Engineering Experiment Station Technical Report

SYNTHETIC LIQUID FUELS FROM COAL AND WOOD

by

Edward F. Thode, Sc.D., P.E.
Professor and Head
Department of Chemical Engineering
New Mexico State University

Prepared for:

7503931

FOREWORD

The following position paper has been prepared as a public service under sponsorship of the Department of Chemical Engineering and the Engineering Experiment Station of New Mexico State University. This report represents solely the views of the author and does not necessarily reflect the views of New Mexico State University.

The conclusions, suggestions and recommendations have been offered by the author as a means of stimulating public interest and activity in the field of production of clean liquid fuel from coal and wood.

<div align="right">

Edward F. Thode
Las Cruces, N.M.
May 1974

</div>

TABLE OF CONTENTS

PART I

EXECUTIVE ABSTRACT

Production of synthetic liquid fuel from coal in New Mexico will be in competition with coal gasification not only for strippable coal but for water. Public policy decisions on the most appropriate use of the scarce water resource will determine how much, if any, liquid fuel is made from coal in New Mexico. While the production of liquid fuel from coal has the theoretical advantage of requiring less water, per BTU of fuel produced, than does coal gasification, there are no presently available data relating to New Mexico conditions which would establish this water-conserving potential in practical operations. Predictive data from pilot-plant studies are urgently needed to settle the question.

Five general methods exist for the manufacture of synthetic liquid fuels from coal. Of these, two are considered particularly suitable for New Mexico conditions and needs. These are, the direct hydrogenation process (H-coal or Synthoil) for petroleum, and indirect conversion to methanol. The writer recommends that appropriate state agencies immediately initiate work in cooperation with industry, the Office of Coal Research, and/or the Bureau of Mines on the adapting of the H-coal or Synthoil process to the more extensive of the New Mexico Coal reserves. A study of product transportation options is also required. The writer also recommends that immediate engineering development work be undertaken with the view of using New Mexico's reserves of excess wood - rather than coal - for the construction of a plant for the production of methyl fuel as a gasoline extender. A critical shortage of

chemical engineers, process plant technicians and construction workers may be a major obstacle to construction of a large coal conversion plant. The more modest wood conversion plant would be less affected by these factors.

PART II

BACKGROUND

So-called indirect conversion of coal to liquid fuels was practiced on a commercial or semi-commercial scale in Germany, France and England from about 1930 to 1945. It is currently being practiced in the Union of South Africa. Indirect conversion has been extensively studied in the U.S. It is felt that this process is economically less desirable than other alternatives. In New Mexico, indirect conversion is also rather undesirable because of the high amount of consumptive use of water compared to some of the other processes.

In general, no method of converting coal or wood to synthetic petroleum fuel has been found economically attractive in the U.S. up to date. Nevertheless, a number of economists, political scientists and demographers believe that it is essential that the U.S. prepare and have plants for coal liquefaction operable – if not necessarily operating – in order to keep a ceiling on the price of imported crude oil. Even allowing for inflation, it is estimated that modern plants could produce synthetic crude oil at a cost of about $7.50 per barrel from strip mined coal. (1974 prices). For this reason, the U.S. Department of the Interior is pushing ahead rapidly with plans for construction of demonstration plants for one or more coal liquefaction processes.

PART III

RESOURCE INVENTORY

The critical resource concerns for coal liquefaction are: 1) strippable

coal, 2) water, and 3) the personnel for construction and operation of the plants. Another position paper presents the complete details of the coal resource inventory. It is sufficient to comment here that present leases and commitments involve only about one third of the readily strippable coal in New Mexico. Most, although not all, of the coal now under "options" is located on the Navajo Indian reservation. Thus coal, itself, is presumably not a limiting factor.

At a meeting of Energy Task Force paper writers, a more critical point was discussed: If all projected coal-gasification plants, for which coal commitments have already been made, are actually constructed, there will be no water resources available for any further gasification or liquefaction plants. The writer of this report was unable to verify this information independently, but has prepared this report on the assumption that the above information is correct.

Coal liquefaction processes theoretically should require less water resources per pound of solid fuel converted to fluid hydrocarbon than the coal-gasification processes. Whether this would actually work out in practice is something that will require considerable further technical study. Assuming that this advantage of requiring less consumptive use of water does apply to the coal liquefaction process, then a policy decision needs to be made as to whether the present water allocation commitment to gasification plants should be changed to include a balance of liquefaction plants.

There is a contrary factor, however, that also requires study: This has to do with the transportation resources available for the products of these plants. As long as it would not be necessary to add to the transportation network for gaseous products, it would seem logical to make use of

this present resource. However, if construction of additional gasification plants would require construction of additional gas transportation facilities, then the tradeoff between this option and the option of installing or expanding a network for the liquid product needs to be examined in depth.

A major problem with regard to manpower has to do with construction of the plants; there is very serious doubt that there exists – on the national scale – a sufficient number of engineers and skilled process plant fabrication workers to build all of the coal gasification and liquefaction plants which the U.S. will need in the next ten years. It is estimated that approximately 2200 chemical engineers will be required for the experimental work, design, construction start-up, and operation of these plants, nationwide. With engineering enrollments all over the country declining, this additional demand would require an immediate turn-around resulting in a ten percent increase in production of B.S. Chemical Engineers, just to meet the coal gasification and liquefaction manpower needs.

PART IV

TECHNICAL

The various categories of processes for obtaining liquid fuels from coal are summarized in Table I, including certain of their characteristics as determined from pilot plant operation. Unfortunately, the present state of the art is that the most promising of the processes have only been tried in bench scale or rather small pilot plants to date. Also, one process about which the most is known (partial conversion or COED) may be unsatisfactory for New Mexico resource conditions as well as for New Mexico market conditions. Comments on specific processes follow.

TABLE I

Liquid Fuels From Coal

Type of Process	Names Used	Estimated Comparative Consumptive use of Water (Gasification=100)	Coal Required	Products	Byproducts
Direct Hydrogenation	Bergius*, H-Coal Synthoil	60	Any bitu. or sub-bitu.	C_4+liquids 63% by wt.	Sulfur, Char Fuel Gas
Extraction	Pott-Broche* CSF, Ulha-Pfirrman SRC(P&M Co.)	60	Any bitu. or sub-bitu	#6 Fuel Oil 40% #2 Fuel Oil 20% Naphtha 4%	Sulfur Slag
Partial Conversion	COED Seacoke	25	High-volatile Bituminous	28° API Crude- 21%	Hydrogen, Char-55%
Indirect Conversion	Fischer-Tropsch* SASOL	80-90	Any	Paraffinic or Oxygenated Hydrocarbons Approx. 50%	Methane Ash Sulfur
Methanol by Indirect Conversion	Synthesis Gas— ICI (see note) (see Appendix C)	75	Any	Methyl Fuel (Impure Methanol) Approx. 60%	Ash Sulfur

Methanol process suggested by combining two existing technologies.

