STATUS OF COAL LIQUEFACTION IN THE UNITED STATES*

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1. INTRODUCTION

A previous paper(1) gave a brief overview of the status of coal liquefaction in the U.S. as of February 1979. Since then, a number of significant changes have taken place. World oil prices have doubled, most of the increase occurring in 1979-1980, but the viability of commercial liquefaction ventures still appears to depend on some form of government support. The 1980 Energy Security Act proposed ambitious goals for synthetic fuels production and established the United States Synthetic Fuels Corporation (SFC) to help in the financing of private-sector ventures to meet these goals. However, as a result of higher prices and a worldwide recession in economic activity, a marked softening in the oil market occurred, and with the change in U.S. administration in 1981, Federally-funded research and development efforts have been reduced and redirected, placing greater responsibility for short-range development and commercialization on the private sector. Two large liquefaction pilot plants, the H-Coal plant at Catlettsburg, Kentucky and the EDS plant at Baytown, Texas, have been placed in service and have accumulated considerable operating experience. A number of proposed commercial projects have applied to the SFC for financial assistance, and preliminary selection of projects for further consideration has taken place.

In the succeeding sections, these developments are discussed in greater detail.

2. COAL LIQUEFACTION PROCESSES

2.1 Classification of Processes

For purposes of discussion, we divide coal liquefaction processes into four categories. These are (1) indirect liquefaction, such as Fischer-Tropsch and methanol synthesis, in which coal is first gasified to produce a synthesis gas which is then recombined to produce liquids; (2) direct liquefaction processes, typified by SRC-I and II, H-Coal, and Exxon Donor Solvent (EDS), in which a slurry of coal and solvent is subjected to high severity liquefaction conditions, either with or without added catalyst; (3) two-stage liquefaction, such as Conoco's CSF process, in which an initial dissolution at mild conditions is followed by a more severe catalytic hydrogenation-hydrocracking step; or the short contact time two-stage liquefaction processes being developed currently by DOE/FE and EPRI; and (4) pyrolysis and hydropyrolysis processes, such as COED and Cities Service-Rockwell, in which coal is carbonized to produce liquids, gases, and char. The order in which we have listed these categories and processes is not meant to imply any technological or economic preference.

In our earlier paper we included simplified flow diagrams and brief descriptions of various processes. In this paper, because of space and time limitations, we will proceed directly to the status of development of some of the major processes.

*Research sponsored by the Fossil Energy Office, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

2.2 Status of Development

2.2.1 Indirect liquefaction

Commercially available technology exists for several indirect liquefaction configurations, and several variants of this technology are being considered as commercial ventures with support requested from the Synthetic Fuels Corporation.

The major contenders in indirect liquefaction are Fischer-Tropsch, methanol, and Mobil MTG. Major interest centers around the development of gasifiers and application of new reactor concepts. Among the latter are the Kolbel-type slurry phase synthesis reactor and the Lurgi tubular reactor (already commercial) in which a coolant such as boiling water or molten salt circulates around catalyst-filled tubes.(2)

The Lurgi gasifier has a proven commercial record for processing low rank coals, and recent tests in South Africa proved the commercial Mark IV gasifier can process caking bituminous coals, albeit with reduced throughput and increased oxygen and steam requirements. The Koppers-Totzek gasifier is commercially available for processing virtually all coals. Gasifiers under development include the Texaco wet slurry feed, the Shell dry feed, the Westinghouse fluidized bed, the British Gas Corporation slagging Lurgi, the KBW, and the Saarberg-Otto molten slag bath type. The Texaco gasifier has been demonstrated at a scale of 150 TPD at Oberhausen-Holten, FRG, and has been installed at a 200-TPD scale at TVA's coal-to-ammonia facility at Muscle Shoals, Alabama. Dow is operating pilot-scale Texaco gasifiers in Freeport, TX, and Plaquemine, LA with lignite feed, and Tennessee Eastman has a commercial-scale Texaco gasifier under construction in Kingsport, TN, to process bituminous coal. A 1000-TPD gasifier is planned at the Cool Water combined cycle facility near Barstow, California. The Shell dry coal feed entrained-flow gasifier has been demonstrated in a 150-TPD pilot plant at Harberg, FRG and plans are under consideration for a 1000 TPD unit in northern Germany. A Westinghouse fluidized-bed gasifier is being installed at the Sasol plant for testing, and Westinghouse and Sasol have recently announced their intention to demonstrate and license this concept. The British Gas Corporation slagging Lurgi has been declared ready for commercial use and is being offered by BGC with commercial guarantees. BGC has announced a decision to construct and test a larger diameter unit at Westfield. The Koppers-Totzek gasifier is being combined with a B&W water-wall steam generator for improved recovery of high pressure steam; the concept is offered by KBW. A 130-TPD Saarberg-Otto gasifier is currently being tested at Furstenhausen, FRG.

