first demonstrated in the United States—and several other processes for making unpressurized gas to be used in chemical synthesis or to be burned under boilers. These processes are hardly ideal, however. The Lurgi is a small gasifier, necessitating 25 or more units for a commercial plant; it is inefficient, converting only about 55 percent of the coal's energy to synthetic natural gas; and it has been operated commercially only with noncaking coals, which are to be found in the western part of the United States, far from most of the major markets for gas. The Koppers-Totzek can use any coal, but it is also inefficient, consumes a lot of expensive oxygen, and cannot be used where pressurized gas is needed. Nonetheless, these processes represent the commercial state of the art in coal gasification.

It is not an art in which there is a lot of recent experience in the United States. No Lurgi or Koppers-Totzek plants are now operating in this country and, despite growing shortages of natural gas, none are yet being built. This lack of a commercial coal gasification industry may become a subject of increasing concern as gas shortages accelerate, as they seem certain to do. Moreover, failure to get a few U.S. plants built with existing technology—to establish financial, regulatory, and environmental precedents—may prejudice the success of the research program aimed at developing and commercializing improved gasification techniques.

The central part of the ERDA program for coal gasification consists of one or more demonstration plants, for both pipeline quality gas (methane, with a heating value of about 1000 Btu per cubic foot) and low-Btu gas (a mixture of methane, carbon monoxide, and hydrogen with a heating value of 100 to 500 Btu per cubic foot). These demonstration plants are to consist of commercial-scale equipment and, under current plans, are to be funded equally by ERDA and industry (*Science*, 20 August, page 665). The program is thus dependent in a major way on the participation of private companies, which many observers consider unlikely to put up the large sums of money (probably $200 million or more) required to build these plants unless they can see a way to commercialize the resulting technology.

Commercial Plants Stalled

Nearly 20 gas pipeline companies or consortia have expressed interest in building coal-based synthetic natural gas plants with Lurgi technology, but only three have so far filed plans with the Federal Power Commission. Even these plans appear to be in abeyance, because the companies involved are having trouble raising the money to build the plants in the absence of federal loan guarantees. Less ambitious plans to install Koppers-Totzek gasifiers to supply industrial plants and utility boilers, especially in the Southwest, have also been shelved. In both cases the principal reason appears to have been a dramatic, nearly threefold increase in the expected cost of such plants.

A full-size commercial facility to produce 250,000,000 cubic feet of synthetic natural gas per day is now estimated to cost $1 billion. The gas itself is estimated to cost close to $4 per million Btu (1 Btu = 1055 joules), compared to imported gas, which reaches the United States at a cost of about $3.15 per million Btu, and domestic natural gas, most of which is sold in interstate markets for $0.52 per million Btu. If a recent ruling by the Federal Power Commission is upheld by the courts, new interstate gas will sell for $1.42 per million Btu.

Gasification, it appears, will be an expensive and controversial way to clean up coal (see box on page 752), although not necessarily more expensive than other alternatives. Synthetic pipeline gas may in fact have one of the best chances of overcoming economic barriers to commercial introduction of any clean fuel from coal because its selling price will be determined by a regulatory decision and not by market forces. A frequently cited example of the power of the regulatory process is the already substantial industry (nearly 500 billion cubic feet per year) producing synthetic natural gas from naphtha, a light petroleum fraction—even though in this instance the result is somewhat irrational because naphtha is in short supply and is a more expensive feedstock than coal. In any case, it does not seem likely that, without government subsidy in one form or another, a coal-based synthetic gas industry will get under way in the next decade.

The U.S. gasification research program during the 1960's and early 1970's was devoted almost entirely to processes for making pipeline quality gas. These processes were to be competitors with and improvements over the Lurgi gasifier—of higher capacity, able to handle a wider range of coals, and more efficient. Four processes, all considered in the mid-1960's to be innovative or to possess some special advantage, emerged as the core of the program. These were the Carbon Dioxide Acceptor, Hygas, and Bi-Gas processes under the joint aegis of the Office of Coal Research and the American Gas Association, and the Synthane process developed by the Bureau of Mines. Pilot plants were built to test each process, and of these two have operated and two are still undergoing shakedown.

