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ABSTRACT

The Foreign Coal Liquefaction Technology Survey and Assessment is part of the International Energy Technology Assessment effort. Although it might have been desirable to include all technologies from all countries, this was not possible with the resources available. Instead, only six countries were chosen. They are Australia, the Federal Republic of Germany (FRG), Japan, New Zealand, South Africa and the United Kingdom. These countries were selected because they have active coal liquefaction programs, are using or developing technologies that could be used in the U.S. and/or are involved with U.S. coal liquefaction programs.

To place the programs in these countries into perspective, the resources that each has and the policies that have been adopted by their governments are presented. This material is covered in the first chapter.

Although each of these countries has numerous programs underway or planned, the amount of information available on each program varies. While brief descriptions of the programs are given in the first chapter, the second chapter deals only with those liquefaction projects and gasifiers associated with direct liquefaction for which an adequate amount of reference material could be found.

Because there are many aspects of direct liquefaction that are critical and for which much development work is still required, there was a need for the third chapter. Here, critical areas that are common to all or many liquefaction systems are described, making use of material from one or more liquefaction projects.

In the final chapter materials of construction are dealt with as a separate topic. Coal liquefaction has placed new demands on the performance of materials. Hostile environments abound and innovations in materials will be necessary in order for some of the less-developed technologies to reach fruition.

SUMMARY

Capsule Summary

Australia has enough coal to meet domestic needs and to become an important energy exporting country, but does not have an extensive liquefaction technology base. Other countries such as Germany and Japan are proposing joint coal liquefaction projects, based on currently available technology, with Australia.

Germany, sensing an economic opportunity in the revivial of interest in coal conversion technology brought about by the oil crisis of 1973-74, has again become a world leader in the development and marketing of coal liquefaction and gasification technology.

Japan has no domestic oil or natural gas resources to speak of and has very little coal. Therefore, the country has not developed much of a coal liquefaction capability and must import practically all of its liquid fuel requirements. Diversification of its energy supply base is the keystone of Japan's national strategy.

New Zealand's short-term plans are to convert much of its natural gas resources into gasoline using the Mobil methanol-to-gasoline process. In the long run, the country's large coal reserves will probably be used to produce synthetic liquid fuels as natural gas supplies are depleted.

South Africa, as a result of a major strategic decision made over 30 years ago, has applied pre-war German technology to its coal resources and developed the only commercial-scale indirect coal liquefaction facilities in the world today. South Africa is increasing its efforts in marketing Sasol technology in other countries.

The United Kingdom possesses large reserves of coal. The need to develop or apply technology to convert it to liquid and gaseous fuels is not immediate, however, because the country is essentially self-sufficient in oil and natural gas (from the North Sea) at the present time.

The United States which has the potential to duplicate the positions of both Germany and South Africa as leaders in the development, application and marketing of coal liquefaction technology has not done so because of a lack of domestic economic incentive (i.e., cheap oil) and the absence of governmental direction and support.

Executive Summary

Australia

Australia is well endowed with mineral resources, including large reserves of coal. Natural gas, oil shale, and uranium, as well as some crude oil, are also found.

At present, Australia is a net exporter of energy, with coal and uranium leading the way. Crude oil and refined petroleum products are the only energy imports, with 65-70% of petroleum products now being supplied from domestic sources.

Australia's coal reserves are its prime energy assets. Black coal, a volatile bituminous type, is found in New South Wales and Queensland. Brown coal, a lignite variety, is found predominantly in Victoria. At present, all the brown coal is used domestically for generating electricity. Of the 77 million tonnes (85 million tons) of black coal mined annually, 44 million tonnes (48 million tons) is exported (chiefly to Japan), making Australia second (to the United States) as a coal exporting country.

Australia is naturally looking at coal as one of the raw materials upon which to base a synfuels industry to supply needed transporation fuels in the face of an expected future decline in crude oil production. Both black and brown coals are being considered as starting materials. Direct liquefaction, indirect liquefaction, and pyrolysis processes are all being considered. The country is also involved in joint studies and projects with Germany and Japan.