A major event in indirect liquefaction technology was the commissioning in 1980 of the SASOL-II plant in South Africa. This Fischer-Tropsch plant uses 36 Lurgi Mark IV dry-ash gasifiers, of which 6 are spares, to gasify about 28,000 tons of coal per day. Total coal feed rate to the facility is about 40,000 TPD; about 12,000 TPD goes to the boiler plant. SASOL-III, which will be completed in 1982, is essentially a duplicate of SASOL-II. The two facilities together will cost about $7 billion and will produce about 120,000 bbl/day of liquid fuels.

The fixed-bed version of Mobil's methanol-to-gasoline (MTG) process is scheduled for commercialization in a 13,000 bbl/day (gasoline) plant in New Zealand. Feedstock for the methanol plant will be natural gas from the Maui field. The fluidized-bed version will be tested in a pilot plant which is under construction in Germany.

2.2.2 Direct liquefaction

The single-stage version of the SRC-I process has been operated in a 6-TPD pilot plant at Wilsonville, Alabama, and in a 50-TPD pilot plant at Fort Lewis, Washington. The Fort Lewis plant has also operated in the SRC-II mode, in which case its throughput is reduced to about 30 TPD. The Fort Lewis plant, which was the largest operational coal liquefaction plant in the U.S. in 1979, has now shut down.

Design, planning, and experimental studies are continuing for the 6,000 ton/day two-stage SRC-I demonstration plant at Newman, Kentucky. Under the cost-sharing agreement reached in 1980, funding for the construction and operation of the plant will be largely by DOE, with International Coal Refining Corporation supplying $90 million and the state of Kentucky supplying $30 million. The total net cost of the project (including design, construction, and operation) has been estimated at $1.77 billion, based on the difference between projected expenditures of $4.57 billion and projected revenues of $2.8 billion.

The SRC-I process concept has undergone some modification since 1979. In the current version of the process, a second stage has been added to convert the heavy first-stage product into lighter materials by catalytic hydrocracking in an expanded-bed reactor. The use of filtration for solid-liquid separation is no longer contemplated and has been replaced by Kerr-McGee critical solvent deashing. The data base for the latter process has been considerably strengthened.

Presently available funding from DOE for the SRC-I demonstration plant is sufficient to complete the design and cost estimate for establishing the project baseline; International Coal Refining Company (ICRC) plans to deliver baseline documentation at the end of March 1982. Additional DOE funding to support the demonstration plant project is presently considered to be unlikely. ICRC is evaluating the possibility of submitting a proposal to the SFC during the current second round solicitation, but no decision on this has been announced. Construction of the project is unlikely to proceed without some form of government assistance.

The SRC-II demonstration plant project has been discontinued and there are no DOE plans for further development of the process. The decision to halt work on the project was reached in mid-1981 following discussions in Bonn among representatives of DOE, Japan, and FRG. Projected cost increases appeared to be the major point of concern.

Operation of the H-Coal and Exxon Donor Solvent pilot plants will be discussed in a subsequent section of this paper.

2.2.3 Two-stage liquefaction

Some interesting developments in two-stage direct liquefaction have occurred. Both DOE and EPRI are supporting active bench-scale and PDU development of two-stage liquefaction concepts. The Wilsonville facility has been successfully operated with a second stage H-Oil hydrocracker and with reduced dissolver severity. As mentioned earlier, the SRC-I demonstration plant concept has been modified to include expanded-bed catalytic hydrocracking of the extract. This in effect changes the original SRC-I concept to a two-stage process. The LC-Fining process (C-E Lummus and Cities Service) has been a principal candidate for use as the second-stage hydrocracker. Process development data for this process combination have been obtained under DOE sponsorship.(3)

2.2.4 Pyrolysis processes

Interest in the development of pyrolysis and hydropyrolysis processes appears to be continuing at a relatively low level in comparison with direct and indirect liquefaction. DOE funding of pyrolysis-hydropyrolysis development has been greatly curtailed. The Cities Service-Rockwell short residence time hydropyrolysis development unit is currently inactive.