*Historical Interest Only
+Requires petroleum feed also

A. Direct Hydrogenation

At the AIME 1974 conference on synthetic hydrocarbons, Johnson, Stotler and Volk quoted a 1973 AEC study as follows: "At present we believe that a catalytic hydro-liquefaction process making a major fraction of product in the motor fuel and middle distillate range (the syncrude flow sheet) has the highest probability of technical success of all the liquefaction processes and a good possibility of producing the most economical product mix. The syncrude flow sheet, by virtue of the simplicity for the production of light oils, has high potential for early commercialization." (1)

The type of process described above is properly categorized as a direct hydrogenation process. It has the potential, especially with low-sulfur coal, of considerably less consumptive use of water than a coal gasification process. The technology is, comparatively speaking, well advanced; a large pilot plant may well be operating within two years.

The direct hydrogenation processes studied most extensively in the U.S. is the so called H-coal process developed by Hydrocarbon Research Inc., under contract with the Office of Coal Research, U.S. Dept. of Interior, and the BuMines Synthoil process. Using Illinois #6 Coal, which is a fairly high-volatile bituminous, the H-coal process produced 63 percent by weight of hydrocarbons of butane and higher in the following proportions: (2)

42.2% Butane to 400° Naphtha

41.5% 400 to 600°F distillate fuel oil

16.3% 640 to 975°F gas oil

Converting to 1974 costs, it is estimated that gasoline made by this process could be sold at a plant value of 21¢ a gallon from a 30,000 barrel a day plant, and somewhat less from a 100,000 gallon a day plant. The water

resources requirement of such a plant are not known but are estimated to be approximately half that of a plant converting the same amount of coal to pipeline gas. The high ash content of New Mexico coal may give some minor technical problems with this process.

B.   Extraction Processes

Extraction process would also be suitable to New Mexico coal. The one most intensively studied recently is that of the Pittsburgh and Midway Coal Mining Company, a Division of Gulf Oil Corporation. The process was likewise developed on contract from the Office of Coal Research and has been analyzed by the Ralph M. Parsons Company for the specific purpose of providing low sulphur #6 fuel oil and #2 fuel oil for utility boiler use. (3) The amount of naphtha and of lowboiling fraction suitable for gasoline production is quite low under the present concept of the process. However, there is no reason, technically speaking, why the product mix cannot be altered by changing the reaction conditions. The overall efficiency of conversion of coal to liquid fuel is approximately the same as that of the H-coal process.

Ralph M. Parsons Company has completed the preliminary design of a plant consuming ten thousand tons a day of coal. From that report it has been possible to estimate the consumptive use of water for this size plant, at twenty six hundred fifty acre feet per year. Total water requirement is forty four hundred acre feet per year. Selected data from the Parsons' report to United States Department of Interior is included in Appendix B.

C.   Partial Conversion

The so-called COED process is being developed by FMC Corporation under contract with the Office of Coal Research. It is suitable only for high volatile bituminous coal and yields a rather low percentage, approximately

21% of 28° API crude oil. The snythetic crude differs somewhat in composition from a conventional natural crude as from the Permian Basin. (4) Byproducts of this process include a great deal of hydrogen plus a char containing pure carbon and all of the ash in the material. Considering the very high ash content of New Mexico coals, and the fact that these coals have a variable volatile combustible matter, the COED process appears to be inappropriate.

D. Indirect Conversion to Naphthas, Gas Oils, and Other Related Hydrocarbons

Indirect conversion depends on formation of synthesis gas, that is, a mixture of CO and hydrogen, by reaction of steam with the basic input fuel. This means that any fuel-not only any kind of coal, but also any kind of vegetable matter or, indeed, refuse - may be used as a source of raw material for the process. The disadvantage of using indirect conversion, even though it is the one for which there exists the greatest amount of knowledge on a commercial scale, is that the consumptive use of water is very high, approaching that for coal gasification. Considering that the plants are a great deal more complicated and therefore more expensive than coal gasification plants and that they produce pipeline gas as a byproduct, anyway, it would seem to be neither cost-effective nor energy-effective to choose indirect conversion to liquid fuels over coal gasification under New Mexico conditions.

E. Methanol by Indirect Conversion

The technology of producing methanol by indirect conversion has been known for a long time. Synthesis gas, in the proportions of two volumes of hydrogen to one of carbon monoxide, is catalytically converted to methanol with some byproducts of higher alcohols. If the objective is to provide a clean burning fuel, purification of the methanol is not necessary. Less hydrogen is required than in the indirect conversion to paraffinic hydrocarbons

or in coal gasification and therefore there is less consumptive use of water.

This impure methanol, known as methyl fuel, has intriguing possibilities for

various applications, particularly as a gasoline additive. It has a blending

octane value of 130, has the ability of reducing emissions, increasing octane

number and increasing miles per gallon obtained, when added to ordinary gaso-

line in a proportion not exceeding 15%. (5) The amount of methyl fuel which

can be blended with gasoline depends upon both temperature and humidity condi-

tions. It is probably unsuitable for hot, humid regions such as the Texas

Gulf coast, but in amounts of at least 10% would appear suitable in New Mexico.

Methyl fuel can be produced from sources other than coal, as mentioned

earlier. New Mexico has a renewable resource in the Sangre de Cristo and

Jemez Mountains of approximately 1000 cords of wood per day. This wood would

otherwise be wasted through wind blown losses, disease, or crowding of trees

which inhibit their growth. New Mexico has another resource, on the order

of two hundred to three hundred cords of wood per day, equivalent, in slabs,

edgings, and waste from sawmill operations. Some such mills have recently

been forced to cease operations because the disposal of this waste could

not be accomplished within restrictions of air environment protection regu-

lations.

Two suggestions for the production of methyl fuel from wood, therefore

seem in order:

(1) Use the thousand cords a day of excess wood in the National Forests

of northern New Mexico to operate a synthesis-gas indirect conversion

plant, presumably somewhere in the vicinity of Santa Fe or Espanola,

with a capacity of approximately six thousand barrels a day of methyl

fuel. The author of this report has estimated the plant cost of such

a product to be on the order of 30 cents a gallon, given the present

level of prices of equipment and operation.

(2) Design a "Mini-Plant" which can be taken from one place to another in the State on semi-trailer trucking rigs and used on the site of sawmills to convert sawdust, slabs and edgings to methyl fuel. While the operating costs of such a plant would be much higher than for a single stationary plant employing wood brought to it from a forest, the raw material has essentially zero value, whereas the raw material for the stationary plant has a very considerable cost incurred for cutting, chipping, hauling and stumpage fees. It could well be then that a mini-plant traveling around the state could produce methyl fuel at a 30 to 35 cents a gallon.

It is recommended that these two alternatives be examined in some depth

(PART V OMITTED)

PART VI

ECONOMIC AND FINANCIAL

The capital cost estimate for the H-coal process, adjusted to 1974 prices, is approximately $210,000,000 for a plant which would use 11,000 tons a day of New Mexico coal. A comparable size plant using the P and M process but intended to be a demonstration plant was estimated at a completion cost of $270,000,000 in November of 1973. This completion cost allowed $43 million increase in construction cost before the project could be completed. The economic impact on the state would be greatest during the construction phase of such a plant, because, by their very nature, all process plants are capital-intensive.

