SYNTHETIC FUELS COSTS VS. OIL PRICE

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To quantify and clarify the present and future relationship between synfuel costs and oil price, seven processes typifying synfuel technology currently under development were evaluated, using established techniques of process engineering analysis. Plant investment and operating costs were projected in relation to anticipated increasing costs of energy, materials and capital. Results of our study show that as oil price rises, projected cost of synfuel from a new plant using currently foreseeable technology increases proportionately. No matter how high the price of oil rises (even to $100 per barrel), a new plant built subsequent to arrival of oil at that price will not be economic, i.e. the necessary selling price of synfuel to achieve economically attractive equity recovery will exceed oil price. However, synfuel operating costs will increase slower than rising oil prices. Thus a synfuel plant built at any oil price, with the required capital investment committed, will become progressively more economic as oil price rises, attaining parity and eventually becoming quite profitable. Quantitative results are presented from our analysis of five coal conversion processes (H-Coal, Exxon Donor Solvent, Fischer-Tropsch, Lurgi SNG and synthetic methanol), Tosco II oil shale treatment and ethanol manufacture via grain fermentation. Specific conclusions and their policy implications for the northeastern United States are discussed.

Ever since coal gasification and liquefaction were reduced successfully to industrial practice in Germany during World War II, there has been extensive speculation about the economic feasibility of large-scale synthetic fuels manufacture. This discussion has intensified, with growing urgency and significance during the past decade, as petroleum prices soared beyond all rational expectations, with no bounds yet in sight.

To ascertain the real relationship between synfuel cost and rising oil price, seven processes typifying synfuel technology presently under development were evaluated in this study, using established techniques of process engineering analysis. Plant investment and operating costs were projected in relation to anticipated increasing costs of energy, materials and capital. Results of our study show that as oil price rises, projected cost of synfuel from a new plant using currently foreseeable technology increases proportionately. No matter how high the price of oil rises (even to $100 per barrel) a new plant built subsequent to arrival of oil at that price will not be economic, i.e. the necessary selling cost of synfuel to achieve economically attractive equity recovery will exceed oil price.

This analysis assumes that the basic workings of the U. S. economy will remain essentially unchanged and that design and construction of a new synfuel plant will take longer than the time required for the effects of oil price rises to ripple through the economy. As the dominant source of our energy, oil "drives" the cost of all modern industry, including synfuels. Firm correlation is shown in this study between oil price and prices of other forms of energy and of key commodities such as steel and cement. As manufacturing plants become more expensive to build and operate, the costs of their products rise, including the cost of synfuels.

Plant operating costs, however, will increase more slowly than rising oil prices. Consequently, a synfuel plant built at any oil price, with the required capital investment committed, with increasing oil prices, will become progressively more economic; and its product cost over time will attain parity with oil price. Thus, the sooner a plant is built, the better, assuming continuing oil price escalation. Even with continuously increasing oil prices, a synfuels plant would not necessarily appear to be a sound investment from the private sector investor point of view. Assuming any reasonable rate of oil price increase, the length of time between expenditure of the capital investment and recovery of capital from future higher prices is too great to be attractive, in light of the current and expected future interest rate and the associated "time value of money." If oil prices should stop rising, then no synthetic fuels venture could be justified economically now or in the foreseeable future.

Realistic evaluation of synfuels, therefore, must always look ahead. Today's decision needs to be made in terms of its effect several years hence. The full economic benefit of building a plant now may not be realized for up to 20 years in a smoothly-running, fully-depreciated facility selling synfuel very competitively with the then-current price of oil.

For example, under present conditions, a new coal hydrogenation plant could produce synthetic liquid fuel for about $60 per barrel, which would appear patently "uneconomical", compared with oil, now about $30 per barrel. However, to have this plant operating at the time when the present oil price doubles would be an attractive commercial venture. In fact, had such a plant been built about 6 years ago, when oil was $9 per barrel, its product cost of $28 per barrel would be "economical" today.

Table 1 summarizes the principal findings of this study. Economic projections for the seven processes evaluated are presented in terms of oil price over the range of $9 to $100 per barrel, with capital and operating costs correspondingly escalated in a base case for each process. Expressed as dollars per equivalent barrel of oil, these projected synfuel-cost figures show the necessary product selling price for full equity recovery in new plants at rates competitive with other opportunities for capital investment. For simplicity and clarity, straight-line depreciation over 20-year plant life and current-cash expenditures are used in all calculations rather than more complex accounting methods.

Although there is necessarily variation among the individual processes evaluated, the results of this study consistently demonstrate the desirability of bringing synfuel plants on stream as soon as possible. The Fischer-Tropsch process, similar to the SASOL plants in South Africa, would be the most expensive of the seven processes considered, with its projected costs more than double those of the H-Coal, EDS or Lurgi Processes. Both methanol and ethanol would be more expensive than coal hydrogenation liquids, with ethanol substantially higher than methanol. Shale oil extraction via the Tosco II Process promises to yield the lowest-cost synfuel, provided high quality shale remains available at relatively low cost.