However, commercial-scale application of low-pressure pyrolysis is being actively investigated by Utah Power and Light Company.(4) In their concept, the carbonization tars and oils would be upgraded to distillate products, while residual tar would be burned along with the char for power generation. UP and L is pursuing two possible carbonization technologies - Lurgi Ruhrgas and Toscoal. Based on favorable economic studies conducted to date, large pilot plant carbonization runs are planned. A decision as to whether to proceed with the commercial plant (20,000 TPD) is expected by 1985.

3. PILOT PLANT OPERATING EXPERIENCE

The H-Coal pilot plant at Catlettsburg started up on oil feed in February 1980 and went to coal feed in May 1980 using Kentucky No. 11 coal in the syncrude mode. Initial operations were hampered by various mechanical problems, principally including failures of the high pressure separator slurry letdown valve and its associated block valves and of the slurry charge pump packing. The plant was shut down in November 1980 for maintenance and resumed operation in February 1981 on Illinois No. 6 coal in syncrude mode. A successful run of 45 days duration was achieved from February 17 to April 3. Previously, the maximum continuous coal feeding run time had been about 5 days. Coal feed rate during the 45-day run was about 85% of design; the run was terminated by failure of a low-pressure flow control valve in hydroclone feed service. By May 1981 the plant had logged over 1500 hours processing eastern U.S. bituminous coal at 200 TPD.(5) Another long run on Illinois No. 6 coal was made from August 1981 to December 1981, feeding a total of over 17,000 tons of coal at design capacity. Operations on subbituminous coal have since been initiated. DOE support for operation is scheduled to end in 1982. There has been some discussion of possible continuation beyond 1982 under private sponsorship.

The 250 TPD Exxon Donor Solvent pilot plant was completed in May 1980 and started up in June of that year. Shakedown runs and operation on bituminous coal (Illinois No. 6) were completed by July 1981. The plant was then modified to recycle bottoms material from the fractionator back to the reactor, and operation on sub-bituminous coal (Wyodak) was started. These runs were completed early in 1982. The plant is currently running with the bottoms recycle operation on Illinois No. 6 coal. The bottoms recycle operation had been tested previously on smaller-scale equipment and has been shown to give an improved overall product yield structure, considerably increasing the yields of naphtha and lighter products while reducing or eliminating 850 F+ fuel oil, and giving improved operability resulting from decreased viscosity of the resulting vacuum bottoms.(6)

During early 1981 the EDS pilot plant achieved a run of 36 days on stream at design capacity with Illinois No. 6 bituminous coal in the original once through configuration. Following a turnaround in which vacuum bottoms recycle capability was installed, the plant achieved a run of 58 days on stream with Wyodak subbituminous coal in the bottoms recycle configuration during the period July-September 1981. During late 1981 and early 1982 the plant achieved a sustained run with Illinois No. 6 coal in the bottoms recycle mode.

During these operations most technological objectives were attained and three design points were demonstrated. Slurry letdown valve and block valve performance has been satisfactory. Initial experience with packing seals on slurry pumps was unsatisfactory, but substantial improvement has been realized through use of improved materials and designs. Several short runs were terminated due to various problems including plugging of the vacuum bottoms recycle line, plugging of the heavy vacuum gas oil circuit, failure of purge tubing, and slurry transfer line erosion. Two process concerns have been identified through extended operation at large scale. Coke deposition in the fired slurry heater has been high and yields have been different from expectations, apparently because slurry residence time in the reactor was less than expected.

4. PROBLEM AREAS

4.1 General

Pilot plant operations have disclosed various problem areas. All coal liquefaction processes place severe demands on certain critical items of process equipment including valves, pumps, compressors, and heat exchangers. Recent work at Morgantown Energy Technology Center has led to substantial improvement in lock hopper valve performance, and experience with the EDS and H-Coal pilot plants have evidenced substantial improvement in the performance of high pressure letdown and block valves for slurry service. Packing life and check-valve performance with slurry charge pumps remains less than desirable, but improvements in materials and design have been noted. Large compressors for oxygen supply to gasifiers and for hydrogen and/or synthesis gas recycle or compression have often proven troublesome. The successful test of a high capacity third stage casing of a DEMAG centrifugal oxygen compressor will permit more economic and efficient designs. Concerns with seals and valves of hydrogen and synthesis gas compressors center primarily on reliable gas clean-up. Commercial performance appears to be satisfactory, but performance with smaller pilot plants continues to reflect imperfect practice. Fired heaters for slurry service and heat exchangers for slurry or dirty gas service have been areas of technical concern. Fired heater tests at Fort Lewis and Baytown have provided greater confidence in design, but experience with coking remains a serious concern. Dirty gas heat exchangers have not performed uniformly well, but the unit designed by Ruhrkohle AG for the Texaco gasifier at Oberhausen apparently has performed well.