Federal Republic of Germany (FRG, West Germany, or Germany)

West Germany has large reserves of hard coal and lignite (brown coal); technically and economically recoverable reserves have been estimated at over 34 billion tonnes (38 billion tons). However, the country has limited supplies of oil and must import about 96% of its needs of this source of energy. About 62% of Germany's requirements of natural gas is also imported.

In the first half of this century Germany led the world in the production of synthetic fuels from coal by both the direct and indirect routes of liquefaction. Interest in these technologies revived again after the Arab oil embargo in 1973-74 and resulted in Germany once more becoming a world leader in the development and marketing of coal conversion processes and equipment.

The FRG, in conjunction with industry, has an ambitious program underway consisting of a total of 14 gasification and liquefaction projects at an estimated cost of $7.4 billion through 1993, a large portion of which is federally funded. The main objective of this program, according to the Ministry of Research and Technology (BMFT), is to help German industry build a new high-technology industry for export to the major coal producing countries of the world.

First-generation gasifier technology such as Lurgi, Koppers-Totzek, and Winkler were used as the basis for corresponding new projects such as the Ruhr 100, Shell-Koppers and High-Temperature Winkler gasifiers. The original high-pressure direct liquefaction processes of Bergius and Pott-Broche have been modified and improved to operate at lower pressures and temperatures, with increased efficiencies and yields. The Fischer-Tropsch indirect liquefaction process [commercialized as the ARGE (fixed-bed reactor) and Synthol (entrained-bed reactor) systems at the Sasol facilities in South Africa] is also being developed in a three-phase (fluid-bed) reactor.

Of nine gasification projects, the Texaco, Ruhr 100, Shell-Koppers, and Saarberg-Otto gasifiers have been proposed for gasification of liquefaction process residues to generate hydrogen required for liquefying coal.

Ruhrkohle and Ruhrchemie jointly operate the 150 ton/day Texaco pilot plant at Oberhausen-Holten. More than 6,500 hours of operation have been achieved with several continuous test runs up to 800 hours. Approximately 36,000 tons of different coals have been converted to synthesis gas at a maximum rate of about 13,000 m^3/hr (460,000 ft^3/hr).

Since 1974, Ruhrgas, Ruhrkohle and Steag in cooperation with Lurgi have been developing the Ruhr 100 gasifier at Dorsten. The pilot plant, which began operation in September 1979, has a maximum design throughput of 170 tons/day of run-of-mine coal. Design features of the Ruhr 100 gasifier make it possible to control heating of the coal in the plastic temperature range and to reduce the rate of gas flow in the coal carbonization and drying zones. This reduces the amount of coal fines entrained in the raw gas. The gasifier is also equipped with a stirrer for breaking up caking coal.

Shell's experience on high-pressure oil gasification combined with Krupp-Koppers know-how of construction and operation of Koppers-Totzek gasifiers is the basis for the joint development of the Shell-Koppers gasifier. Following successful operation of a 6-ton/day bench-scale plant since 1976, a pilot plant with a coal throughput of 150 tons/day has been operated at the Shell refinery in Hamburg-Harburg since November 1978. This project has not been subsidized by public funds and therefore results are proprietary.

Saarbergwerke and Dr. C. Otto & Co. are demonstrating the Saarberg-Otto system of pressurized [2.5 MPa (360 psi)] coal gasification. A 260-ton/day pilot plant was commissioned in 1978. The specific feature of this gasifier is a liquid slag bath and a system of nozzles directed tangentially toward the surface of the bath. The bath is rotated by the impulse of the injected coal and gasifying agents. Tests runs are focused on the key problems of controlling the feedstock injection and of removing the slag.

Government-supported liquefaction projects based on modified old German technology are being carried out by Ruhrkohle, Saarbergwerke, and Rheinbraun.