In addition to the base cases summarized in Table 1, calculations were made demonstrating sensitivity of synfuel economics to four key parameters--investment estimate level, raw material cost, equity recovery rate, and loan interest rate.

Methodology

Standard procedure for plant cost estimation in the chemical process industries relies upon several cost indexes which are well documented and historically validated in the engineering literature[1]. These indexes track the history of selected components of plant equipment, installation, and operating costs, providing reliable means of scaling these costs from past experience to present time, and of projecting them, with reasonable confidence, into the near future. Selected as the most appropriate one for this study was the Chemical Engineering (CE) Plant Cost Index[2]. It has a reliable "track record", and its composition is consistent with the anticipated configuration of synfuels plants. Current values--monthly and annual--of the overall CE Index and each of its component items are published bi-weekly in the journal, Chemical Engineering, as illustrated in Table 2. Ready availability of these figures facilitates future projection of synfuels plant cost estimates and enables adjustment of values reported and discussed in this paper, should prove desirable in the months to come.

All manufacturing processes consume significant quantities of energy. In recent history, petroleum and natural gas have been the predominant sources of energy in the United States. Thus, it is intuitively logical that major components of manufacturing cost, such as plant investment and operation, should "track" with the price of energy. Since no direct correlation of this kind has been found in recent literature, pertinent data were collected and tested empirically. Interestingly enough, relationships do exist which are useful in making economic comparisons between synthetic fuels and petroleum.

Information was collected on prices of crude oil, coal, natural gas, and electricity over the past decade. Also included were several commodities which are important components in the fabrication and erection of processing equipment, namely, steel, aluminum, copper, and Portland cement, as well as values of the CMR Index, showing the price trend of major chemical products[3]. These are listed in Table 3, together with their sources.

These price data could be plotted vs. time, to display the historical price track of each commodity and possibly to extrapolate into the future. However, as shown in Figures 1 and 2, strong correlations were obtained between these data and energy cost, specifically the price of oil. Figure 2 is a semi-logarithmic plot over the decade 1970-79, with oil price as the linear horizontal coordinate. Although some "cycling" is evident, reflecting time lags between rapidly increasing oil price and its full economic effects, the correlation is positive and strong for each of the quantities plotted, demonstrating the linkage between rising costs and oil price over the past decade. Lines drawn on the figure show ten-year trends, established by computer-aided regression analysis, with correlation coefficients of 80% or better.

Even stronger correlation (95% or better) was shown for coal price, CMR Index and CE Plant Cost Index vs. oil price on the fully-logarithmic coordinates of Figure 1. This figure was used as the primary vehicle for projecting plant costs in relation to oil price.

Our projection began with a realistic predesign engineering cost estimate for each process, exactly as would be required for any new venture in the chemical process industries[1]. As input data for each process, we chose the best such estimate currently available of required investment and operating costs. This information was drawn from the most recent available reports rendered to the U. S. Department of Energy by various contractors, from research and development reports at recent professional conferences and meetings, and from the technical literature. Specific sources are identified below.

To avoid discrepancies caused by comparing facilities greatly disparate in size, we chose where possible cost estimates applying to plants designed to produce 50,000 barrels per day of oil equivalent, which is the plant capacity designated by the Department of Energy for its so-called "Phase-0" evaluation of liquid synfuel processes. Data were available at this plant size for five of the processes included in our study. The exceptions were ethanol production from corn (evaluated at 100 million gallons per year, equivalent to 4400 barrels of oil per day) and the Lurgi Process for synthetic natural gas (evaluated at 250 million standard cubic feet per day, equivalent of 42,200 barrels of oil per day).

All of the starting estimates used in our study were in terms of mid-1979 dollars, except for the Lurgi and Tosco Processes (mid-1978) and ethanol (December 1978). First we projected these estimates "backward" to mid-1974 (when average oil price was $9 per barrel) via the Chemical Engineering Plant Cost Index. Projections into the future were then made in terms of oil price, using our correlations derived earlier for the CE Index CMR Index and coal price, as appropriate (Figure 1). Calculations were made at oil price levels of 30, 50, 75 and 100 dollars per barrel. Since it is reasonable to expect that investors will demand higher rates of return as inflation continues, we correspondingly increases the equity recovery rates used in our base case calculations.

To account for inflation of raw material costs, we used Figure 1 for coal price, and assumed that the cost of oil shale would follow a similar trend, starting with its mid-1978 price ($1.44 per ton). By-product values were calculated from mid-1980 market prices (corresponding to oil at $30 per barrel) and projected upward via the CMR Index of chemical prices (Figure 1).

Table 4 summarizes, in relation to oil price, the projected values of the various indexes, prices and related factors used in making our base-case economic projections. By combining these elements appropriately, the component items of capital and operating costs for each process were scaled up with respect to oil price and summed to arrive at synfuel product costs. The results of this procedure are presented and discussed below.