The corrosive and abrasive environment characteristic of all coal liquefaction processes presents severe challenges to the materials of construction. Satisfactory performance has generally been observed, but several specific problems have arisen. Considerable technological progress in mitigating these problems has been made.

Concerns with the refractory life in entrained-flow gasifiers have been satisfactorily addressed through refractory selection, thickness, and/or cooling. Erosion problems in handling slurries are generic; especially severe erosion has been noted under severe service conditions, but in each instance these problems have been mitigated by improved design and materials selection.

4.2 Slurry Preheat

Economic design requires slurry make-up at the highest temperature consistent with reliable operation. Recent work at Ft. Lewis and ORNL has indicated that mixing can be performed at temperatures exceeding 350°F and likely as high as 420°F without unacceptable viscosity increase. Questions remain, however, regarding

possible problems of vapor evolution at high mix tank temperatures. Design uncertainties also remain with regard to the maximum practicable make down rate of coal of a given size consist into a slurry of given temperature.

To our knowledge, none of the operating U.S. liquefaction plants have demonstrated feed slurry heat exchange with reactor effluent streams. Such heat exchange may offer cost and efficiency advantages in commercial plants and is included in the design for the SRC-I demonstration plant. We understand that the German pilot plant at Bottrop includes heat exchange between the feed slurry and the condensate from the vapor-liquid separator on the reactor effluent.

The final preheat of slurry feed to the reactor is accomplished in a fired heater; technical uncertainties regarding the design and operation of fired slurry preheaters has been recognized as one of the generic technical challenges to direct liquefaction. Recent tests at Ft. Lewis provided data for design of the fired slurry preheaters in the SRC-I and SRC-II Demonstration Plants; service conditions during the Ft. Lewis tests approached conditions of commercial interest without important problems. Significantly, coke deposition ranged from light to moderate. Uncertainties remain in predicting the flow regime, pressure drop, and inside heat transfer characteristics of large scale fired slurry preheaters. ICRC has proposed large scale flow tests with model fluids, but even if these tests confirm predictions of correlations, uncertainties will remain until full scale preheaters have operated with coal liquefaction feed slurries.

The EDS pilot plant utilizes vertical hairpin tubes in the heater while H-Coal and Ft. Lewis utilize near-horizontal helical and/or rounded-rectangular tubes. The configuration in the Bottrop plant is not known, but the earlier German plants employed vertical hairpin tubes.

Among the results reported to date only the EDS unit has experienced serious difficulties with coke deposition in the fired preheater. Operating conditions in the EDS preheater have been planned to determine the limits of commercial operability, and, thus, in some instances have been more severe than in the fired preheaters of other plants. Nevertheless, there are indications that coking difficulties may depend on solvent properties and other process parameters and may occur even when preheaters operating conditions (skin temperature, heat flux, etc.) are not severe.

4.3 Reactors

In direct liquefaction processes operated at a large scale to date (with the single exception of the H-Coal process), the liquefaction reactor consists of one or more open bubble column reactors. Because the kinetics of coal liquefaction is not well understood, because the physical properties of coal liquefaction slurries are not well known, and because the fluid dynamic performance of large open bubble columns is uncertain; performance of large-scale direct liquefaction reactors cannot be predicted with confidence. The aim of the EDS process was to approach plug flow conditions through a series of high L/D reactors; redistribution trays were originally installed in the pilot plant but were removed after early operating difficulties. The SRC-I design also aims for some plug flow character, and two vessels in series are planned. Prior German operations were with four or five back-mixed reactors in series, and it is presumed the Bottrop plant follows this approach. In contrast, to promote thermal mixing in the reactor and thereby lessen the demands on the fired slurry preheater, the SRC-II demonstration plant employed a parallel arrangement of two or four reactors.

Slurry residence time and mixing studies in the Ft. Lewis dissolver (reactor) have indicated a high degree of axial mixing and phase holdups as predicted from correlations. Similar studies in the EDS pilot plant may have given indications of substantially less than expected slurry residence time.