After construction is over, the principal impact would be that of

providing jobs for those operating the coal mining equipment and the work force of the process plant. The cash flow generated by payroll and local purchases would be in the vicinity of $25,000,000 per year. Using the usual three-times-around figure, this would produce an increased generalized cash flow in the State of $75,000,000 per year, thereby producing increased gross receipts and income tax revenues of about four million dollars a year to the state and municipalities involved.

PART VII

ENVIRONMENTAL IMPACT

Environmental impact is principally that of the strip mining of the coal and is therefore covered in the other appropriate position papers. The plants themselves, it is assumed, would meet all appropriate federal and state emission standards. The sulphur content of the material would be produced in the form of elemental sulphur, which might have to be stockpiled, the ash or slag would be returned to the mining site as backfill.

(PART VIII OMITTED)

PART IX

SOCIETAL

It is obvious that the principal societal impact of construction of a coal liquefaction or a methyl fuel plant would be that of providing jobs for New Mexico residents where none had previously existed. During the preliminary stages and construction stages, there will be job impact requiring skilled construction workers and engineers, also pilot plant and development engineers. Then, there will be a smaller number of people, mostly at the professional or fairly skilled worker level, operating the plants for a period of 20 to

30 years.

Since there is anticipated to be a nationwide shortage of people with the requisite skills to design, build and operate these plants, it appears doubly undesirable for New Mexico to import any larger faction than necessary of people to do the necessary job. First, it is undesirable because there are people who need significant, well-paying jobs and have the potential of performing them within our present population. Second, it would be undesirable because of the competition for people with existing skills, which would make it difficult to attract the needed personnel from outside the state.

Thus, training and education seem to be the key to the required societal adjustment. There will sizeable lead times available before many of the people required in either the construction or the operating aspects will be needed. This lead time is none too great if we need to obtain qualified persons in increased numbers to take the long course of preparation required for professional engineering work. If some of these process plants will be going on stream in five or six years, then there is comparatively little time to identify, motivate, and recruit talented young persons needed to staff the junior professional positions in the plants. It is obvious that the senior positions must come from those already in the field and gaining experience. It is significant that a number of New Mexico "natives" who outmigrated upon completion of their college careers are now returning, as technical opportunities in coal-conversion and related areas are opening up.

Perhaps the biggest obstacle to successful completion of any one of the important middle-term solutions to the energy crisis is that of arranging for the effective joining together of economic resources, water resources, and human resources for the accomplishment of the needed tasks.

PART X

PROGRAMS FOR THE FUTURE

An intensive research and development stage is immediately required
in the field of this report. Specifically, the following items should be
pursued:

1. Pilot-plant studies (in existing pilot plants), of representative
New Mexico coals, for production of liquid fuel.

2. Projection of yields, costs, and water requirements of such
processes in full-scale operation, using the pilot plant data.

3. Study of the trade-offs of water consumption, product yield, and
transportation costs between gasification and liquid fuel plants.

4. A technico-economic study of the feasibility of constructing a
6000 bbl/day methyl fuel plant in the Santa Fe - Espanola region.

5. Engineering study of the possibility of constructing a portable
methyl fuel "mini-plant" to utilize sawmill wastes.

PART XI

BIBLIOGRAPHY

1. Johnson, C. A., Stotler, H. H. and Volk, W., "H-Coal Process for Pro-
   ducing Liquid Hydrocarbons," paper presented at AIME 1974 Conference
   on Synthetic Hydrocarbons, Dallas, Texas, February 24-26, 1974.

2. Johnson, C. A., Stotler, H. H. and Volk, W., "H-Coal Prototype Plant
   Program," paper presented at AIChE 66th Annual Meeting, Philadelphia,
   Pa., November 11-15, 1973.

3. Ralph M. Parsons Company, "Demonstration Plant - Clean Boiler Fuels from
   Coal," R&D Report No. 82, Interim Report No. 1, Vol. 1, Washington, D.C.,
   Office of Coal Research, U.S. Dept. of the Interior, November 1973.

4. Seglin, L. and Eddinger, R. T., "Synthetic Crude Oil from Coal," in
   Kirk-Othmer Encyclopedia of Chemical Technology, 2nd Ed., Supp. Vol.,
   pp. 178-198 (1971).

5. Reed, T. B. and Lerner, R. M., Science, 182(4119):12299-1304 (Dec. 28, 1973).

APPENDIX A

SELECTED INFORMATION ON H-COAL PROCESS

The following tables and figures were extracted from References (1) and (2).
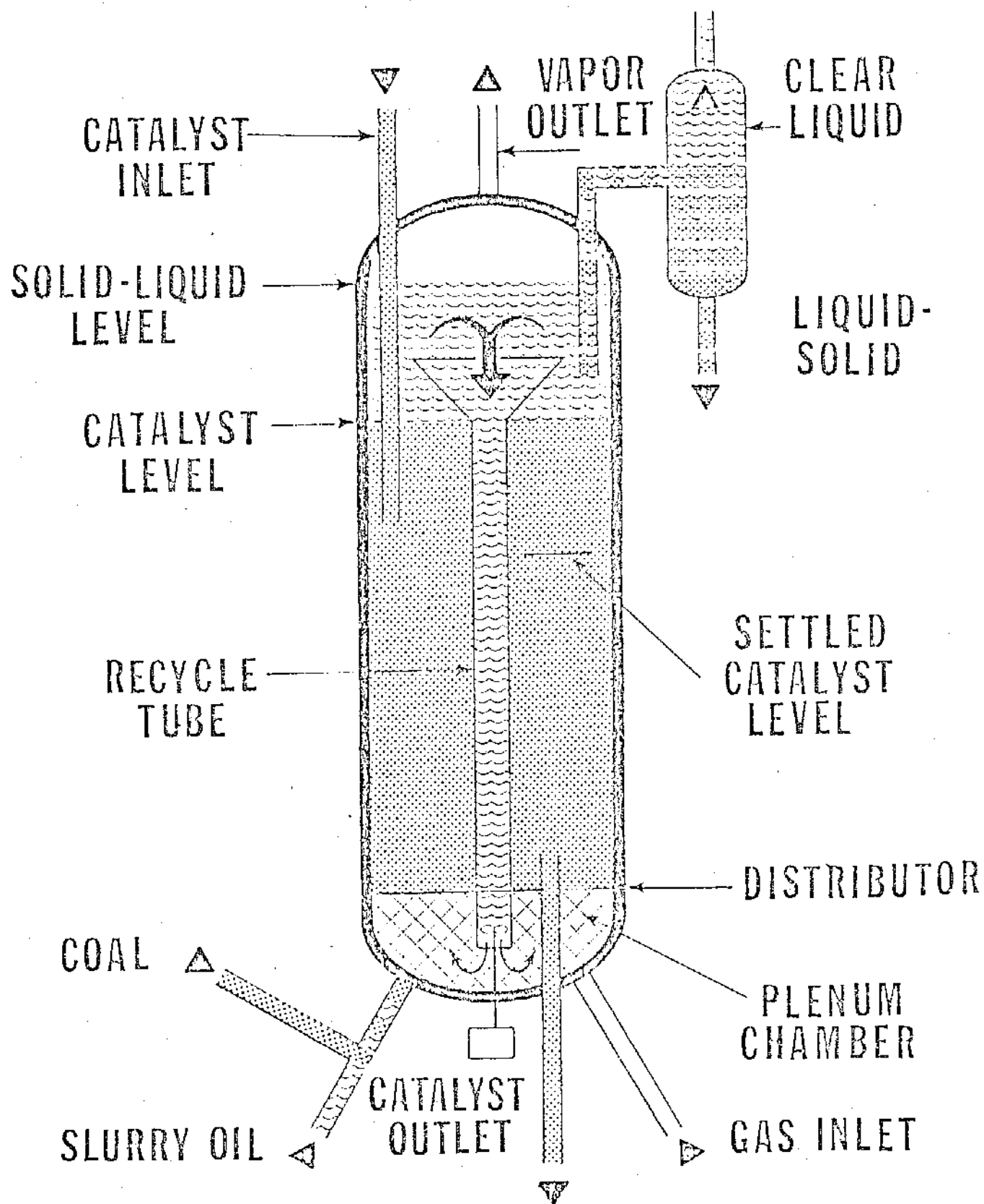
EBULLATED BED REACTOR