Results and Discussion

Table 1 summarizes the product costs calculated for the seven processes evaluated, in each case showing the selling price necessary to earn a satisfactory rate of equity recovery in a new plant, starting with its first year of operation.

All of these processes are sufficiently well developed so that reliable estimates of investment and operating costs are available, and three are in commercial operation. Grain fermentation has long been used to make ethanol; the Fischer-Tropsch Process is presently[2] operating at the SASOL installation in South Africa; and methanol synthesis from carbon monoxide and hydrogen has been standard in the chemical industry for many years.

Coal is the raw material proposed for the first five processes listed above. The first three will produce synthetic hydrocarbon liquids, and the Lurgi Process will make synthetic natural gas. Methanol and ethanol are under consideration as alternative motor fuel liquids.

Space limitations here preclude detailed discussion of all seven processes, but the H-Coal Process is reasonably typical and, perhaps, closest to commercial operation. Based on over 20 years of laboratory and pilot plant studies[4], a semi-works unit (600 tons/day) is operating in Kentucky[5,6], and detailed engineering design of a 50,000 B/D facility is underway.

Figure 3 is a block flow diagram of the H-Coal Process, showing principal input and output streams, flow rates, and other requirements for making 50,000 barrels per day of syncrude from typical high-grade bituminous coal. Estimated capital investment and operating expenses as of mid 1979 were, respectively, $1,404 million and $328 million per day[8]. Using the methodology outlines above, these amounts are projected in terms of oil price in Table 5. Calculated product costs are also presented in Table 5 and graphed in Figure 4.

At each of the five oil prices considered -- ranging from $9 to $100 per barrel -- synfuel cost (or necessary selling price) to achieve full equity recovery is substantially above the current oil price. On the graph, the curve labeled "100% Equity" lies consistently above the diagonal line representing "price equality". Thus, in each of the columns of Table 5, synfuel manufacture via the H-Coal Process as a new plant venture appears "unattractive". To be sure, the situation can be relieved somewhat by extended financing, whereby part (say 50%) of the required capital is acquired via long-term, relatively low-rate loan. This situation is shown in the lower part of the table and by the dashed line on the graph. But even under such an arrangement, synfuel cost from a new plant exceeds oil price until about $90 per barrel.

In an inflationary economy, however, evaluations such as these must be oriented toward the future. Thus, the proper perspective for viewing synfuel economics is horizontally across Table 5, rather than vertically in each column. The first column represents the circumstances prevailing in 1974, when precipitous escalation of oil prices began; the second column shows mid-1980 conditions, with oil at about $30 per barrel. If a plant had been built in 1974, its product cost of about $28 per barrel, even with full equity recovery financing, would be very attractive today. Similarly, a new plant will look very good when the present price of oil doubles. The same reasoning applies across the remainder of the table.

To ascertain the sensitivity of our economic projections for the H-Coal Process to input data used in working up the "base case" (Table 5 and Figure 4), detailed calculations were made showing the effects of four economic parameters. Results of these calculations are presented in Table 6. They further demonstrate the capital-intensiveness of the process economics. For ample, for the mid-1980 situation (oil at $30 per barrel) changing the capital investment estimate by 50 percent changes the calculated synfuel product cost at 100% equity recovery in new plants by about 33 percent ($20 per barrel). Reducing the equity recovery from 17.5 to 15 percent reduces calculated product cost about 7.5 percent ($4.70 per barrel); raising the equity recovery rate from 17.5 to 25 percent per year increases calculated product cost by 23 percent ($14.20 per barrel). By comparison, reducing coal price from $34 to $20 per ton (over 40 percent) reduces calculated product cost only 9.5 percent ($5.90 per barrel), and increasing coal price to $80 per ton (more than double) increases calculated product cost only 31 percent ($19.50 per barrel). Comparable effects at other oil price levels are seen in Table 6.

Although differing in detail to some degree, our evaluation of the other processes yielded similar results. All of the coal-based processes proved strongly capital-intensive, with financing cost comprising 60-70% of the product cost and raw material cost only about 10-25%. The notable exception was ethanol via fermentation of corn, where raw material comprised about 50% and capital financing only about 25% of calculated product cost.

From this analysis it is evident that a synfuels industry will not start spontaneously from "grass roots", since this would require very large investment, knowing in advance that its economic success will require continuously-rising crude oil prices and a time period of negative cash flow much longer than the current private-sector investment climate accepts. However, if oil prices do indeed continue rising, such an investment could become immensely profitable once its cash flow turns positive, and the sooner a synfuels plant is built the better. Government encouragement, possibly via tax incentives, investment guarantees or capital loans, at both federal and state levels, could be very significant in this process. Further, incremental investments, adding synfuels manufacture step-wise to existing oil refining facilities, should also be considered and possibly encouraged. This type of investment could prove particularly attractive at refineries where units in hydrogenating heavy crude or residuum exist or are planned.