There have been observations of solids buildup in the EDS, Wilsonville, and Ft. Lewis reactors. Such buildup may provide beneficial catalytic action; at the same time, by occuping volume, solids build-up presents a concern for the stable long term operation of commercial reactors. Thus, solids withdrawal systems have been tested in Wilsonville and Ft. Lewis and are included in demonstration plant designs. Operability of such systems on large-scale reactors remains uncertain. Operation of a similar system for catalyst withdrawal from the H-Coal reactor has been generally satisfactory, but the system has plugged at least once.

The design of the 6000 ton/day dissolver for the SRC-I demonstration plant will be based on scale-up of data from the dissolvers at the Wilsonville and Ft. Lewis pilot plants. Accumulation of mineral-rich solids in the Wilsonville dissolver has been observed for several years. The mechanism of this accumulation is not clearly understood but seems to be due to the growth and agglomeration of solid particles. It is not clear whether solids will accumulate in the large-scale demonstration plant dissolver, in view of the higher gas and slurry velocities. The accumulated solids in the Wilsonville dissolver have been observed to catalyze the dissolution reactions, so a limited amount of solids accumulation is not necessarily detrimental.

4.4 Vapor-liquid Separators and Fractionation

Economics and efficiency are favored by operating the reactor effluent vapor-liquid separator at or only slightly below reactor temperature with minimal slurry hold up consistent with level control. The H-Coal pilot plant has experienced repeated, serious difficulties with the build-up of massive deposits of coke-like material in the separator. A hydrogen sparge in the separator which cools the slurry by about 100 F, maintains a high hydrogen overpressure, and agitates the slurry. The problems observed in the H-Coal separator may be due in part to excessive residence time, since the vessel was designed for the higher throughput boiler fuel operation.

5. ENVIRONMENTAL AND HEALTH CONSIDERATIONS

The principal areas of environmental and health concern for coal liquefaction include health and environmental effects of materials produced during liquefaction, industrial hygiene and occupational health, effluent control and waste management technology, and assessment of environmental impacts and health risks. Raw liquids produced by the direct liquefaction of coal contain appreciable quantities of phenols, polycyclic amines, and polynuclear aromatics which may pose problems in transportation or end use. Generally, these concerns appear to be tractable, and experience during the recent operation of large pilot plants and design of demonstration and commercial plants provides confidence that a coal liquefaction industry can be acceptable from an environmental and health point of view.

However, this hopeful contention remains to be demonstrated. Results of preliminary scoping research on health and environmental effects must be confirmed by long term testing and large scale demonstration. Likewise, the effectiveness of industrial hygiene practices can only be confirmed by experience; improved monitoring capability is needed. The performance of wastewater treatment schemes and solid waste management approaches must be confirmed through the long term operation

of large facilities. Finally, the data base and methodologies for assessing the environmental impacts and health risks of coal liquefaction plants require improvement and validation so that sound decisions can be made.

The Environmental Impact Statements of DOE's planned coal conversion demonstration plants provide a thorough assessment of the state of understanding of environmental and health concerns associated with coal liquefaction and gasification plants as well as means for mitigating these concerns. Similarly, Draft Pollution Control Guidance Documents for indirect and direct liquefaction by the EPA and comments thereon embody the best available scientific and technical data. Substantial uncertainties remain however in understanding and dealing with potential health and environmental risks of producing and utilizing coal liquids. A great deal of work has been completed in these areas, but much also remains to be done. Likewise, the transport and fate of trace constituents from specific coals in specific processes is substantially unknown.

Technologies for treating and disposing of gaseous, aqueous, and solid wastes from coal liquefaction plants have generally operated in compliance with existing regulations; however, these regulations do not address many of the potential pollutants where uncertainties and concerns are the greatest. Key areas of concern appear to be the assured performance of waste water treatment technologies for near-total recycle or for effluent release; safe disposal of oily wastes, sludges, and brines from wastewater treatment; and landfill design for solid waste disposal. In a commercial plant, the area required for solid waste disposal can be a major part of the total project land requirement.

A great deal of progress has been made in upgrading distillate products from direct liquefaction processes. Experimental studies by UOP, Chevron, Exxon, and others have been carried out under DOE sponsorship and have established that distillate fractions from SRC-I and -II, H-Coal, and EDS processes can be successfully upgraded by processes such as hydrotreating, hydrocracking, and catalytic reforming.

6. ECONOMICS AND COMMERCIALIZATION

6.1 Recent Economic Studies

Most of the economic studies reported in 1978-1979 indicated a production cost for liquid fuels from coal of about $25-$35/bbl in 1979 dollars. Economic studies since that time indicate that costs have risen substantially. As noted previously, such calculated product costs are subject to wide variation depending on the type of financing and other economic assumptions, on the completeness and realism of the design, and on the conservatism used in estimating costs.