Ruhrkohle and Veba Oel have built a 200 ton/day direct coal liquefaction pilot plant at Bottrop. Plant design is based on a modified version of the old German (Bergius) catalytic hydrogenation process developed by Bergbau-Forschung. Owing to the process modifications (for example, substitution of vacuum distillation in place of centrifugation for separating solids from the coal oil product), the following improvements are expected: (1) a drop in pressure from 700 to 300 bars (10,500 to 4,500 psi), (2) an increase in specific coal throughput of 50%, (3) an improvement in heat recovery, (4) an increase in thermal efficiency of 25%, and (5) a decrease in specific conversion costs. The plant was completed in early 1981 and start-up operations began in July 1981.

The Saarberg process for direct liquefaction is also based on the I. G. Farben (Bergius) high-pressure catalytic hydrogenation process. Construction of a 6-ton/day (coal feed) pilot plant was completed in 1980. The plant produces about 2-3 tons of oil products per day. Liquefaction residue is gasified to provide hydrogen for the plant. Saarbergwerke's partner BASF is developing product upgrading processes, including catalytic gas-phase hydrogenation, for making transportation fuels.

The Rheinbraun HVB direct liquefaction process is based on the work of Bergius and Pier in the 1920s and on operation of WW-II production facilities at Wesseling. The key feature of the catalytic HVB process is the application of this technology to brown coal (i.e., lignite). Rheinbraun has operated a test plant at Wesseling with a feed rate of 0.3 tons of coal per day since 1978. In the HVB process, liquefaction of coal is carried out in two stages. In the first stage (called sump-phase hydrogenation), dry brown coal is catalytically converted into coal oil. In the second stage (gas-phase hydrogenation), coal oil is converted into motor fuels by conventional oil refining techniques. Development work has been centered on improvements to the sump-phase hydrogenation stage.

The Fischer-Tropsch indirect liquefaction technology has been well-established at the Sasol facilities in South Africa. The ARGE (fixed-bed) and Synthol (entrained-bed) reactors have been steadily optimized and moderized to present-day technology. (This is covered in a separate report by T. D. Pay, *Foreign Coal Liquefaction Technology Survey and Assessment. Sasol — The Commercial Experience,* ORNL/Sub-79/13837/4, November 1980.)

Liquefaction of coal is at present not economical in Germany. However, the production of synthesis gas from brown coal is close to becoming economical. Liquid products and SNG from hard coal cost two to four times as much as crude oil products or natural gas.

Japan

The major problem facing Japan is that the country depends on foreign sources for 88% of its energy supplies. In 1978, imported oil (about 90% from OPEC countries) accounted for over 70% of Japan's energy supply. Domestic coal production is about 20 million tonnes (22 million tons) per year, which represents about a quarter of the demand. Renewable resources such as hydropower and geothermal energy are being used for electricity generation, but supply only about 5% of the overall energy demand. Nuclear energy is also used for generating electricity.

The deterioration of the world oil situation in 1973 forced Japan to consider its energy options. It was recognized that while the quantity of imported energy could not be significantly reduced, the base of energy supplies could be diversified. Thus, diversification has become the keystone of Japanese energy strategy - the more fuel types in the mix, the more countries that would be supplying Japan with energy.

Japan's effort to diversify primary energy soruces led to the initiation of the Sunshine Project in 1974. The major goal of this project, funded by both government and private enterprise, is to stabilize future energy supply in Japan through development of innovative technologies to make use of such nonnuclear energy sources as solar energy, geothermal energy, coal-derived liquid and gaseous fuels, and hydrogen energy. Total R&D funds for the project for the 1980-1990 period are about $10 billion of which two-thirds are public funds and one-third is private funds. Coal conversion R&D activities account for about 70% of the total.

Development of liquefaction technology in Japan is concentrated on direct liquefaction processes. Under the Sunshine Project, three processes are under develpment: solvolysis, solvent extraction and direct hydrogenation. A one-ton/day solvolysis PDU (process development unit) is operating, and a 40-ton/day PDU is in the design stage. A one-ton/day solvent extraction PDU is operating, and a 2.4-ton/day direct hydrogenation PDU is under construction. Two privately-financed projects are underway: the Kominic Project has a 0.5-ton/day SRC-type PDU in operation, and the Mitsui SRC Project is operating a five-ton/day PDU making liquid SRC product.