Because of indigenous high-grade coal in large supply, urban markets demanding liquid and gaseous fuels and its efficient transportation networks, the northeastern United States appears hospitable for early investments in coal-based synfuels. Looking toward the future, as current technology improves with experience and perhaps totally new processes are developed, such investments might well become the basis of a major new industry for this region and for the country, relieving in a significant way present dependence on imported oil.

Work reported in this paper was done in response to a request from the Committee on Science and Technology., US House of Representatives. Complete report, entitled "Costs of Synthetic Fuels in Relation to Oil Prices", was issued by that Committee in March 1981 as Document No. 75-313 0 (Serial B), US Gov. Printing Office, Washington, DC.

References

1. Peters, M. S., and K. D. Timmerhaus. Plant Design and Economics for Chemical Engineers. 3rd Ed., NY: McGraw-Hill, 1980.

2. Arnold, T. H., and C. H. Chilton. New Index Shows Plant Cost Trends. Chemical Engineering, 70 (4) 143-52 (Feb. 18, 1963).

3. Chemical Marketing Reporter. Weekly publication of Schell Publishing Co., 100 Church St., New York, N.Y., 1970-80.

4. Hydrocarbon Research, Inc. Laboratory Program to Support H-Coal Pilot Plant Operation. Report No. FE-2547-19, to U.S. Dept. of Energy, June 1978.

5. Knight, Jerry. Made-from-Coal Synfuel Begins Dripping from Kentucky Plant. Washington Post, June 10, 1980, p. D7.

6. Chemical Engineering, v. 87, no. 13, p. 47, June 30, 1980.

7. Synfuels, April 11, 1980.

8. Clark, C. F., and D. R. Simbeck. Coal Liquefaction, ETEP '79. Project No. 5159, SRI International, 1979. pp. 85-96.

TABLE 1. Economic Comparison of Proposed Synfuels Processes

Process	Oil Price: $/barrel 9	30	50	75	100
	Projected Synfuel Cost in New Plants: $/barrel of oil equivalent				
H-Coal	27.82	61.78	81.60	100.72	117.72
EDS	25.10	55.57	73.88	90.72	105.76
Fischer-Tropsch	62.03	137.41	183.22	227.06	267.13
Lurgi SNG	25.15	54.82	72.54	90.47	106.87
Methanol	34.66	76.75	101.77	125.93	147.59
Tosco II Shale Oil	17.11	36.18	49.97	63.75	76.80
Ethanol from Corn	59.03	101.66	125.52	152.76	177.24

NOTES: (1) Above figures based on 100% equity recovery.

(2) Divide $/BOE by 5.8 to obtain $/MM Btu.

TABLE 2 . Current Values of CE Plant Cost Index (1957-1959 = 100)

	9/80 Prelim.	8/80 Revised	7/80 Final	9/79 Final
CE Plant Cost Index	266.1	264.9	263.6	243.4
Major components				
Equipment, machinery, supports	296.8	296.0	295.3	268.4
Construction labor	208.3	206.1	203.8	199.9
Buildings	243.1	242.7	240.5	233.2
Engineering & supervision	222.0	220.0	217.0	193.4

Annual Index Values for Previous Years

1970	=	125.7	1975	=	182.4
1971	=	132.2	1976	=	192.1
1972	=	137.2	1977	=	204.1
1973	=	144.1	1978	=	218.8
1974	=	165.4	1979	=	238.7

Source: Chemical Engineering, 87(23), 7 (Nov. 17, 1980).

Table 3.

PRICES & INDEX VALUES USED IN CORRELATIONS

DATE	OIL a/	CE INDEX b/	CMR INDEX c/	STEEL d/	ALUMINUM d/	COPPER d/	CEMENT d/	COAL a/	NAT.GAS a/	ELECTRICITY a/
	$/Barrel			$/Ton	$/Ton	$/Ton	$/Ton	$/Ton	¢/MSCF	¢/KWH
1970	3.15	125.7	85.0	154	574	1162	17.88	6.26	NA	NA
1971	3.35	132.2	85.8	168	580	1042	19.01	7.07	NA	1.10
1972	3.35	137.2	86.6	190	526	1028	20.59	7.66		1.16
1973	3.94	144.1	86.9	198	506	1190	22.23	8.59		1.25
1974	9.07	165.4	100.0	222	682	1546	26.79	12.00		1.69
1975	10.38	182.4	108.3	262	796	1284	31.41	16.21	73.2	2.07
1976	10.89	192.1	109.1	284	892	1392	34.25	17.90	97.2	2.21
1977	11.96	204.1	115.2	312	1032	1336	36.76	19.25	131.9	2.50
June 1978	12.48	217.7	118.4	354	1105	1332	46.10	22.88	148.3	2.81
Dec. 1978	12.93	225.9	122.5	374	1110	1438	49.10	23.99	169.9	2.76
Mar. 1979	13.70	232.5	131.2	390	1160	1934	52.60	24.82	186.8	2.89
June 1979	17.00	237.2	137.5	394	1190	1764	53.81	25.91	180.5	3.02
Sep. 1979	20.14	243.4	142.1	406	1235	1918	54.78	26.45	212.4	3.14
Dec. 1979	23.53	247.6	144.0	415	1375	1975	56.00	27.10	211.4	3.23