CATALYST INLET

SOLID-LIQUID LEVEL

CATALYST LEVEL

RECYCLE TUBE

COAL

SLURRY OIL

CATALYST OUTLET

VAPOR OUTLET

CLEAR LIQUID

LIQUID-SOLID

SETTLED CATALYST LEVEL

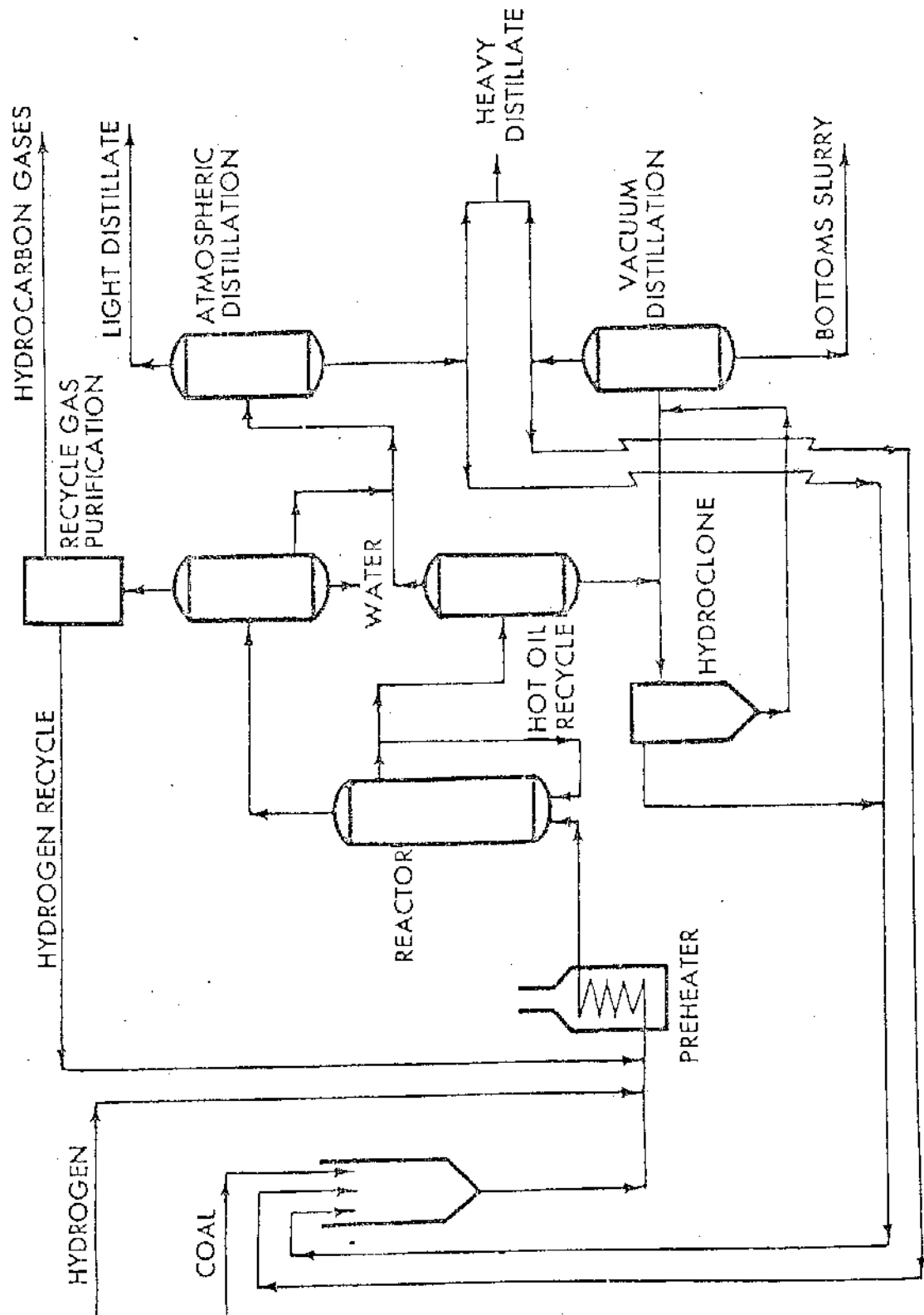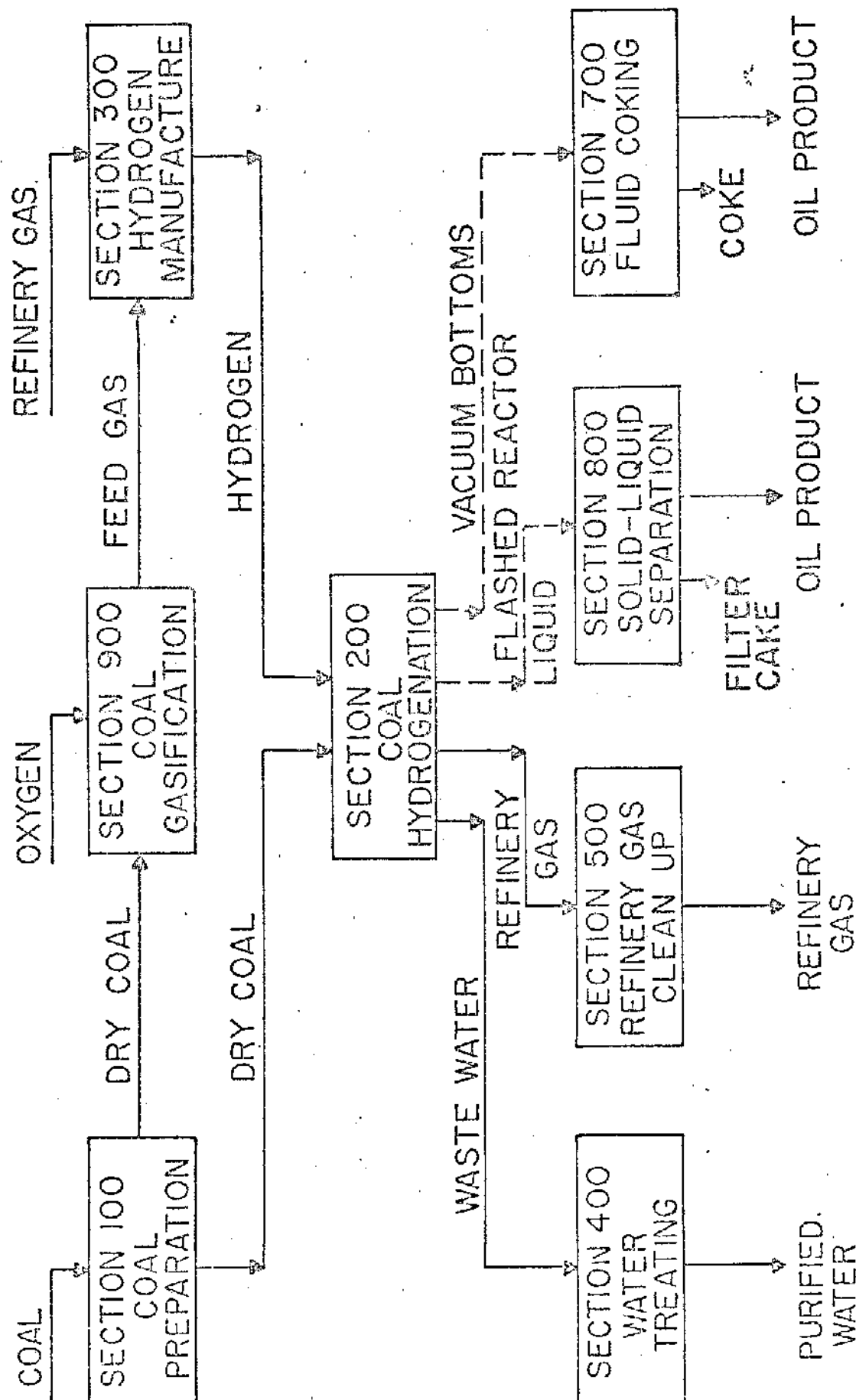DISTRIBUTOR