In the international area, a consortium of twelve Japanese companies is participating (about 8% of total funding) in the EDSS (Exxon Donor Solvent) Project. Japan was also a partner in the SRC-II project until it was cancelled.

Nippon Oil Ltd. and Chevron Research Company are involved in a cooperative pilot plant project in Japan to use Chevron's proprietary catalytic liquefaction technology to process Australian brown coal.

Nippon Brown Coal Liquefaction Company (consisting of five Japanese companies) is engaged in a joint Japanese-Australian undertaking to liquefy Australian brown coal. The initial phase of the project calls for construction of a 50-tonne (55-ton) per day (dry coal) pilot plant in Victoria coming onstream in 1983. The plant will be based on a catalytic SRC process. The second phase of the project involves construction of a 5000-tonne (5500 ton) per day demonstration plant to be completed by 1985. The demonstration plant will serve as the first unit of a six-unit 30,000-tonne (33,000 ton) per day commercial plant to be constructed by 1990.

New Zealand

Coal is New Zealand's most plentiful resource. At the present rate of consumption, the country's proven and measured deposits of bituminous, subbituminous coal and lignite would last about 100 years. Oil that is found is condensate associated with natural gas. Estimated reserves from the Maui and Kapuni gas fields represent less than a seven-year supply at the present total annual consumption rate of oil. At present rates of use, the natural gas would last about 100 years, but plans are to use the Maui field at a rate that would deplete it in about 30 years. The gas will be converted to gasoline in a synthetic fuel plant based on the Mobil methanol-to-gasoline (MTG) process.

On April 1, 1980 Petrocorp, New Zealand's state-owned oil company, signed an agreement with Mobil for a $500 million synthetic fuel plant that is expected to produce about 4.5 million barrels per year (12,000 barrels per day) of motor gasoline. (This is approximately one-third of the country's current requirements.) The government will have a 75% share-holding and Mobil the remaining 25%.

Petrocorp has also entered into an agreement with Alberta Gas Chemical Ltd. of Canada for construction of a methanol facility. This will also use Maui field gas as feedstock to produce about 1200 tonnes/day (1320 tons/day) of methanol. The plant will cost an estimated $130 million and is expected to be producing by late 1982. Most of the methanol will be exported.

At the present time, coal plays a very small role in providing synthetic fuel energy. In the long run, however, New Zealand's large coal reserves will probably be used to produce synthetic liquid fuels to replace the dwindling supply from the Maui gas field.

South Africa

South Africa has abundant mineral resources with one excpetion - petroleum. Coal represents the largest energy resource, with extractable reserves estimated at 61 billion tonnes (67 billion tons). At present, South Africa supplies between 75 and 80% of its energy needs from coal.

Because of its original complete dependence on foreign sources to supply its liquid fuel requirements, South Africa over 30 years ago decided to exploit its coal resources and has since developed the only commercial-scale coal liquefaction facilities in the world today. The indirect liquefaction process on which the plants are based is pre-war German (Fischer-Tropsch) technology.

Sasol One went on line in 1955 and is still producing a variety of fuels and chemical feedstocks from coal. The 1973 oil embargo led to a government decision in 1974 to construct Sasol Two at Secunda. The change in the Iranian government led to a decision in 1979 to build Sasol Three adjacent to Sasol Two. When Sasol Three comes into production as expected in 1982, the combined output of Sasol Two and Three will provide about half of South Africa's transportation fuel requirements. (For a more detailed description of the Sasol plants, see the first report in this series by T. D. Pay, Foreign Coal Liquefaction Technology Survey and Assessment. Sasol - The Commercial Experience, ORNL/Sub-79/13837/4, November 1980.)

The price of gasoline (last quarter of 1980) was about $2.80/U.S. gal. Approximately $0.20 of this represents a levy that is helping to finance the Sasol Two and Three facilities.

South Africa is rapidly increasing its efforts in marketing Sasol technology in other countries.

