FE-2468-25

FOSSIL ENERGY

COMPARISON OF COAL LIQUEFACTION PROCESSES

Final Report on Task 006

By
K. A. Rogers
A. S. Wilk
B. C. McBeath
R. F. Hill

April 1978
Date Published

Work Performed Under Contract No. EF-77-C-01-2468

The Engineering Societies Commission on Energy, Inc.
Washington, D. C.

U. S. DEPARTMENT OF ENERGY

NOTICE

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $4.50
Microfiche $3.00

FE-2468-25
Distribution Category UC-90d

COMPARISON OF COAL LIQUEFACTION PROCESSES

Final Report
on Task 006

K. A. Rogers

A. S. Wilk

B. C. McBeath

R. F. Hill

The Engineering Societies Commission on Energy, Inc.
444 North Capitol Street, N.W., Suite 405
Washington, D.C. 20001

Date Published - April 1978

PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Under Contract No. EF-77-C-01-2468

DISCLAIMER

ESCOE TASK 006

COMPARISON OF COAL LIQUEFACTION PROCESSES

ABSTRACT

Five processes were studied to determine which could give best results for supplying hydrocarbon fuels to replace petroleum products. The processes were: Fischer-Tropsch; M-Gasoline; H-Coal; Exxon Donor Solvent; and Solvent Refined Coal.

The conlcusions of the study are that all of the processes are considered commercially feasible and, because the different products from the different processes will meet different market demands, any significant future liquids from coal market will probably use some of each of these processes.

The anticipated conversion efficiency values are given to indicate resource utilization.

Simplified capital costs are approximated for each process. These are used in combination with product amounts and relative values to achieve a cost ranking.

Because the study was concerned solely with liquid products, Fischer-Tropsch was at a disadvantage. The remaining four were relatively close and a final decision would depend upon the actual end use requirements. For a situation with residual fuels selling at severe discounts, M-Gasoline and H-Coal (Syncrude Mode) were the better choices.

Summary

Five processes for the conversion of coal to liquid fuels were reviewed and compared from technical and economic viewpoints. The processes studied were:

1. Fischer-Tropsch
2. M-Gasoline
3. H-Coal
4. Exxon Donor Solvent
5. Solvent Refined Coal

The technical review supports the belief that any of the processes can be made to operate on a commercial scale.

To arrive at an objective economic comparison, a single criterion cost index was defined and used. The cost index reflects plant investment, feed, labor and utility costs and particular values considered realistic for each of the products produced. To complete the comparison, it was necessary to estimate a capital investment requirement for each process. For cost ranking purposes, a simplified bare plant estimate was adequate as all plant costs were priced on a basis of same coal feed rate. The need for contingencies and future price forecasting was avoided. Where process development was considered inadequate, some cost contingency was included. The resulting cost index has comparative value only and thus is not a price prediction.

The five processes differ significantly in the mix of products made. Fischer-Tropsch gives a wide range of hydrocarbons including many alcohols and other oxygen bearing materials. H-Coal gives heavy and light hydrocarbon fractions still deficient in hydrogen and requiring further treatment if used for any purpose other than boiler fuel. This is also true for Exxon Donor Solvent, which produces an additional marketable LPG product. The naphtha produced by SRC is poorer quality than H-Coal and EDS. M-Gasoline produces two products, LPG and high quality gasoline.

A simplified energy conversion efficiency based on major products only is calculated and shown. This value gives an indication of the amount of original resource converted to usable product.

If liquid fuels are the only desired products, the relatively inefficient energy conversion and relatively high product cost would exclude the Fischer-Tropsch process from consideration. However, if credit is allowed for the gas products, the proven technology and absence of sulfur and nitrogen in the products bring the F-T process into competition. H-Coal, Exxon Donor Solvent and the Solvent Refined Coal processes are comparable and all give useful liquid hydrocarbon fuels. The particular needs of the market will be the strongest factor to determine the best future process choices. If gasoline is the desired product, the M-Gasoline process offers strong technical and cost advantages compared to the other coal liquefaction processes.