These experimental plants offer a clue to the scale and complexity of a synthetic fuels industry—perhaps the best clue now obtainable in the United States, where there has been no operating experience with Lurgi plants. The core of each pilot plant is the gasifier vessel, typically about 2 meters in diameter and, together with its support structure, more than 40 meters high. In addition, however, most of the plants include coal hoppers, coal pretreatment systems, additional reactor vessels, intricate valves, gas cleanup and sulfur recovery systems, process vessels for converting the raw synthesis gas from the gasifier into methane, power stations, oxygen and steam plants, and miles of piping—which in all account for as much as 80 percent of the plant cost. The complexity stems

from the necessity to process a solid, impure fuel at high pressure and temperature.

The pilot plants look very much like miniature oil refineries (Fig. 1), and they are miniature, with capacities of processing only 40 to 120 tons (1 ton = 0.91 metric ton) of coal per day. A commercial gasification plant would be fully 200 times the size of the present units. It would have several gasifier vessels, each 10 to 20 meters in diameter, and it would process 20,000 tons of coal a day. More than 200 such plants would be required to produce as much pipeline quality gas as was consumed in 1975. Clearly, a synthetic natural gas industry represents an undertaking of staggering proportions, comparable in some ways to the nuclear power industry.

The gasification pilot plants are a long way from commercial plants in more than size, however. In the judgment of many independent experts, no one of the four processes has yet proven a suitable candidate for commercialization, and it appears quite possible that none of them will survive past the pilot plant stage of development. The reasons differ from process to process and are instructive for what they reveal not only of the technical difficulties involved in engineering development but also of the state of the coal gasification program.

The Carbon Dioxide Acceptor process, for example, is widely acknowledged as perhaps the most elegant gasification technology yet attempted. It was developed by Consolidation Coal Company (now a subsidiary of Continental Oil), which gets high marks from observers for both the development job and the extent to which both progress and problems were reported in the open literature. The key feature is a flow of limestone or dolomite (the acceptor) that is cycled between the gasifier, where it reacts with carbon dioxide and releases the heat needed to drive the gasification reaction, and a regenerating vessel. This eliminates the necessity for combustion in the gasifier and hence the need for an expensive oxygen plant (combustion with air would contaminate the product gas with nitrogen, thus lowering the heating value; hence most other gasification processes burn oxygen, in varying amounts). The circulating acceptor has other advantages as well, but it makes for a complicated process which will operate within only a narrow range of conditions. Seymour Alpert of the Electric Power Research Institute labels the fact that it was made to operate at all "a unique scientific achievement."

But the chemistry of the process is such that it will only work with reactive coals—lignite or subbituminous coals found in the western United States—a restriction that was not known when development began, and one that is probably fatal. Western coals are low in sulfur and thus ideal for burning directly, they are located far from the major markets for pipeline gas, and many observers believe that in any case the more familiar Lurgi would be the technology of choice for gasifying these coals. "It's just one of those things that happen in this business," Alpert says, "they got to the end, but nobody needs it." Significantly, although the pilot plant is still in operation, Continental Oil itself earlier this year proposed a different process as the basis for a demonstration pipeline gas plant.

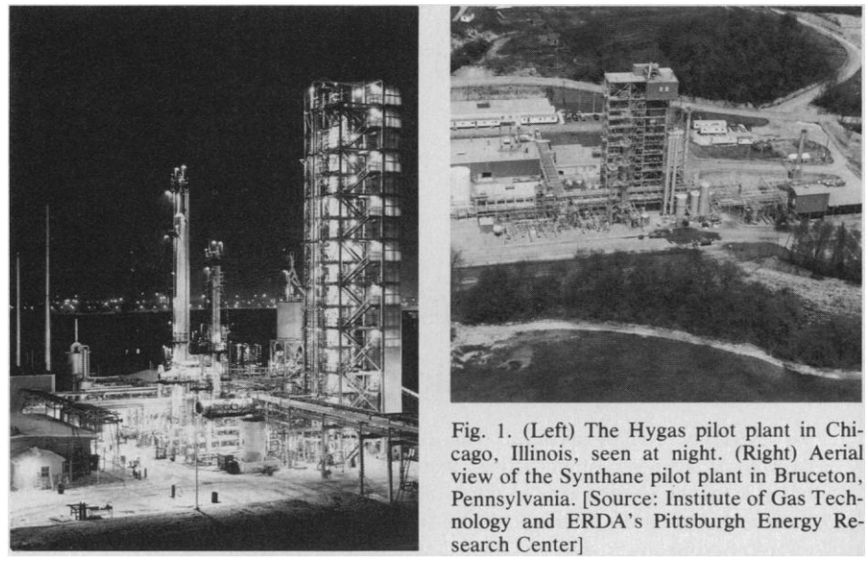

Fig. 1. (Left) The Hygas pilot plant in Chicago, Illinois, seen at night. (Right) Aerial view of the Synthane pilot plant in Bruceton, Pennsylvania. [Source: Institute of Gas Technology and ERDA's Pittsburgh Energy Research Center]