Sources:

a. Monthly Energy Review, U.S.Dept. of Energy Pub. DOE/EIA 0035

Oil: Crude Oil Refiner Acquisition Cost (composite)
Coal: Utility Fossil Fuels, Average Delivered Prices (contract)
Natural Gas: Sales by Interstate Pipeline Companies to Industrial Users
Electricity: Average Retail Prices (Industrial)

b. Chemical Engineering, McGraw-Hill Publishing Co., bi-weekly

c. Chemical Marketing Reporter, Schell Publishing Co, weekly

d. Minerals & Materials: A Monthly Survey, Bureau of Mines, U.S.Dept. of Interior

TABLE 4.

Cost Indexes, Prices, and Rates Used in Base Case Calculations

	Oil Price: $/Barrel				
	9	30	50	75	100
CE Plant Cost Index	156	270	334	384	424
CHR Chemical Price Index	100	167	205	241	270
Raw materials:					
Coal: $/ton, delivered					
Bituminous	12	34	44	52	57
Sub-Bituminous	4.50	13	16	20	22
Shale: $/ton	1.20	2.80	4.20	5.75	7
Corn: $/bushel	1.90	2.90	3.40	4.00	4.50
Electricity: cents/KWH	1.70	4.50	7	10	13
Process water: cents/Mgal	30	50	60	65	70
Equity recovery: %/year	12	17.5	20	22.5	25
Loan Interest: %/year	7	10	12.5	15	17

Table 5

H-COAL PROCESS ECONOMIC PROJECTIONS

Base Case

	OIL PRICE - $/Barrel				
	9	30	50	75	100
CAPITAL INVESTMENT - MM$	973	1590	1965	2260	2495
OPERATING EXPENSES - MM$/yr					
Coal	82	233	295	357	391
Other	128	202	236	262	284
Total	210	435	531	619	675
FINANCING (100% Eq.) - MM$/yr	269	607	844	1081	1312
TOTAL REVENUE REQ. - MM$/yr	479	1042	1375	1700	1987
By-product credit	27	38	49	61	74
Synfuel Revenue Req.	452	1004	1326	1639	1913
$/Barrel	27.82	61.78	81.60	100.86	117.72
$/MM Btu	4.85	10.75	14.20	17.55	20.49
FINANCING (50% Eq.) - MM$/yr	190	419	590	760	924
TOTAL REVENUE REQ. - MM$/yr	400	854	1121	1379	1599
By-product credit	27	38	49	61	74
Synfuel Revenue Req.	373	816	1072	1318	1525
$/Barrel	22.95	50.22	65.97	81.11	93.85
$/MM Btu	4.00	8.74	11.48	14.11	16.33

TABLE 6

H-Coal Process Economic Projections

SENSITIVITY STUDY RESULTS

	Oil Price - $/Barrel				
	9	30	50	75	100
	SYNFUEL COST ($/Barrel) at 100% EQUITY RECOVERY				
BASE CASE	27.82	61.78	81.60	100.86	117.72
Effect of INVESTMENT ESTIMATE LEVEL					
Base Case - 50%	18.28	41.05	53.05	64.62	74.03
Base Case + 50%	37.42	82.65	110.22	137.17	161.42
Base Case + 100%	46.95	103.38	138.77	173.42	205.11
Effect of COAL PRICE					
$20 per Ton	31.20	55.88	71.88	87.32	102.09
$40 per Ton	39.69	64.37	80.37	95.82	110.58
$60 per Ton	48.12	72.80	88.80	104.25	119.02
$80 per Ton	56.55	81.23	97.23	112.68	127.45
Effect of EQUITY RECOVERY RATE					
15% per Year	31.26	57.11	69.97	80.74	88.15
20% per Year	37.05	66.52	81.60	94.09	102.95
25% per Year	42.77	75.94	93.17	107.51	117.72
	SYNFUEL COST ($/Barrel) at 50% EQUITY RECOVERY				
BASE CASE	22.95	50.22	65.97	81.11	93.85
Effect of LOAN INTEREST RATE					
Equity Recovery Rate = 15% per Year					
5%/yr. Loan Interest	24.06	45.42	55.51	64.18	69.85
15%/yr. Loan Interest	27.08	50.34	61.54	71.14	77.54
Equity Recovery Rate = 20% per Year					
5%/yr. Interest Rate	26.95	50.15	61.35	70.89	77.23
15%/yr. Interest Rate	29.97	55.08	67.38	77.85	84.92
Equity Recovery Rate = 25% per Year					
5%/yr. Interest Rate	29.85	54.83	67.20	77.60	84.62
15%/yr. Interest Rate	32.86	59.75	73.23	84.55	92.31