The present coal extraction rate is over 100 million tonnes (110 million tons) a year but this is expected to increase substantially to meet demands of the Sasol Two and Three synthetic fuel plants [combined requirement 27 million tonnes (30 million tons)], increased exports to Japan and Europe, and requirements of additional domestic electric generating capacity currently being installed. Nevertheless, the coal reserves will continue to supply the country for at least 200 years.

United Kingdom

The United Kingdom has large coal reserves (45 billion tons of proven reserves minable by existing technology). Due to an adequate supply of oil and natural gas from the North Sea there is no demand at present for synthetic fuels manufactured from coal.

The United Kingdom's coal liquefaction program is based primarily on development of the LSE (liquid solvent extraction) and the SGE (supercritical gas solvent extraction) processes. At present the National Coal Board is looking for sponsors to invest in a 25 t/d coal liquefaction pilot plant planned for Point of Ayr, North Wales, which can operate in either the LSE or SGE mode. Construction of the plant will take three years to complete.

The LSE process uses a process-derived solvent to dissolve coal at about 420°C (790°F) and 1.0 MPa (145 psi) pressure. The process is somewhat similar to the SRC process. The solvent acts as a mild hydrogen donor, and hydrogen is not added directly to the reactor. The coal extract is separated from ash and mineral matter by filtration. In a second stage, the extract is hydrogenated and cracked to produce liquid fuel. A 30 kg/hr (66 lb/hr) experimental facility is located at the Coal Research Establishment, Stoke Orchard.

The SGE process uses an organic solvent (such as toluene) to extract a hydrogen-rich fraction of the coal, leaving a char behind. The SGE process is currently being studied in a pilot plant having a capacity of 5 kg/hr (11 lb/hr) and which operates at pressures up to 40 MPa (5800 psi) and temperatures up to 500°C (930°F). The coal is initially pulverized, slurried with the solvent, and pumped through a preheater into a fluidized bed where char is separated from the extract batchwise. The NCB is working on a continuous method of char separation. After leaving the reactor, the extract is hydrocracked to produce fuel and chemical feed stock.

Before the discovery of North Sea oil and gas in the mid-1960s, Britain had a town gas distribution system fed with gas manufactured from coal. Recently, the British Gas Corporation set up a 20-year program to develop a process (including a full-scale demonstration) for manufacturing SNG from coal for use when the natural gas supply declines. This program is based primarily on the use of the British Gas/Lurgi Slagging Gasifier and the development of an advanced gasifier known as the Composite Gasifier that couples an entrained flow gasifier with a slagging gasifier to better handle coal fines. A methane synthesis process known as the HCM (high carbon monoxide) process is being developed specifically to exploit the characteristics of the slagging gasifier.

The Lurgi gasifier produces only a moderate amount of methane, and for SNG manufacture methane must be produced from the carbon monoxide and hydrogen present. The British Gas HCM process is tailored to take advantage of the high CO and low CO_2 and steam content of gas from a slagging gasifier and to produce most of the steam required by utilizing waste heat. Process conditions chosen for the HCM process have been validated by laboratory and pilot plant tests.

The British Gas 20-year program includes continued operation of the 6-ft diameter slagging gasifier at Westfield for performance evaluation. An 8-ft diameter gasifier is to be installed to check out commercial design and operating parameters. The program includes testing on a range of British coal, testing of injection of tar and fine coal into the gasifier, a three-month demonstration run, and the production and distribution of SNG using the slagging gasifier and the HCM process. Construction of the 8-ft diameter gasifier and the three-month run during which the gas will be treated by the HCM process to make SNG should be completed in 1982.

Although slagging gasifiers can handle some fines by injection into the gasification zone, the ability of the gasifier to consume the entire run-of-mine coal which could contain as much as 60% fines is desirable. To achieve this, British Gas initiated development of the Composite Gasifier. This unit consists of a pressurized entrained-flow slagging gasifier for coal fines coupled with a lump coal slagging gasifier. The experimental unit (20 t/d) to test the composite gasifier concept as well as other methods of handling fines is to be built at Westfield and is expected to be ready for commissioning in 1983.