1.0 Introduction

This study was made to provide an assessment of coal liquefaction processes for R&D planning purposes. Any assessment must recognize the differing needs and values for the several different kinds of fuels. Home heating oil and gasoline sell for a premium compared to industrial fuel. The premium is even greater on an energy ($/Btu) basis than on a volumetric ($/BBL) basis. The amount of the premium has changed considerably during the past decade. This study used a criterion capable of reflecting different product values. Product values from 1978 and 1970 were used to show the effect for a period when industrial fuels are in excess supply. The cost index, which is the economic criterion used, is an effective weighted cost of product from each process.

Comparisons for the five designated processes were done on both technical and economic bases. The technical evaluation was for the purpose of anticipating future problems prior to use in a commercial plant. The economic comparison was done to determine which processes would be competitive for supplying future energy needs for the USA.

The processes studied include:

1. Fischer-Tropsch		(F-T)
2. M-Gasoline		(M)
3. H-Coal	a.	(H-Syn) Syncrude mode
	b.	(H-FO) Fuel Oil mode
4. Exxon Donor Solvent		(EDS)
5. Solvent Refined Coal	a.	(SRC - I) solid product
	b.	(SRC - II) liquid

These processes are in various stages of development. They also have differing amounts and quality of hydrocarbon products.

2.0 Technical Comparison

2.1 Process Descriptions

There are many descriptions by others for the processes studied. A recent survey which includes descriptions, some assessment and history is the Gilbert/Commonwealth study.

Very briefly, key features of the processes studied are:

1. The Fischer-Tropsch process begins with complete gasification of the coal. Fixed bed catalytic reactors cause reaction of the $CO-H_2$ feed gas to form a wide spectrum of hydrocarbon and oxygenated hydrocarbon products.

2. The M-Gasoline process uses fixed catalyst beds to convert methanol into a premium quality motor gasoline. A small stream of LPG is produced. Producing methanol from a $CO-H_2$ mixture obtained by coal gasification is proven commercial technology.

3. For the H-Coal process, dry finely ground coal in oil and hydrogen are fed into an ebullated bed catalytic reactor. In an ebullated bed, the solid catalyst remains in a relatively fixed position while fluids and fine particles bubble and flow upward through the solid. The pressure-temperature severity may be varied to favor production of either syncrude or fuel oil with a low quality naphtha produced in either mode. The effluent from the reactor is separated from entrained solids and the fluid portion then separated into liquid products.

4. The Exxon Donor Solvent process avoids contacting the coal with solid catalyst by using a special coal-oil base solvent to dissolve the coal and contribute hydrogen to increase the hydrogen-to-carbon ratio for the effluent products. The recycled solvent is re-hydrogenated on a continuous basis. Exxon has included Flexicoking in their proprietary process to convert the heavy residual type materials to more desirable products

5. The Solvent Refined Coal process is quite similar to EDS except for the particular solvent used. The hydrogen is injected into the solvent as a gaseous phase rather than being in chemically combined form as with the EDS liquid. SRC can be operated in a liquid or solid product mode. The solid mode, SRC-I, requires solids separation which has encountered problems in the development stage. Scale-up of this step may pose problems. Adding recycle and increased hydrogenation to achieve more severe conversion gives lighter products for SRC-II. The bottoms containing solids and minerals are sent to a gasifier to make the hydrogen required for the process. This seems to effectively shift a difficult operation from the main process to the gasifier system where it can be handled.

2.2 Feed Requirements

All five of the processes covered can accept all common types of coal. Caking coals do not require pretreatment. There will be differences in product rate and quality from different source coals. Feed systems are simplest for F-T and M-Gasoline as the coal is gasified. The remaining three processes require fired oil-coal slurry preheaters which can give operating problems. H-Coal requires a dried coal. While all kinds of coal have not actually been run in every process, no process restrictions as to coal source are expected.

2.3 Reactor Systems

Since most other unit operations within each of the plants use proven technology, only the reactors are unique. For the processes examined, the H-Coal reactor system has the greatest technical uncertainty. This reactor is a mechanically sophisticated design which has not yet been proven in large scale continuous coal slurry service. The M-Gasoline, SRC and EDS processes are also unproven in large scale service, but their reactor systems use a simpler technology.

2.4 Products

The most complex of the product mixes is Fischer-Tropsch as it makes a wide range of products, many of which are undesirable for fuel. If several large scale coal conversion plants were built using the F-T process the output of certain chemicals would be many times the world consumption for these materials. Thus, the only practical choice would be to burn some of these hydrocarbons as low value boiler fuel. This is the approach used in our economic comparison. In a real market, many of the materials are valuable specialty feed stocks which could displace present compounds from petroleum sources. The M-Gasoline process has the most valuable product, assuming motor gasoline will continue as a desirable commodity. There are no residual materials produced by this plant which cause disposal problems.