Figure 1

CE PLANT COST INDEX
CMR INDEX AND COAL PRICE VS. OIL PRICE

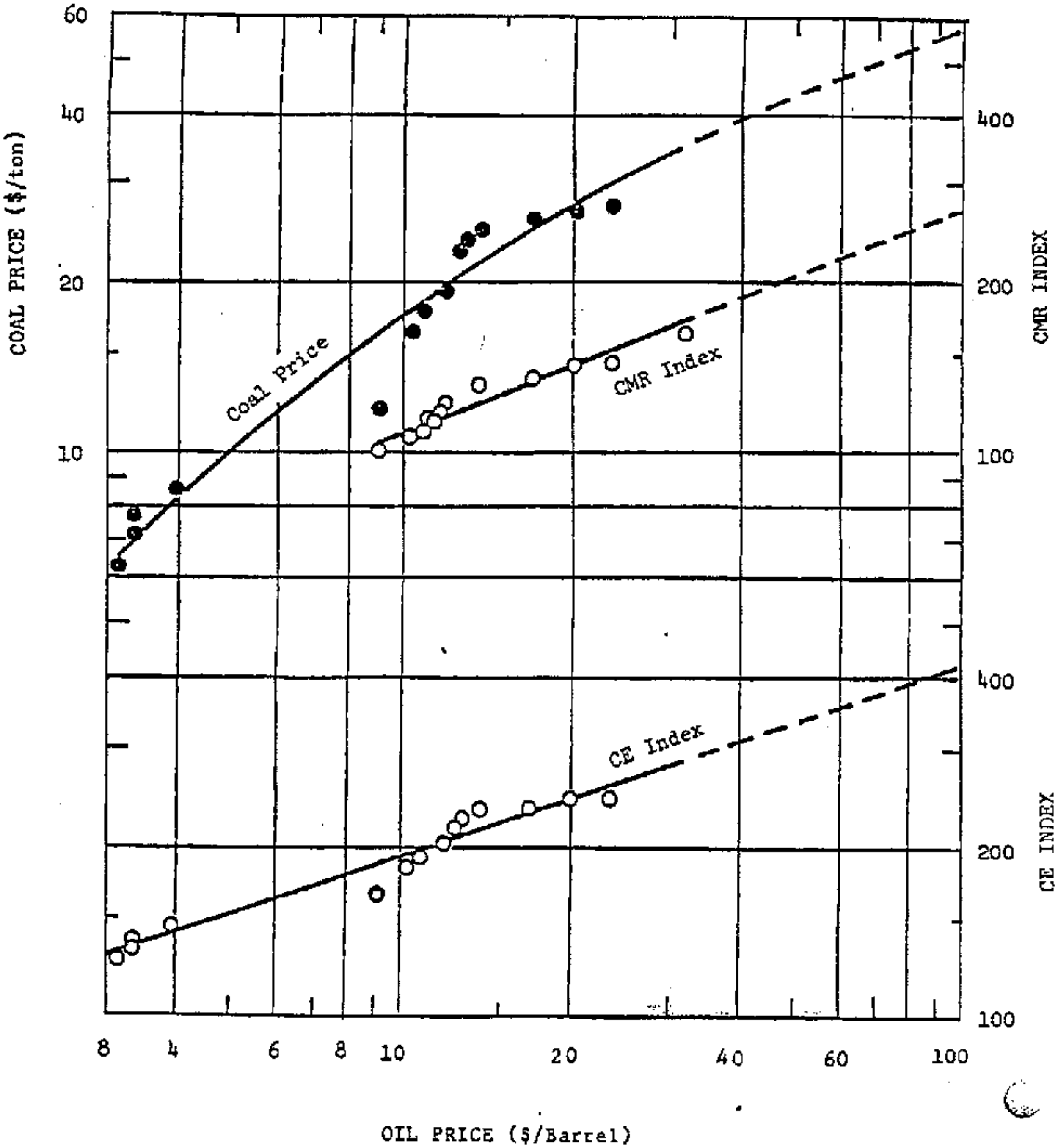


Figure 2