The economics and status of commercialization of the H-Coal process were reviewed by HRI in 1981. Economics were based on a 1979 ESCOE study performed under DOE contract.(7) Energy costs reported were $3.30 per million Btu for the fuel oil mode and $3.58 per million Btu for the syncrude mode. The same study showed costs of $3.62/million Btu for SRC-II, $3.96/million Btu for EDS, $4.37/million Btu for methanol, and $4.89/million Btu for Mobil-MTG. The $3.58/million Btu for the H-coal syncrude mode corresponds to about $21.50/bbl using an approximate conversion factor of 6 million Btu/bbl.

A large-scale commercial plant using the H-Coal process has been proposed for Breckinridge County, Kentucky. The Breckinridge project has applied for SFC support

and is one of the five projects that have entered the second stage of SFC's selection procedure. The proposed plant would be designed to run about 22,500 TPD of run-of-mine Illinois No. 6 coal to produce a nominal 50,300 bbl/day of liquid products and about 25 million SCF/day of SNG. Total liquid product corresponds to 2.24 bbl per ton of run-of-mine coal, or about 30% by weight.

An ORNL study in 1981 reported on the economics of producing gasoline from western U.S. coal using Lurgi gasification, ICI methanol synthesis, and Mobil-MTG conversion to gasoline.(8) Coal feed rate on an as-received basis was about 30,000 TPD. The plant was self-sufficient in steam and power and had a capital investment of $2.8 billion in 1979 dollars. A gasoline cost of $1.59/gal in 1979 dollars was calculated using 100% equity financing with 15% annual after-tax return on equity. In this case, methane produced by the Lurgi gasifiers was reformed to synthesis gas in order to maximize gasoline production and minimize the production of SNG. Overall thermal efficiency was 50% and specific investment was $57,600 per daily barrel of product.

A Fluor study done for EPRI in 1981 reported on the economics of producing methanol from Illinois No. 6 coal using Texaco gasification and ICI methanol synthesis.(9) The conceptual plant capacity was 16,234 TPD (as received) and methanol production rate was 10,930 TPD, giving an overall thermal efficiency of about 58%. Total investment was $1.45 billion in 1979 dollars. The first-year production cost of methanol using EPRI's economic bases was about $0.30 gal or $4.71/million Btu. This assumes product cost inflation of 6% per year. Specific investment was $42,800 per daily barrel of fuel oil equivalent product.

The same report also mentions earlier studies by Fluor of distillate fuel production from Illinois No. 6 coal by the H-Coal process. Using a plant of the same throughput and the same economic assumptions, H-Coal distillates were estimated to have a first-year cost of $4.06/million Btu in 1979 dollars. Overall thermal efficiency was estimated at 70.7%. Total capital investment was $1.27 billion in 1979 dollars. Specific investment was $32,500 per daily barrel of fuel oil equivalent product.

Exxon's revision of their 1975-1976 study design for the Exxon Donor Solvent process was issued in 1981.(10) Two designs were presented, a base case and a market flexibility study. Both cases used Illinois No. 6 coal; they differed principally in the method used for producing hydrogen, resulting in substantial production of high-Btu gas and C_3 LPG in the market flexibility case. The updated designs showed considerably higher capital investment than the 1975-1976 design. Reducing all estimates to a common time frame (1985-1986 startup) to eliminate inflationary differences, total erected costs for the updated designs (30,000 TPD) were $3.9 billion for the base case and $3.7 billion for the market flexibility case whereas the 1975-1976 design (24,000 TPD) showed a cost of $2.2 billion. Part of the increase in cost can be attributed to the increased coal feed rate, but the major portion of the increase was due to differences in design and cost estimation. Product cost (required initial selling price) for the updated cases were $61.20/bbl for the base case and $48.60/bbl for the market flexibility case. These costs were based on 100% equity financing with a 15% annual after-tax rate of return and 6% annual escalation of all costs and product prices. The capital costs for the updated cases correspond to about $71,100 and $65,300 per daily barrel of product; these are as-spent dollars based on 1985-1986 startup.

Deflating the required initial selling prices from 1985 to 1982 at a rate of 6% gives $51 and $41/bbl in 1982 dollars for the base case and market flexibility case

respectively. In contrast, the required initial selling price projected under the same economic ground rules in the 1975-1976 study was $29/bbl in 1978 dollars or about $44/bbl in 1985-1986 dollars, and the capital cost was about $41,000 per daily barrel of product in as-spent dollars based on 1985-86 startup.