The EDS, SRC and H-Coal processes give relatively high amounts of desirable fuel products and for this reason are attractive with the economic criteria used.

2.5 Probability of Commercial Success

With regard to commercial operation, the F-T process is the most proven as complete plants have been built and Sasol is operating full scale. The source information for this study was prepared by Pullman-Kellogg, the original contractor for the Sasol plant.

It is felt that all five processes discussed have a good probability of producing the quality and quantity of products claimed. The process with the greatest overall risk of the five considered is H-Coal, partly for the reasons covered under the Reactor section above. Paradoxically, the use of catalyst in a controllable reactor could give H-Coal an edge over SRC and EDS with regard to modulating product slate. A more serious problem exists with the liquid-solid separation required. This has not yet been demonstrated to be satisfactory technology for a commercial operation. Critical solvent deashing could well be the answer to eliminate the need for cumbersome filters.

After F-T, the process with minimum risk from inadequate development and corrosion is M-Gasoline. Most of the steps involved are already commercial technology. This process also has the advantage of requiring relatively mild pressure and temperature conditions.

The time required to build a commercial size plant for any of the processes is in the order of five years. This assumes a concerted effort for early completion. Even the F-T process which has been demonstrated commercially could easily require this length of time. Pullman-Kellogg, the original designer-contractor, has indicated they would use an improved process design. An expansion for the Sasol plant is now being designed by Fluor.

The considerable amount of work already done by many different groups precludes high expectations for major technical breakthrough. Some significant improvement could occur in gasifier systems or methanol production. Gasifiers would help Fischer-Tropsch, both would benefit M-Gasoline. Development work continues on F-T catalysts. These would give improved product selectivity rather than greater thermal efficiency. It is doubtful that a truly significant increase in overall process thermal efficiency will occur for any of the five processes in the coming decade.

All sources used are included in a bibliography in the back of this report. Questions concerning consistency exist with respect to the proprietary reaction sections for each of the processes. A summary of other technical details is given below.

<u>Fischer-Tropsch</u>

It must be recognized that, in this study, many of the diverse products produced by F-T were considered to have no market except as fuel. The methanol and ethanol products were converted to M-Gasoline and blended with the remainder of the gasoline product. This blended gasoline was still a low octane and assigned an appropriate product value factor.

The total products from the plant were increased to reflect use of a Texaco Partial Oxidation gasifier. Values for this correction came from a recent EPRI study. The F-T process gives about 35 wt% of the total hydrocarbon output as medium-heating-value fuel gas which received no credit in the product efficiency or cost index calculation of this liquid fuels study. For a more fundamental analysis, this gas would be sold or used to generate electric power and contribute to better product cost and efficiency. Solid-liquid separation problems are avoided in this process as the coal feed is all gasified.

M-Gasoline

Over three quarters of the plant cost is associated with coal conversion and generation of methanol. This is proven technology. The Texaco gasifier appears to be the best current choice and was used in this study. Except for the conversion of methanol to M-Gasoline, all process steps may be considered commercial. There is an absence of undesirable by-products from this process. Studies, so far, have been based upon fixed bed reactors.

This process has no materials-of-construction problems. Solid-liquid separation problems are avoided in this process as the coal feed is all gasified.

The amount of durene, a gum-forming material, formed by this process could be a disadvantage. Mobil has indicated they can control the fraction of this compound.

H-Coal

The ebullated bed reactor has certain operating advantages, including reduced possibility of plugging and ease of maintaining catalyst activity.

The mode of operation can be varied to produce maximum fuel oil or syncrude. There is no limitation on the type of coal which may be used as a feed. Operation of the fired preheater varies with coal type and improved techniques are expected to develop with operating experience.

The products from this process have a high nitrogen content, which make further refining expensive and difficult. There is difficulty separating solids from the heavy oil product.

The low H/C ratio of products requires further hydrogenation and reforming.

There is a strong indication that the heavy oil product from this process is incompatible with petroleum fuel oil.