PLENUM CHAMBER

GAS INLET

FIGURE 2

H—COAL PROCESS DEVELOPMENT UNIT

BLOCK FLOW DIAGRAM OF
H-COAL PROTOTYPE PLANT

TABLE 8

SUMMARY OF RAW MATERIALS, UTILITIES AND PRODUCTS - ILLINOIS NO.6 COAL

CAPACITY: 25,000 TPSD DRY COAL

Products	Case 1			Case 2		
	Volume %	Gravity °API	Sulfur W%	Volume %	Gravity °API	Sulfur W%
Synthetic Crude Oil, Bbl/SD	67,466			15,000		
Naphtha, Bbl/SD		-		48,122		
Fuel Oil, Bbl/SD		-			-	
IBP Cuts						
IBP-400°F	42.18	44.6		1.51	27.1	0.1
400-650°F	41.51	17.3		35.47	15.4	0.5
650-975°F	16.31	5.0		29.94	-4.4	
975°F+				38.08	-16.6	
	100.00	25.2	≤0.2	100.00	-3.1	
Sulfur, LT/SD	977			801		
Ammonia, ST/SD	205			152		
High Btu Fuel Gas, MMM Btu/SD	89.90			34.09		
Raw Materials and Utilities						
As-Received Coal, ST/SD	27,778			27,778		
Fuel	1,064					
Total	28,842					
Operating Electricity, KW	209,740			163,819		
River Water, GPM	11,482			8,700		

TABLE 9

ECONOMIC SUMMARY - ILLINOIS NO.6 COAL (CAPACITY: 25,000 TPSD DRY COAL)

	Case 1	Case 2
Solids Separation	None	Settling
Hydrogen Feedstock	Vacuum Bottoms	Settler Bottoms
Plant Investment		
On-Site	$312,295,785	$252,371,785
Off-Site	54,816,700	44,180,900
Initial Catalyst	3,420,000	2,000,000
Total	$370,532,485	$298,552,685
Annual Revenue, $ MM		
Fuel Oil Naphtha Product $6.06/Bbl (Average)		126.20
Synthetic Crude Oil, $5.80/Bbl (Average)	129.02	
High Btu Fuel Gas, $1/MM Btu	29.67	11.25
Sulfur, $20/Long Ton	6.45	5.29
Ammonia, $33/Short Ton	2.23	1.65
Total Revenue	167.37	144.39
Annual Operating Costs, $ MM		
As-Received Coal, $5.00/Ton	47.59	45.83
Electricity, $0.006/KWH	9.97	7.78
Catalyst & Chemicals	9.49	8.91
Payroll with Benefits	4.46	4.46
Repair Materials	5.36	4.31
Contract Shutdown Maintenance Labor	6.38	4.82
Other Contracted Services	0.60	0.60
Overhead & Other Expenses	2.00	2.00
Insurance & Local Taxes @ 2% Investment	7.41	5.97
Annual Capital Charges @ 20% Investment	74.11	59.71
Total Operating Cost	167.37	144.39
Crude Oil Cost, $/Bbl	5.80	-
Fuel Oil Naphtha Product Cost, $/Bbl	-	6.06