The Hygas process, developed by the Institute of Gas Technology (IGT), uses more straightforward chemistry than the Carbon Dioxide Acceptor process, essentially combining hydrogen with coal to produce gas. The engineering scheme to accomplish this has undergone considerable evolution, and what has emerged is a process that is complicated enough to make many engineers doubtful. Coal is passed into one zone of the reactor as a slurry with oil, which evaporates and is later recovered; the dried coal is then moved to a second and then to a third reactor zone before gasification is complete, leaving a residue of char (carbonized coal); some of the hot char is also circulated among reactor zones as a source of heat for the gasification reaction. The hydrogen consumed in the process is generated when the char residue is burned in still another reactor zone with steam and oxygen. The amount of solids-handling involved is tricky under the best of conditions and becomes more so with caking coals, such as eastern bituminous coal, that have a tendency to stick together when heated. IGT gets around the problem by pretreating bituminous coals, heating them at about 425°C to form a protective skin around the outside of the coal particles, and it seems to work, although some engineers are not convinced that pretreating in this manner will be as effective in larger equipment.

The Hygas process recently completed a continuous 9-day test on caking coal that ERDA describes as demonstrating its technical feasibility, and it had previously been operated successfully with lignite. The process was among those proposed to ERDA for a demonstration plant, but its future seems uncertain. ERDA found the Hygas process technically attractive for a demonstration plant but ultimately decided against it, noting that the subsidiary of Texas Gas Transmission Company that proposed the project was willing to put up only 15 percent of the plant cost.

The Synthane process, developed originally by the Bureau of Mines, is in many ways similar to the Hygas process. Its main distinction is simplicity, in that it accomplishes gasification in a single reactor stage. Coal is reacted with steam and oxygen to form carbon monoxide and hydrogen, which are later converted to methane. The coal enters the reactor in such a way that it comes in contact first with these hot product gases, however, releasing volatiles from the coal and forming directly more than half of the methane ultimately produced, thus reducing the amount of processing required downstream of the gasifier. Coal tars are also released and must be

cleansed from the gas stream. A char residue is removed from the bottom of the reactor vessel; this residue is to be burned separately to generate steam. Pretreatment of bituminous coal is also required with this process.

If it works, Synthane is expected by many observers to be an attractive process because of its inherent simplicity. Operation of the pilot plant began only in July and has not yet advanced to the point of permitting any careful assessment, although Robert Lewis of ERDA's Pittsburgh Energy Research Center says progress so far is "encouraging." Like Hygas, the process was proposed as a candidate for the demonstration plant but without strong financial backing. An ERDA review committee ranked the process lowest of those considered for demonstration, apparently largely because of the lack of operational data, although the committee also identified as technical weaknesses its "unknown ability" to

Questioning the Synthetic Fuels Option

Why convert coal to gas at all? That is the question being asked by a number of scientists who are skeptical of synthetic fuels and their role in the U.S. energy economy. Elburt Osborne of the Carnegie Institution of Washington, for example, believes that coal-based synthetic fuels cannot be produced in large quantities soon enough to avert shortages of natural gas, perhaps not even before world oil production starts to drop. "We have a terrible problem," he says, "and production of coal-based synthetic fuels before about 1990 will be minuscule," an assessment that is widely agreed to.

Osborne and others point out that the largest and most rapidly available source of "new" natural gas is that now burned under electric utility boilers, which could be liberated for other uses if these power plants were converted to burn coal. If done nationwide, for which the Federal Energy Administration already has the requisite authority, such wholesale conversion would make available about 3.5 trillion cubic feet per year—nearly 20 percent of U.S. gas consumption and an amount that would require 40 large coal gasification plants to produce. The same measures for oil-burning power plants would save about 3 million barrels (1 barrel = 160 liters) of oil a day, a comparable portion of U.S. oil consumption. The conversion would not be easy, since it would, among other things, require doubling U.S. coal production. Nor would it be inexpensive, since many power plants cannot readily switch to coal and some, such as gas turbine generators, cannot burn coal at all. The Texas Railroad Commission estimates that it will cost Texas utilities alone about $18 billion to convert their gas- and oil-fired power plants to coal. Nonetheless, conversion to coal does appear capable of making a far larger contribution to oil and gas supplies over the next 20 years than synthetic fuels.