Exxon Donor Solvent

While the process has not yet been demonstrated on a large scale, the unit operations involved are fully developed. No significant equipment development is required. Some corrosion problems have not yet been solved. There is a potential problem with calcium carbonate deposition in the reactor. The slurry preheater problem is the same as with H-Coal.

The undesirable heavy bottoms materials resulting from the basic process are treated within Flexicoking units to give only usable products from the integrated plant. Questions involving solvent self-sufficiency still exist. The fuel oil product from this process has a low gravity and a high nitrogen content. It is incompatible with petroleum-derived fuel oil.

Solvent Refined Coal

The SRC main product is industrial boiler fuel which can meet existing pollution standards. If a proposed 90% sulfur removal requirement is enacted, the SRC process has problems. It is difficult to remove 90% of the sulfur from low sulfur coals. This can be achieved with high (4%+) sulfur coals.

Successful operation of a 50 ton/day pilot plant gives good assurance that a commercial size plant is feasible now. There do not appear to be any serious material-of-construction problems with this process. The slurry preheater problem is the same as with H-Coal.

3.0 Economic Comparison

The method developed for the economic comparison portion of this study involves a single economic criterion, named here the cost index.

The cost index is an incomplete hypothetical average product cost. It is based on the fact that selling prices will reflect desirability for the product in the marketplace and that a product can be upgraded with added processing and investment. Because of the many real costs not included in the computation of the cost index, it does not indicate a real world cost. Excluded costs, such as taxes and profit are not necessary for the purpose of ranking the processes. Taxes, interest rates, future inflation and price regulations will be major determinants for all liquid fuel prices.

In addition to value and amount of product produced, the cost index includes the effect of plant operating cost, including cost for capital. Thus it will be seen that both product efficiency and investment costs are reflected in the cost index. The results of any particular comparison will depend directly upon the values used for capital recovery and product value factors. This index also allows costs such as labor, chemical and utility requirements to be included. A detailed definition of the cost index is given in Appendix A together with a sample calculation.

3.1 Product Value

Ratios between product value factors do not remain constant with time. Table I shows the product value factors which were used to calculate the cost indices. ˋese product value factors are ratios of market price for the particular product relative to premium gasoline. Two different time frames were chosen to anticipate a future period which may repeat the past when residual fuels were a glut on the market. It is felt that this situation could occur again. If many large plants are converted to burning coal directly and many additional plants are converting coal to hydrocarbon products, there will be an abundance of residual type fuels. The two time frames used are 1978 and 1970. It will be noted that the product value factors are noticeably different for these situations.

Table I - Product Value Factors

Product	1978 $/BBL	Value Factor, f_i 1978	Value Factor, f_i 1970
No. 6 Fuel Oil	12.30 = B	.70 (=B/A)	.44
SRC-I solid	-	.63	.40
No. 2 Fuel Oil	14.90 = C	.85 (=C/A)	.71
Naphtha: H-Coal		.89	.79
EDS		.88	.78
SRC		.85	.71
LPG	12.12	.69	.43
Regular Gasoline	16.30	.93	.87
F-T Gasoline	-	.90	.84
Premium Gasoline	17.50 = A	1.0	1.0

Notes:
1) H-Syncrude equivalent to No. 2 Fuel Oil
2) SRC & EDS Fuel Oil are No. 6 Fuel
3) 1970 Premium Gasoline Price is 6.25 $/BBL
4) Market prices from the Oil & Gas Journal - Midwest
5) Identifiers used in this report:

F-T = Fischer-Tropsch
M = M-Gasoline
H-Syn = H-Coal-Syncrude mode
H-FO = H-Coal-Fuel Oil mode
EDS = Exxon Donor Solvent
SRC = Solvent Refined Coal

3.2 Capital Cost

The plant capital investment is an important part of the input to calculate cost index. Published cost estimates were studied for each process. Because the best capital estimates came from five different sources, and slightly different time frames, corrections were made. As a check, outside sources were contacted for current cost information on items such as tonnage oxygen plants and methanol units. It is felt that the costs used are on a reasonably consistent basis for the five processes studied. Lack of detail in available studies leaves uncertainty that all plants are completely consistent with respect to engineering standards.

All of the processes anticipate some use of commercial technology on a scale exceeding anything existing. Scale-up progress in areas such as air plants, hydrogen generation, fluid bed reactors, etc, will give better costs than those used to date. This type of development affects cost only and not process conversion efficiency.