The 1981 study design update does not include any evaluation of the bottoms recycle operation. Exxon has indicated their intention to make such an evaluation in the near future.

Costs of upgrading SRC-II liquids to distillate fuels have been estimated by Chevron Research in a DOE-sponsored study.(11) Estimates were based on experimental upgrading of whole SRC-II syncrude in Chevron's pilot plant facilities. Commercial petroleum refining technology, including hydrotreating and hydrocracking, was used to produce gasoline, kerosene jet fuel, diesel fuel, and No. 2 heating oil. Refining costs to convert SRC-II syncrude to transportation fuels were estimated to be $14 per barrel of product for a product slate of motor gasoline and jet fuel or $16 per barrel to produce motor gasoline only. Cost of producing No. 2 heating oil only was estimated to be about $10/bbl. These costs include the cost of producing the hydrogen used in processing and are based on self-sufficient grass roots refineries of 50,000 bbl/day capacity. Liquid volume yields were estimated at 88-91% of syncrude feed. Plant capital investments for the upgrading refineries ranged from $443 to $708 million. All these costs are in first quarter 1980 dollars. An annual capital fixed charge rate of 30% was used, which is equivalent to about 15% annual after-tax return on equity. Significant savings were found when the upgrading facilities were located at the same site as the coal liquefaction facility.

6.2 Commercialization

Prospects for commercialization of liquid fuels from coal in the U.S. have been affected by a number of major developments since 1979. Some of these have been favorable and some have been adverse.

The price of world oil in early 1979 was about $15-17/bbl, and the projected cost of liquid fuels from coal, as noted earlier, was about $25-$35/bbl in 1979 dollars. From 1979 to 1980 the price of oil doubled, rising to $34-$37/bbl.

Spurred by the rapid increases in world oil price and the recognition of the insecurity of Middle East oil supplies, the U.S. in 1980 passed the Energy Security Act. This Act established national production goals for synthetic fuels, provided an initial $20 billion in financial assistance to accelerate synfuels production, and created the United States Synthetic Fuels Corporation to help the private sector build the necessary productive capacity. The national synfuel production goals were stated as 500,000 bbl/day oil equivalent by 1987 and 2 million bbl/day oil equivalent by 1992. The principal role of the Synthetic Fuels Corporation is to give financial assistance to private-sector projects, in the form of purchase agreements, price guarantees, loan guarantees, loans, and joint ventures.

Militating against the commercial production of synfuels in the U.S., however, is the fact that in the last two years there has been a softening of demand, a drastic reduction in U.S. oil imports and total oil consumption, and a weakening of oil price in international markets. The high cost of oil has caused a substantial shift to cheaper supplies of energy such as coal. The trend toward smaller automobiles has contributed appreciably to the reduction in gasoline demand. The OPEC nations have reduced their production in an attempt to offset the tendency toward an oil glut and price competition among the cartel members. Fig. 1 shows the history of U.S. oil consumption and imports since 1974. The reduction in oil demand and oil prices obviously diminish the immediate prospects for synfuel commercialization,

since the economic feasibility of synfuels ventures depends to a large extent on future increases in the price of oil beyond the general rate of inflation. If this projection appears to be questionable, synfuels projects lose much of their attractiveness as private commercial ventures.

The future goals and policies of SFC have not been defined in precise terms. This may be due in part to the somewhat ambiguous definition of the SFC's mandate under the Energy Security Act. Two goals were established that are to some degree contradictory: a rapid build-up of production capacity on the one hand and the use of a range of diverse technologies and resources on the other. There are recent indications that a greater emphasis will be placed on diversity than on quantitative production goals. Under this policy there could be a tendency to use SFC's resources to promote the demonstration of a wide range of technologies rather than to maximize the rate of buildup of production capability. Such a policy decision, if made, will have significant consequences for the U.S. synfuels program. If early buildup of productive capacity were the main goal, the use of already demonstrated commercial technology would be a logical course of action. But if diversity of approach is judged to be a more important objective, the demonstration of a wide range of near-commercial technologies may become a primary activity of the program. Thus there are a number of questions about the precise details of SFC's commercialization policy. The outcome of such questions will be awaited with great interest by the synfuels community.

7. REFERENCES

1. L. E. McNeese, Royes Salmon, and H. D. Cochran, Jr., "Recent Developments in Coal Liquefaction in the United States," presented at 6th Energy Technology Conference, Washington, D.C., February 26, 1979.