CE PLANT COST INDEX, CMR INDEX
AND COMMODITY PRICES VS. OIL PRICE

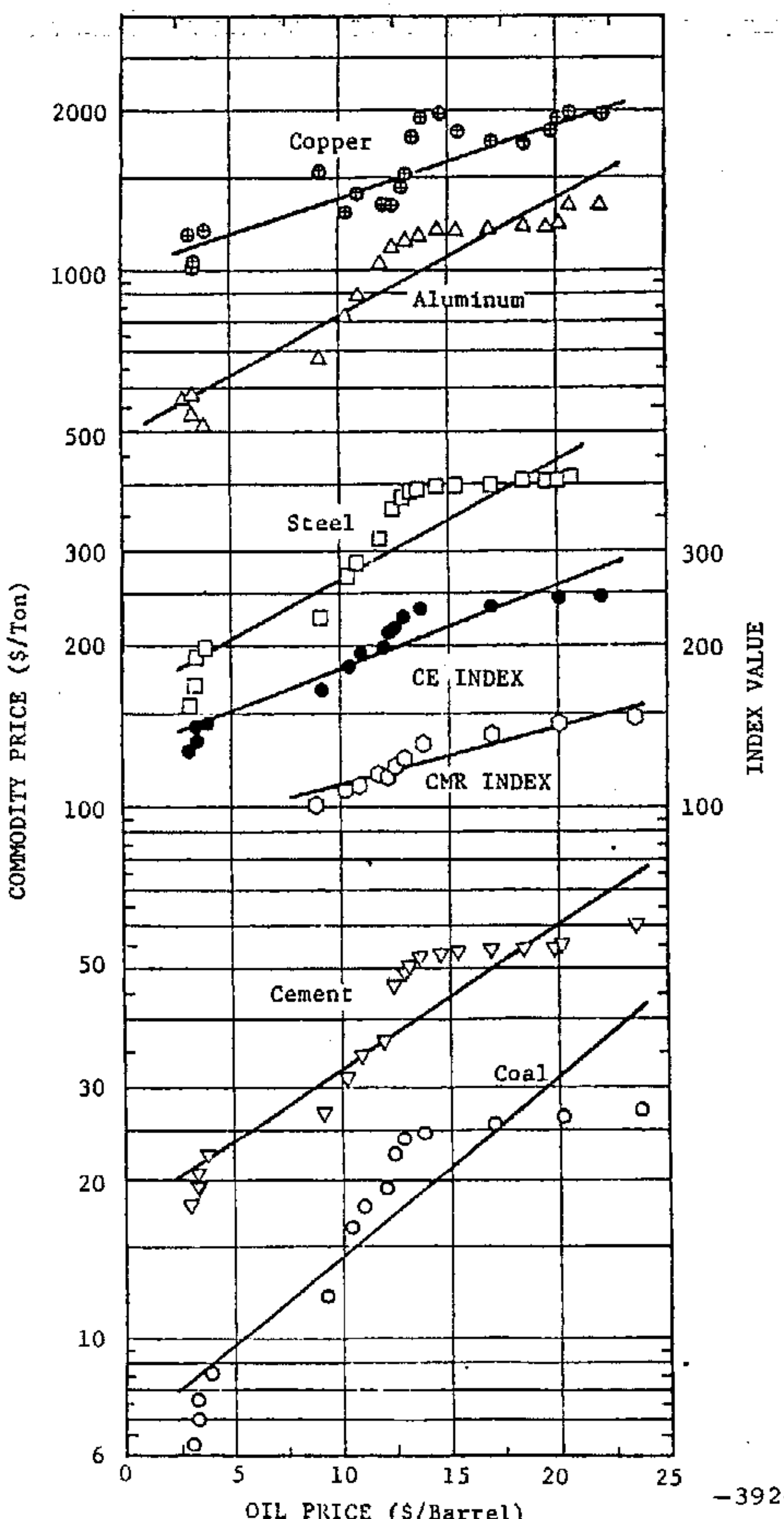
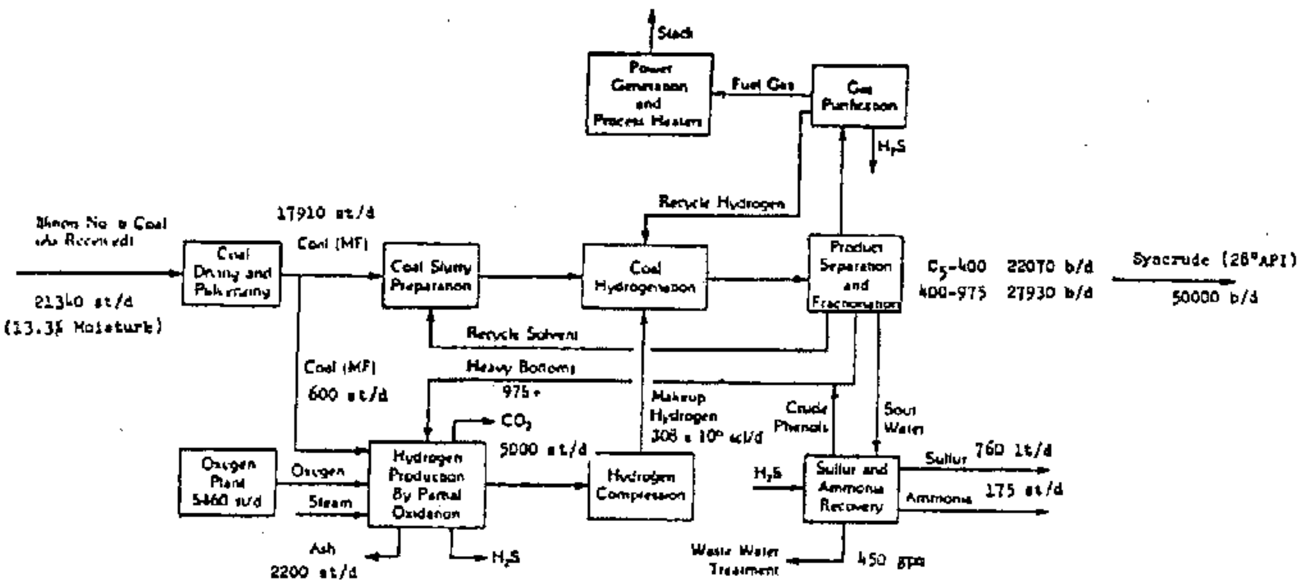