APPENDIX B

CLEAN BOILER FUEL DEMONSTRATION PLANT

The two figures and the text discussion in this Appendix are taken from OCR R&D Report #82 (Ref. 3) and are concerned with a projected large coal liquefaction plant based on the P & M Process.
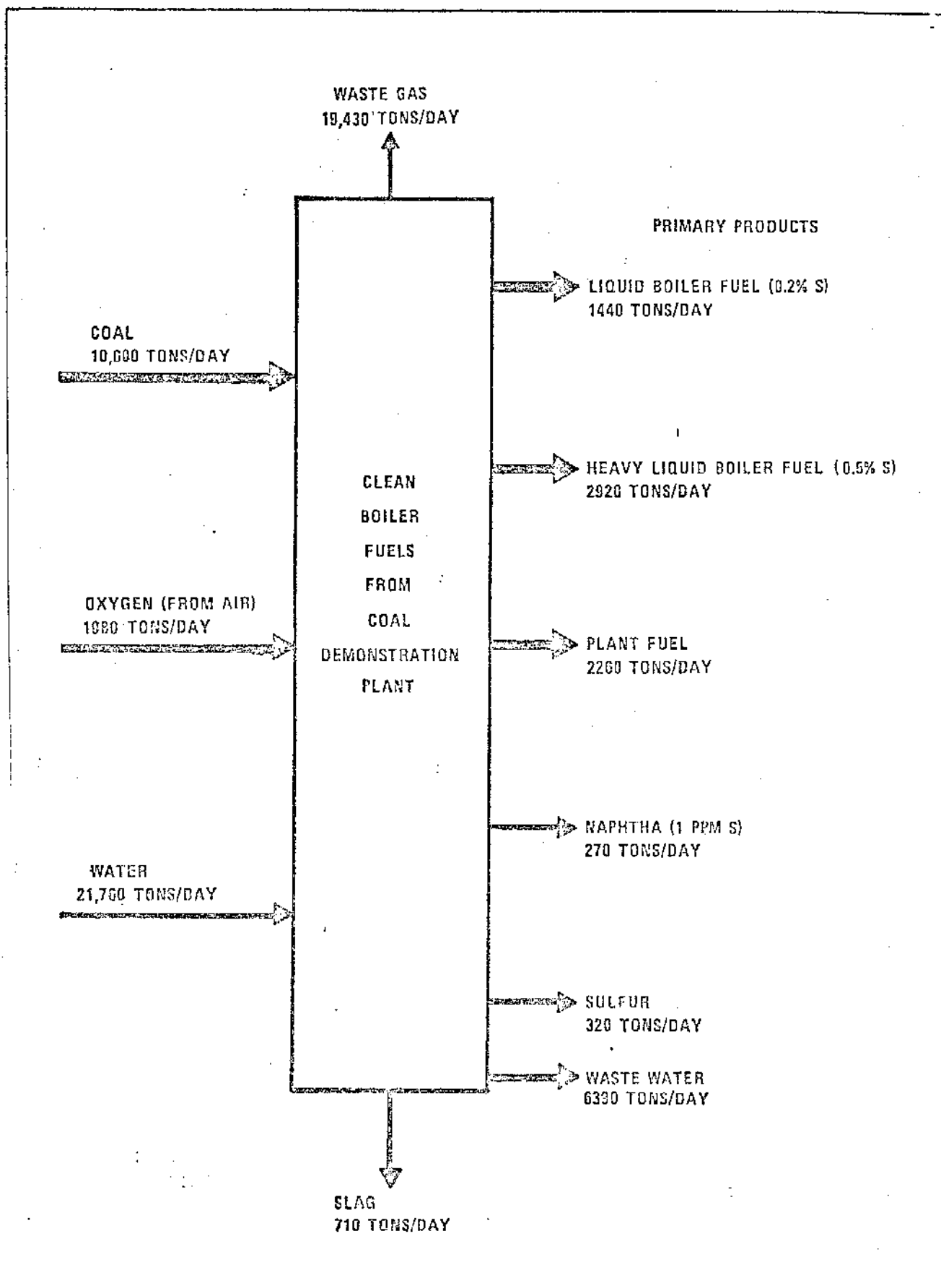
WASTE GAS
19,430 TONS/DAY

COAL
10,000 TONS/DAY

OXYGEN (FROM AIR)
1080 TONS/DAY

WATER
21,700 TONS/DAY

CLEAN BOILER FUELS FROM COAL DEMONSTRATION PLANT

PRIMARY PRODUCTS

LIQUID BOILER FUEL (0.2% S)
1440 TONS/DAY

HEAVY LIQUID BOILER FUEL (0.5% S)
2920 TONS/DAY

PLANT FUEL
2260 TONS/DAY

NAPHTHA (1 PPM S)
270 TONS/DAY

SULFUR
320 TONS/DAY

WASTE WATER
6390 TONS/DAY
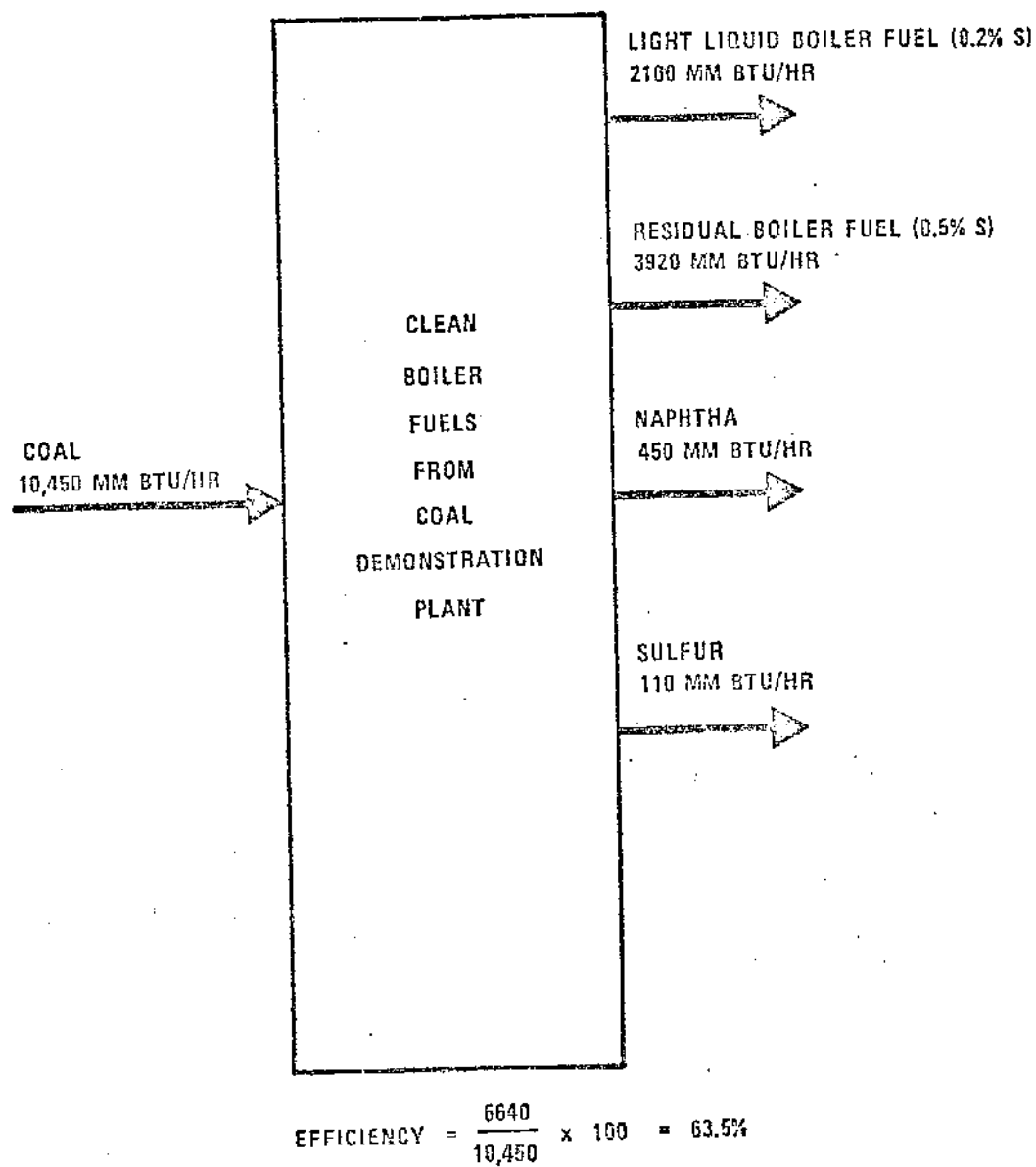
SLAG
710 TONS/DAY

Figure 2 - Overall Material Balance

Figure 4 - Overall Energy Balance

SECTION 11

PROJECTED PLANT PERFORMANCE

The demonstration plant design presented in this report is based upon the data
and information available at this time.