2. G. Alex Mills, *Synfuels from Coal: Progress in the U.S.A.*, presented at American Institute of Chemical Engineers International Synfuels Symposium, New Orleans, November 8-12, 1981.

3. J. D. Potts et al, *LC-Fining Support Activities for Two-Stage Liquefaction*, presented at AIChE meeting, New Orleans, November 1981.

4. J. R. Thurgood and F. D. Wareham, Utah Char-Oil Project, presented at A.I.Ch.E. 1982 Winter Meeting, Orlando, Florida, February 28-March 3, 1982.

5. R. M. Eccles and G. R. DeVaux, *Current Status of H-Coal Commercialization*, CEP May 1981 pp. 80-85.

6. W. R. Epperly, D. T. Wade, and K. W. Plumlee, *Donor Solvent Coal Liquefaction*, CEP 77(5) (May 1981) pp. 73-79.

7. K. A. Rogers and R. F. Hill, "Coal Conversion Comparisons," Engineering Societies Commission on Energy, Inc. (July 1979).

8. R. M. Wham et al, *Liquefaction Technology Assessment - Phase I: Indirect Liquefaction of Coal to Methanol and Gasoline Using Available Technology*, ORNL-5664, February 1981.

9. P. A. Buckingham et al, *Coal to Methanol - An Engineering Evaluation of Texaco Gasification and ICI Methanol Synthesis Route*, EPRI AP-1962, August 1981.

10. *EDS Coal Liquefaction Process Development, Phase IV. EDS Commercial Plant Study Design Update - Illinois Coal*, DOE/ET/10069-T1 (3 Vols.), March 1981.

11. R. F. Sullivan et al, *Cost Comparisons of Alternative Routes for Converting SRC-II Oil to Distillate Fuels*, presented at the Conference on Synthetic Fuels, San Francisco, October 13-16, 1980.

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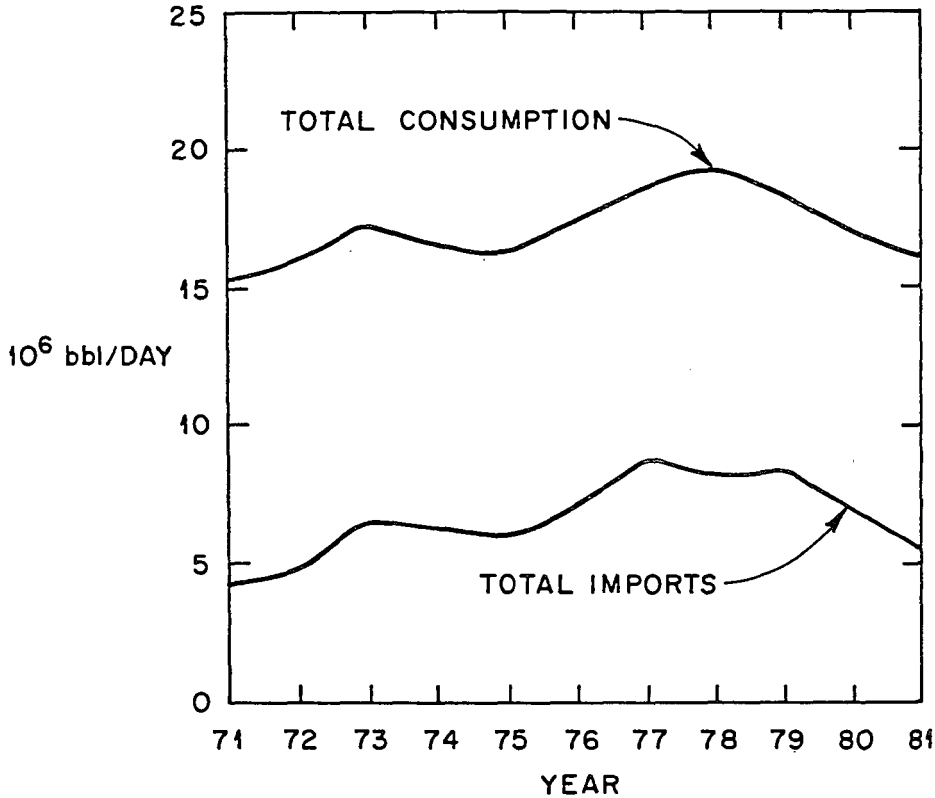

COMPARISON OF TOTAL U.S. LIQUID FUELS CONSUMPTION AND IMPORTS

Fig. 1