Figure 3

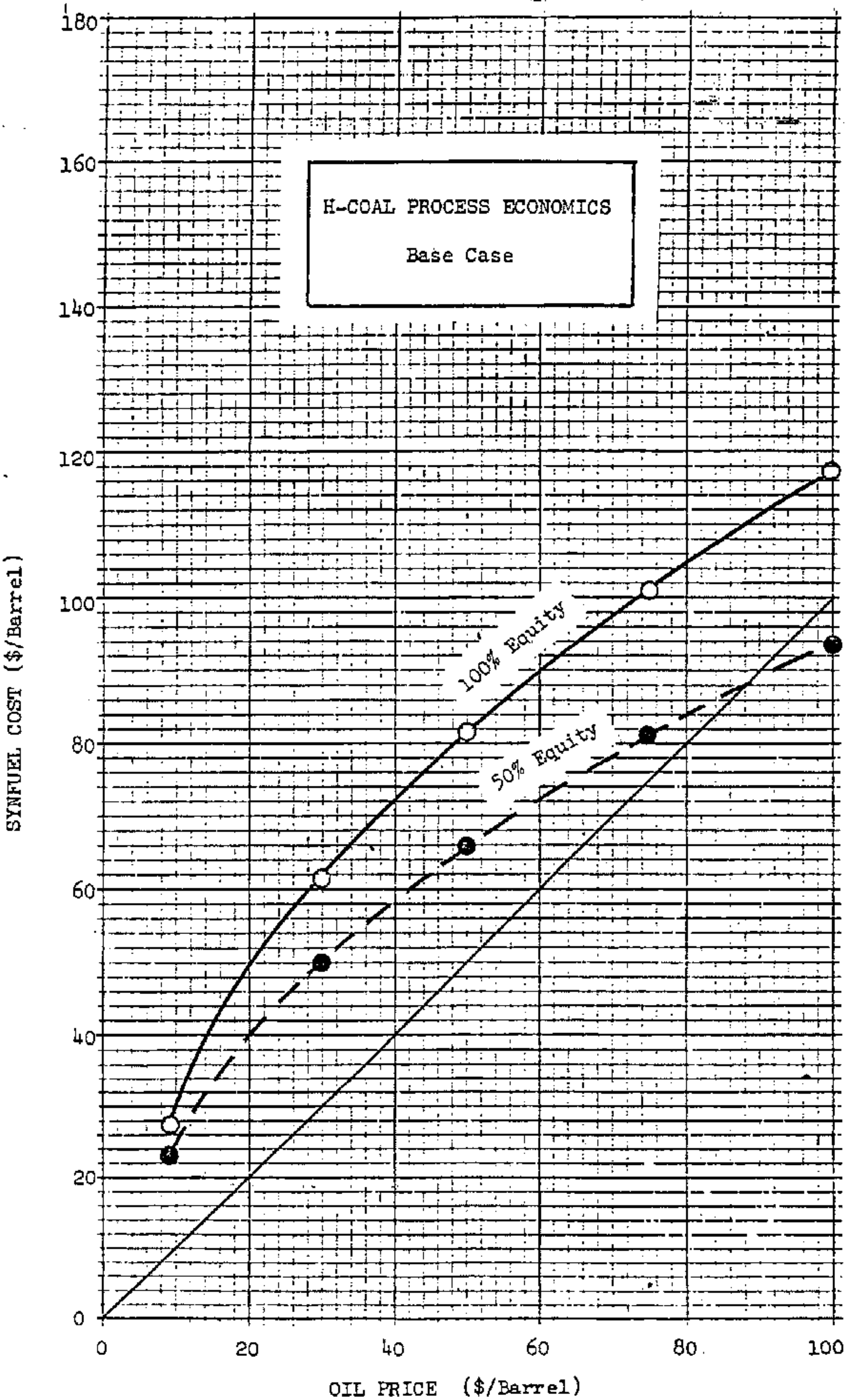
H-COAL PROCESS FLOW DIAGRAM[4]



<u>Other Requirements:</u>

Operating Labor - 77 men per shift
Cooling Water - 10,000 gpm

Figure 4


H-COAL PROCESS ECONOMICS
Base Case
100% Equity
50% Equity
SYNFUEL COST ($/Barrel)
OIL PRICE ($/Barrel)
0
20
40
60
80
100
120
140
160
180