The capital costs assembled for use in calculating cost index were purposely kept simple. By using the same coal feed rate to all five hypothetical plants, ordinary auxiliaries and off-sites may be considered essentially the same. The effects of future inflation should also be the same for all. Taxation and need for profit and other capital-related charges are considered to have the same effects for all processes. Including these items would not further the purposes of this study.

The basis for plant capital estimates is as follows:

a) Feed rate of 25,000 dry tons/stream day of Illinois No. 6 coal.

b) No contingencies were included except for processes where uncertainty indicated costs might increase in the future because of insufficient commercial development at this stage.

c) Cost shown as First Quarter 1978 $ with plant at a Gulf Coast location.

d) No off-site or storage charges are included.

e) No working capital is included.

f) 90% on-stream factor.

Table 2 shows major on-site capital investment for each process for the basis described above. Process contingency was included in the reactor section only and this is only included for the H-Coal process where the contractors' contingency value was left in. The totals shown were used to calculate the cost indices shown in Table 4.

TABLE 2 - PLANT CAPITAL

Major On-Site Plant Cost in Millions of 1978 $

Category	PROCESS						
	F-T	M	H-Syn	H-FO	EDS	SRC-I	SRC-II
Coal preparation	63	63	84	84	63	63	63
H_2 or gasification	228	228	158	138	190	152	253
O_2 plant	117	175	87	67	-	84	129
(T/D)	(11,070)	(21,000)	(7,200)	(5,400)	-	(6,800)	(13,000)
Gas shift	-	40	35	30	-	-	-
Acid gas & Sulfur plants	57	57	57	57	60	60	60
Reactor section	55	106	210	140	180	160	195
Conversion	100	75	-	-	-	-	-
* Gas plant	25	10	25	30	-	177	30
Flexicoker	-	-	-	-	160	-	-
Pollution systems	40	40	40	40	44	44	44
Solvent Hydro. or catalyst prep.	3	-	-	-	82	-	-
	688	794	696	586	779	740	774

*M includes HF Alkylation; EDS solvent system in Flexicoker; SRC includes filtration

3.3 Cost Comparison

To complete the required input for calculation of cost index value for each of the five processes, coal and labor values were assumed. A delivered coal price of 15 $/dry ton was used. It is not apparent at this stage that there would be any noticeable difference in the labor required for the five processes. The same labor cost of 7.6 million $/year was used for all plants.

Electric power is exported by the plant designed for H-Coal by Fluor and purchased by the EDS and F-T plants. The others are self-sufficient. Electric power rates are shown in Table 3. A purchase price of 2¢/KWH was used. A credit of 1¢/KWH was given to H-Coal to reflect that no capital was included to generate the power. More engineering detail is required for all plants to be certain there is prime mover and power use consistency.

Table 3 shows the products produced by each of the plants. The amount of further treatment required for the naphthas is reflected in the product value factor assigned and shown in Table 1.

TABLE 3

Products & Power Requirement

Process	Products in BPSD	Electric Power in MW
F-T	19,600 gasoline 20,300 LPG 1,300 No. 2 fuel oil 2,100 No. 6 fuel oil	40
M-Gasoline	47,800 Premium gasoline 5,700 LPG	0
H-Syn	24,700 Naphtha 36,400 Syncrude	(-81.6)
H-FO	15,500 Naphtha 51,300 No. 6 fuel oil	(-4)
EDS	27,500 Naphtha 10,700 LPG 37,200 No. 6 fuel oil	135
SRC - I	13,000 Naphtha 64,400 Solid (equivalent)	0
SRC - II	13,000 Naphtha 6,400 No. 2 fuel oil 52,900 No. 6 fuel oil	0

BPSD = Barrels per stream day (SRC-I equivalent based on 6.2 million Btu/BBL)

MW = Megawatts (negative value indicates export)

The costs described above were used to calculate a Cost Index for each case. These are shown for the two time frames in Table 4. As explained earlier, the second time frame was chosen to show a possible future time when residual fuels are again in excess supply as they were in 1970.

Table 4 also shows a value for product conversion efficiency. This is defined as the energy value of all liquid products divided by the energy input of coal and required electric power. This value reflects the energy lost in converting the coal to more desirable liquid products. Conventional process thermal efficiency will be a higher value for all processes as every process input and output is accounted for rigorously. The simpler product efficiency concept used here gives no credit for by-products such as sulfur and ammonia. It also does not account for all process heat.