Some of the equipment items required for this plant must be newly developed pro-
ducts; therefore, their reliability and performance will be unknown factors until
the plant has started. Alternative and best operating conditions for the indi-
vidual units may have to be established during the startup period, together with
the training of the operating staff. These factors considered, the initial oper-
ation period required for shakedown and training will take considerably longer
than for a commercially demonstrated process facility. About two years should
be scheduled for this initial shakedown and testing period; during this time the
production group would be working to produce specification grade products and to
increase the production rate.

In order to improve confidence in the expected operability and reliability of the
demonstration plant, certain areas of the design basis and data would require
verification and/or new supporting data. The paramount process areas that need
additional data support are discussed.

COAL LIQUEFACTION

While there is considerable data available for coal liquefaction from P&M work, the specific conditions of recycle of unfiltered dissolver product to form the feed coal slurry is based upon relatively few data runs and, therefore, will require additional work to assure the design yields and operability of the process. The basis used for this design is essentially that established at the kickoff meeting for the assignment. The critical parameters set at that time were:

(1) Recycle unfiltered liquid effluent from the dissolvers.

(2) Hydrogen consumption for the dissolving section is 3 weight percent of the coal feed.

(3) Residence time for liquid in the preheater and dissolver should be 1 hour.

(4) Use syngas (hydrogen plus carbon monoxide) to supply hydrogen requirements of the dissolving operation.

(5) Conversion, solid to liquid, of coal in the dissolver is 91 percent.

(6) Filtration shall be employed on net dissolver product to remove undissolved solids from the product and the filter cake shall contain equal weights of undissolved solid and liquid product.

(7) Preheater outlet and dissolver temperatures shall be 900°F and 840°F, respectively.

(8) Solvent recycle rate shall be twice the weight of the coal feed.

The limited laboratory results indicate that the use of unfiltered solvent is attractive for both yield and character of liquid product from coal. The demonstration plant is designed on this basis. As a consequence of the recycle of undissolved product, the resultant product is lower in boiling point, is liquid at ambient temperatures, and is lower in sulfur content than if the recycle solvent were free of solids. Ultimately, it may be possible for the liquid product from the dissolving section to be marketed without further treatment. A deleterious consequence of this scheme, vis-a-vis use of full filtered recycle feed to the dissolver, is that the hydrogen input to the coal is higher, tending to lower the plant's thermal efficiency.

Additional data should be developed to define the residence time required to achieve the liquefaction of the coal. It is logical that residence time could be reduced if higher temperatures and possibly higher pressures were employed at the dissolvers. Sufficient data should be obtained to accurately establish the relationship between temperature and residence time. It is most critical that experimental operation be carried out to achieve equilibrium with regard to recycle liquid composition and quantity. Since prediction of yield, product quality, and ease of filtration are dependent upon accurate laboratory results, more laboratory or pilot plant work is required in this area. Runs should be made where equilibrium recycle liquid composition is attained with hydrogen gas and then syngas. It would be valuable to extend this data to include the effect of higher temperature and shorter residence times since the liquefaction section is a high capital investment area. More specifically, future P&M SRC laboratory experiments should demonstrate the effects of pressure and gas rate on conversion. To date, there have been experimental difficulties that have prevented the work from going above 1,000 psi except on a few occasions. The effect of gas rate

should be tested by running experiments at, say, 1 and 2 liquid space velocity and, say, 150, 250, and 350 gas space velocity, all at 450°C. Based upon these results, process design economics could be improved.

Product properties must be well known to properly specify the filters and any downstream processing step for the product oil. When equilibrium yields are obtained, sufficient product from this type of run should be prepared so that the product can be distilled into, say, 200°F boiling range cuts and the properties such as API gravity, sulfur content, nitrogen content, and viscosity determined for the separate cuts. Furthermore, viscosities should be run on the tar bottoms at elevated temperatures and some viscosity determinations should be made on tar cut back with some of the heavy distillate cuts.

GASIFICATION

Gasification unit design is principally based upon BCR suspension flow technology modified to maximize syngas production. Some serious heat considerations that are a direct result of the mechanical design of the gasifier must be resolved in this unit. The heat loss value used in the design prepared for this report is 270 Btu per pound of coal. Reported values from the various sources range from a heat loss of 55 to 1,200 Btu per pound of coal. With higher heat loss, more oxygen is required and, consequently, more carbon dioxide is produced. This question needs to be resolved before finalizing the design of the gasifier and its supporting facilities.

It is also critical to determine the amount of liquid that must be carried with the filter cake to make it pumpable and injectable into the gasifier. Laboratory experiments should be conducted using mixtures of dry filter cake and filtrate at

near pumping temperatures to determine the physical properties and flow and injection characteristics of the material.

DESULFURIZATION

The general conditions for the desulfurization units has been taken from FMC data on COED oil. The severity of desulfurization and the feed stock are less demanding in this design than would be the case for full-range COED oil. The technology for this process is generally known; the specific conditions for this stock is not precisely known. To assure the reliability and performance of such a unit, actual feed stock for the unit should be derived from pilot plant operation and made available for at least bench scale test on the catalyst to be used. Specifically, laboratory testing should be conducted to determine to what extent organometallic compounds are present in the feed and in what boiling range of the feed these materials exist.

No provision has been made in this design for the presence of organometallic compounds and their detrimental effect on catalyst performance and life because the material desulfurized in this design boils below the temperature where these compounds would be expected in petroleum-derived liquids.

The detailed design of the proposed demonstration plant would be in progress while the Tacoma pilot plant is in operation. It is possible that many of the operating and quality questions can be answered and/or demonstrated by the performance of this pilot plant. It is recommended that the schedule of operations of the Tacoma pilot plant be directed toward support of the demonstration plant design.

SECTION 12

DISCUSSION

This demonstration plant design represents the first step in the development program to bring coal-conversion processes to commercial reality. It represents engineering judgment of the equipment required and processing steps and conditions to be utilized to achieve the plant's objectives.

After the completion of this first step, design improvements may be possible with desirable improvements in economics, operability, utilities consumption, and overall plant thermal efficiency. Using as a basis the cost data and the inter-relations established in this preliminary design, a description of the more significant potential improvements of these process areas is presented in the following subsections.

ACID GAS REMOVAL

Acid gas removal processes used in this design are the nonproprietary amine process for Units 13, 17, and 19 and a proprietary hot carbonate process in the hydrogen plant. These processes are not final selections and are, therefore, typical of those available. Other possible acid gas removal processes may well demand less utilities than those used in this design. Final selection can be made when all proper process agreements are accepted and finalized.