A second, related question frequently debated is whether it makes economic sense to convert coal to gas. This is largely an argument over energy distribution systems, since the direct use of coal for heat outside the electric utility industry is limited and what was formerly a national distribution system for coal has been essentially dismantled. Two major distribution systems that remain are the electric grid and the gas pipeline network, both expensive, fixed-in-place systems that are potential competitors as carriers of coal-based energy. At present, the pipeline system transports about three times as much energy as the electric grid, not counting the gas ultimately used to generate electricity. But as U.S. gas production declines, the pipelines must either turn to coal gasification, to imports of liquefied natural gas, or face obsolescence.

The gas industry has an obvious interest in keeping the pipelines full. But it also appears to have a valid point in asserting that prolonging the usefulness of the pipeline system will be cheaper than creating whole new distribution systems—whether electric grids, coal slurry pipelines, or rail-barge lines. Given the existing distribution systems, however, is the incremental cost of energy from coal cheaper when delivered in the form of synthetic gas or in the form of electricity?

The answer seems to depend both on the application being considered, since electricity and gas are not directly comparable for many uses, and on what assumptions are made. Gas advocates such as Henry Linden of the Institute of Gas Technology in Chicago point to several factors that favor synthetic fuels: conversion efficiencies are higher, 55 to 70 percent as compared to about 37 percent for power generation; gas plants are expected to operate about 90 percent of the time, whereas power plants operate on an average only about 55 percent of the time in response to the varying demand for electricity; and gas is more cheaply transported. Critics of gasification, on the other hand, argue that the capital costs for these plants will be substantially higher than for an equivalent coal-fired power plant even when equipped with stack gas scrubbing devices and that the greater efficiency with which electricity can be converted to useful work or heat more than compensates for lower generation efficiencies.

Several investigators of the relative economics of coal-based gas and electricity for one widely used application, home heating, have concluded that gasification is a more efficient use of coal than power generation with electric resistance heating, the predominant method at present; conversion of coal to electricity appears to gain a slight advantage, however, if heat pumps are used. Clearly both gas and electricity will be needed, but the economic superiority of gasification has yet to be firmly established.

A third critique of synthetic gas is related to its high cost. At wholesale prices approaching $4 per million Btu, some geologists contend, large additional quantities of natural gas can be extracted from heretofore unexploited sources such as coal seams and brown shale deposits. In most cases the gas-bearing material would have to be hydrofractured—a technique in which water is forced into wells under very high pressure to induce cracks in the surrounding rock—before gas production could begin. But a National Research Council panel recently concluded (*Science*, 13 Feb., p. 549) that these deposits contain more than 500 trillion cubic feet of gas. That is enough, critics argue, to question the wisdom of a commitment to a large gasification industry until more is known about the cost and extent of these resources.—A.L.H.

handle extremely fine particles of coal and the need to burn char residues separately. Having "missed the boat" for the ERDA demonstration plant, as one engineer put it who believes Synthane to be a workable process, the development of this process past the pilot plant stage will apparently depend on the willingness of industry to adopt the process and shoulder the associated risks.

The Bi-Gas process being developed for ERDA by Bituminous Coal Research, Inc., faces a similar problem since operation of the pilot plant is still some months away. Bi-Gas is characterized by some engineers as a brute force approach to gasification, since the reaction is carried out at higher temperatures than any other process—3000°F. Pulverized coal, steam, and oxygen are blown very rapidly through a two-stage reactor, unreacted coal and char are separated from the product gases and recycled, and molten ash is removed from the bottom of the reactor. Bi-Gas is a bold—some would say foolish—gamble, in that the complete process has never been tested on a scale smaller than the present $60 million pilot plant, and the extreme conditions require some novel equipment and operating techniques. "It will require many separate miracles to make it work," one skeptical engineer observes, "but it might." If it does, the process is expected to be able to use all types of coal without pretreatment and to produce a high yield of methane directly. The degree of uncertainty about its prospects is sufficiently high, however, that no industrial organization proposed the process for a demonstration plant.