TABLE 4 - PROCESS COMPARISON

Process	Liquid Products Efficiency	Cost Index 1978	Cost Index 1970
F-T	32	20.5	26.0
M-Gasoline	44	14.0	14.5
H-Syn	56	12.6	14.7
H-FO	66	12.9	18.4
EDS	65	13.6	18.5
SRC - I*	70	13.6	20.1
SRC - II**	77	13.7	20.4

* SRC - I solid treated as a liquid for this purpose.

** SRC Product data is less proven than most of the others shown. Efficiency value shown may be high and cost index low.

4.0 Conclusions

The conclusion shown by the cost indexes is that the F-T process has a severe disadvantage if considered solely as a method for liquid fuels.

All processes include the necessary technology to meet existing environmental standards for air and water. Implementation of any of the processes should be a net national benefit from the standpoint of reduced dependence on foreign sources and economic consequences. Effect of each process on resource reserves depletion is roughly indicated by the product efficiency. This criterion does not tell the full story as some processes produce usable fuel gas.

The use of two time frames shows clearly that choice of a fuel process depends strongly on the desired products. The M-Gasoline process appears both competitive and relatively free of process risk. If industrial boiler fuel is the needed fuel, then H-Coal, EDS and SRC are all serious contenders.

Appendix A

Sample Calculation

The Cost Index, CI, is calculated as follows:

$$CI = (A+F+L+U) / (324\ \Sigma\ f_i B_i)$$

Definitions:

CI = Cost Index

A = Annual Cost for Capital = (TOTAL CAPITAL)x(RECOVERY FACTOR)

F = Annual Cost for Coal

L = Annual Labor Cost

U = Annual Utility Cost (or credit)

f_i = Product Value Factor for product i

B_i = Amount Produced of product i per stream day

324= (360 days/idealized year)x(0.9 stream factor)

Calculations: F-T Process	Cost in Million $
A = 688 x .1339 capital recovery factor	92.1
F = 25,000tons/day x 15$/ton x324 DAYS/YR.	121.5
L = 350 employee x 10.50$/HR. x 2080 HRS/YR.	7.6
U = 40 MW x 1000 x 324 x 24 x .02$ KWH	6.2
SUB-TOTAL	227.5

i	Product	Bi BPSD	1978 f_i	$f_i B_i$
1	No. 6 Fuel	2,100	.70	1,470
2	No. 2 Fuel Oil	1,300	.85	1,105
3	LPG	20,300	.69	14,007
4	Gasoline	19,600	.90	17,640
5	Premium Gasoline	0	1.00	0
				34,222

$$1978\ CI = (A+F+L+U) / (324\ \Sigma\ f_i B_i) = 20.5$$

Appendix B

The Capital Recovery Method

This method uses the capital recovery factor to estimate the annual cost of capital. In concept the method assumes a single capital investment is made at the beginning of the project operation and repayment is made, with interest, in equal annual amounts each year of the project life.

Algebraically this is defined as follows:

C = Single capital investment at the beginning

R = Equal annual repayment amount

i = Time-discount-rate, or interest rate

M = The project life in years

$$R = C\ [i(1+i)^{M}]\ /\ [(1+i)^{M} - 1]$$

The expression, $[i(1+i)^{M}]\ /\ [(1+i)^{M} - 1]$, is known as the Capital Recovery Factor for the given values of i and M.

For this study an interest rate of 12% (i=0.12) and a project life of 20 years (M=20) are used. The capital recovery factor is then 0.1339. For each dollar invested (C=1) the uniform annual cost is $0.1339.

Appendix C: DATA and Calculated Values

Process	Coal HHV Btu/LB	(L+U) million \$/yr.	$\Sigma f_i B_i$ '78	$\Sigma f_i B_i$ '70
F-T	12,400	13.8	34,222	27,040
M	12,115	7.6	51,733	50,251
H-Syn	13,241	1.3	52,923	45,357
H-FO	13,241	7.3	49,705	34,817
EDS	12,663	28.6	57,623	42,419
SRC-I	12,400	7.6	51,622	34,990
-II	12,400	7.6	52,496	35,258

Product Properties	HHV million Btu/BBL	Density LBS/BBL
F-T		
Gasoline	5.2	265
LPG	4.1	190
No.2 Fuel Oil	6.2	284
No.6 Fuel	6.7	311
M		
Gasoline	5.2	265
LPG	3.8	189
H-Coal		
Syncrude	6.1	339
No.6 Fuel	6.7	382
NAPHTHA	5.7	291
EDS		
LPG	4.1	191
NAPHTHA	5.2	284
No.6 Fuel	6.2	367
SRC		
LPG	3.8	-
NAPHTHA	5.8	-
Fuel Oil	6.2	-
Solid	15,600 Btu/LB 6.2 million BTU/equivalent BBL	

HHV = Higher heating value

(L+U) & $\Sigma f_i B_i$ used in Cost Index, See APPENDIX A

V. BIBLIOGRAPHY

Bechtel Corporation. Coal Mine-Coal Conversion Plant Interface Evaluation and Conceptual Design, Vol. I, Prepared for U.S. Energy Research and Development Administration, FE-2370-16. San Francisco: Bechtel Corporation. Nov. 1977.

C.F. Braun & Co. Factored Estimates for Western Coal Commercial Concepts, also Technical Appendixes I and II, interim Report. Prepared for the U.S. Energy Research and Development Administration, and American Gas Association, FE-2240-5. Alhambra, Calif: C.F.Braun & Co. Oct. 1976.

Bureau of Mines, U.S. Department of Interior. Preliminary Economic Analysis of H-Coal Process Producing 50,000 Barrels Per Day of Liquid Fuels from Two Coal Seams: Wyodak and Illinois. Prepared for the U.S. Energy Research and Development Administration, ERDA 76-56. Morgantown, W.V.: Process and Evaluation Group. U.S. Bureau of Mines. Mar. 1976.

Dravo Corporation. Handbook of Gasifiers and Gas Treatment Systems. Prepared for the U.S. Energy Research and Development Administration, FE-1772-11. Pittsburg; Dravo Corporation. Feb. 1976.

Electric Power Research Institute. Screening Evaluation - Synthetic Fuels Manufacture. EPRI AF-523. Palo Alto, Aug. 1977.

Exxon Research and Engineering Co. EDS Coal Liquefaction Development Phase III A. Prepared for U.S. Energy Research and Development Administration, FE-2353-1. Baytown, Texas: Exxon Research and Engineering Co. July 1977.

Fluor Engineers and Constructors Inc. H-Coal Commercial Evaluation. Prepared for U.S. Energy Research and Development Administration, FE-2002-12. Los Angeles: Fluor Engineers and Constructors, Inc. March 1976.

Fluor Utah, Inc. Economic System Analysis of Coal Preconversion Technology Phase I, Vol. 4, Interim Report. Prepared for the U.S. Energy Research and Development Administration, FE-1520-4. San Mateo, California: Fluor Utah, Inc. July 1975.

Gilbert/Commonwealth. Fossil Energy Technology Characterization and Assessments (5 Vols). Draft interim report, Jan. 1978. Prepared for the U.S. Department of Energy.

Hydrocarbon Research, Inc. H-Coal Integrated Pilot Plant Laboratory Studies, Quarterly Progress Report, October-December 1975. (U.S. Energy Research and Development Administration), FE-1544-22. Morristown N.J.: Hydrocarbon Research, Inc.

Mobil Research and Development Corporation. Development Studies on Conversion of Methanol and Related Oxygenates to Gasoline. Prepared for the U.S. Energy Research and Development Administration, FE-1773-25. Paulsboro, N.J.: Mobil Research and Development Corporation. Nov. 1976.

The Ralph M. Parsons, Co. Mobil M-Gasoline Process. DRAFT dated 6/15/77 Unpublished.

The Ralph M. Parsons Co. Screening Evaluation, Synthetic Liquid Fuels Manufacture. Prepared for the Electric Power Research Institute, EPRI AF-523. Pasadena: The Ralph M. Parsons Co. Aug. 1977.

Pullman Kellogg. Synthol Feasibility Study, for Standard Oil Company (Indiana) Base Case, J-5109. Furnished to U.S. Department of Energy per contract EF-77-C-01-2763. Houston: Pullman Kellogg Division of Pullman, Inc. June 1975, Revised Oct. 1977.

*U.S. GOVERNMENT PRINTING OFFICE: 1978-740-306/4287. Region 4.