Taken together, the gasification pilot plants do not seem to make an overwhelming case for the success of the Office of Coal Research (OCR) program. Raymond Zahradnik, who now heads coal process development for ERDA, defends the effort as "an outstanding record," but another ERDA official says it is "embarrassing that they haven't produced data or convinced industry." In any case ERDA appears to have shifted its immediate hopes for new pipeline gas processes to other choices. Demonstration plants will be based on one of two processes, and possibly both: an upgraded version of the Lurgi and a process known as Cogas. The modified Lurgi, because it operates at temperatures high enough to melt coal ash, is known as a slagging Lurgi, while Cogas is a composite process that produces gas and liquids. Both are based in part on recent British work on pilot plant development.

The slagging Lurgi, proposed by Continental Oil, represents an improvement over the commercial version of this gasifier. The process is expected to be somewhat more efficient and to be able to use some caking coals, although there have been relatively few test runs with U.S. coals at the British Gas Corporation's pilot plant in Westfield, Scotland. Nonetheless, the process is described as "robust" by one American engineer, Arthur Squires of Virginia Polytechnic Institute and State University, and it was ranked highest of those considered by an ERDA review panel. Perhaps because the process is not totally new, the panel described it as having low technical risk despite unresolved problems with its refractory design and its ability to process very finely divided coal.

The Cogas process, proposed by a group of Illinois gas pipeline companies, is rated by ERDA as more of a gamble since it involves putting together for the first time two separate coal conversion techniques. One is a process to produce char and synthetic oil that was developed for OCR by FMC, Inc., and for which the pilot plant was dismantled earlier this year. The other is a new British process, still under development, for gasifying char. The main attraction of this gasification process is that it does not require an expensive oxygen plant. The integrated process as contemplated would produce nearly equal amounts of gas and oil, and would be extremely complicated, apparently requiring four separate reactors for the char-oil step alone. Moreover, several observers familiar with the oil by-product have questioned whether it can be readily sold, as it is not easy to burn in most boilers without further refining. Nonetheless, ERDA's review panel was favorably impressed by the potential thermal efficiency and overall economics of the combined process.

Rejected for a demonstration plant, in addition to Hygas and Synthane, was a Texaco process developed for gasifying heavy oils. The Texaco process partially oxidizes coal by burning it incompletely with oxygen. The process can use caking coal without pretreatment and has in fact operated over a number of years with a wide range of coals, a degree of experience that is impressive to many observers. ERDA assessed it as having low thermal efficiency and high product cost, however, and disliked Texaco's proposal to retain all revenues from a demonstration plant for itself.

Counting U.S. and British processes together, industrial- and government-sponsored, a total of seven processes for making pipeline quality gas have been considered as alternatives to the Lurgi and tested in pilot plants. Still others considered very promising by ERDA are in earlier stages of development. But the first commercial Lurgi plants have yet to be built in the United States, and that fact appears to weigh more heavily in the prospects for making pipeline gas than the considerable technical ingenuity represented by the new processes.

New processes to convert coal to low-Btu gas are also being developed, but they are not as far advanced. ERDA is supporting half a dozen development efforts, none of which has yet reached the pilot plant stage. These projects are of relatively recent origin, compared to the pipeline gas program, and, with a few exceptions, they are considered by most observers to be of generally greater technical quality. Several of the pipeline gas processes, without their methanation stage, are also considered competitors for producing low-Btu gas, especially for use with gas turbines in combined-cycle generating plants. Despite the lack of pilot plant experience for many of the newer processes, ERDA has decided to push ahead with a low-Btu demonstration plant and is now evaluating proposals from industry.

Many observers express guarded optimism about the technical future of coal gasification but point out that the political and economic climate is more important to the realization of that future than technology. Eric Reichl, a respected coal scientist who is president of Continental Oil's coal development company, believes that "technology is not the key to success in coal conversion; politics is," despite the fact that his company was one of those awarded a contract to design a demonstration gasification plant. Reichl contrasts the national commitment made by Germany in the 1930's to develop synthetic fuels to the present lack of a political consensus on this subject in the United States, and goes on to say, "We could start building coal-to-gas plants right now. If we do not, this is again a political, not a technical decision. The issue after all is cost. Gas from coal will cost more, much more, than the price we have become accustomed to paying for natural gas." One ERDA official voiced a similar view of the problem, saying, "it hasn't been politically appealing to stand up and say, 'clean energy will cost you a lot of money.' "

—ALLEN L. HAMMOND