DISSOLVER PREHEAT

In the present design, no preheat of coal is included prior to mixing the coal with recycle liquid. The dissolver preheat furnaces are the largest and most

expensive utilized in the plant design. Since these furnaces will be a new design because of the slurry feed and since they will be subject to very severe operating conditions, it will be prudent to reduce their size as much as practical. One method of size reduction - to preheat coal prior to mixing with recycle liquid - has been defined and is being evaluated. In addition to possible reduction in utility consumption, this method could eliminate a possible foam production in the slurry vessel and, therefore, also be attractive from an operational standpoint.

SULFUR PLANT

The sulfur plant is the combination of the Claus process and the Beavon sulfur removal process. This plant design is relatively expensive because of the very low hydrogen sulfide content of the feed gas. This is because syngas has been chosen as the type of reducing gas to use in the coal dissolving section. When this syngas is utilized, large volumes of carbon dioxide are produced, thus, greatly diluting the hydrogen sulfide produced. Furthermore, when the cost of the shift conversion step is compared with that of the sulfur plant, the shift conversion unit is relatively cheap. It appears that a lower cost plant with greater sulfur plant reliability would result if the syngas produced by the gasifier were converted to at least moderately high purity hydrogen by shifting all this gas in one or more stages of shift conversion prior to using the gas in the coal dissolving section. From our analysis of the laboratory data, there appears to be a slightly higher conversion of coal to liquid possible when high-purity hydrogen is employed in the dissolving step. All factors considered, the design changes appear attractive. This process is now under study.

FILTRATION

The filtration step is a relatively proven operation to remove undissolved coal and ash from the dissolved coal product. It is also operationally difficult and an expensive system. The equipment costs presented in this report are based upon incomplete and possibly optimistic separation rates and actual filtration rates should be established for the demonstration plant process materials prior to filtration equipment commitment. Other systems to achieve separation of the insoluable residual particles from the liquid produced have been reported. A study is recommended to determine the impact on the design by the more promising of these systems plus an assessment of additional data and testing required to assure better reliability for this process step.

GASIFICATION

The removal of particulate matter from the gasifier product gas prior to further processing is a major requirement of the gasifier system. The present design includes a combination of dry and wet solids separation techniques. It would be highly desirable to accomplish this without resorting to the wet scrubbing step because these solids must be returned to the gasifier to prevent excessive carbon loss from the system.

The design and economic evaluation contains no provision for major equipment redundancy nor alternate process procedure operation for the purpose of increased performance reliability. For example, the gasifier employed in this design is a single unit. While it is desirable to demonstrate the performance capability of a gasifier unit, this unit in its present role is subordinate to the coal dis- solving unit. As such, it should be designed to have a reliability factor com- parable to a utility unit such as a steam boiler. A single gasifier unit is not consistent with this requirement.

It is suggested that gasifier design studies continue and cost comparisons be made in order to determine the economics of parallel gasifier units versus a single unit for increasing the overall operation reliability of the demonstration plant.

APPENDIX C

CONTINENTAL OIL COMPANY METHANOL PROCESS

The two pages which follow were copied from a CONOCO Company
Publication dated December 1973.

Here is a summary of the status of gasification development:

- A sound basic process – the Lurgi Process – is available now as is the Koppers-Totzek Process;
- The necessary methanation technology is now available; and
- A number of alternative processes are currently in the testing and demonstration phase.

PRODUCING COAL LIQUIDS

Let me now turn to the manufacture of liquids from coal. For the most part, technology for producing coal liquids is not fully developed. Production of fuel oil or synthetic crude oil from coal will require substantial additional bench and pilot scale research. There is one interesting exception, however, for which technology is available now. This is the manufacture of methanol, an idea which only recently has begun to receive public attention.

Figure 30 provides a pictorial presentation of how coal-based methanol can be produced. The system uses the same Lurgi or Koppers-Totzek technology mentioned before except that a methanol synthesis reaction is substituted for the methanation step. This methanol synthesis reaction is commercially used today in the production of methanol. Hence, the technology required to produce methanol from coal is – if anything – more fully developed than the technology for producing high BTU gas from coal. Methane included in the raw gas is not affected in the methanol synthesis process. Hence, combining methanol synthesis with the Lurgi Process would still yield substantial quantities of high BTU gas.

Figure 31 compares the cost for a methanol synthesis plant with the SNG plant costs. Capital costs are quite similar. Because of less loss in conversion, the methanol process actually yields a lower cost energy than the SNG plant. This assumes availability of the same 8,000 BTU per pound western coal at a price of $5.00 per ton. Let me reemphasize

Available Coal Conversion Technology - Liquefaction
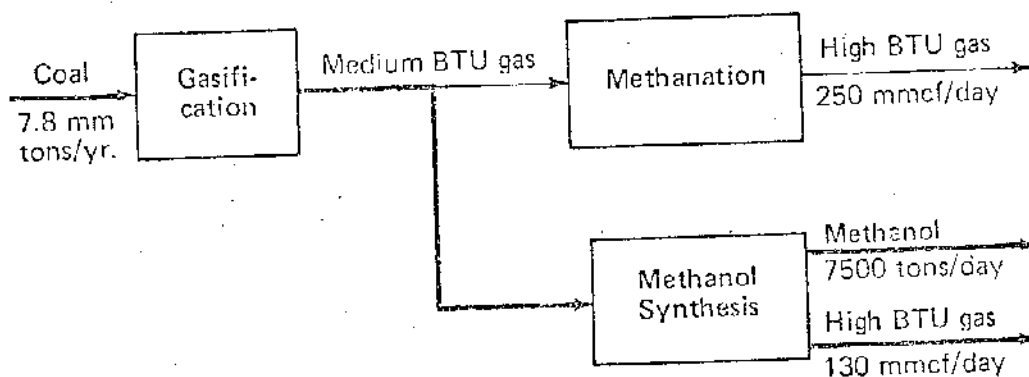
Comparative Costs
(SNG vs. Methanol)

	SNG	Methanol
Basis		
High BTU gas (MM CF/D)	250	130
Methanol (tons/day)	—	7500
Coal feed ($/ton assuming 8,000 BTU/lb.)	5	5
Capital ($MM)		
Gasification	218	218
Methanation	43	—
Methanol synthesis	—	47
Utilities and offsites	135	138
	396	403
Costs ($/MM BTU)		
Capital charge	1.09	0.99
Coal cost	0.49	0.43
Operating cost	0.37	0.33
	1.95	1.75

that both of these processes are commercially proven today.

You may not be familiar with the potential of methanol as a source of energy. Methanol is an easily stored and transported clear liquid. It has a heating value about one-half that of kerosene, but is clean burning and can be used as a fuel for almost any kind of energy converter.

- Methanol's primary use today is as a petrochemical feedstock. This will continue to be an important market.
- Methanol can be converted cheaply for peak shaving of natural gas markets.
- A group of utilities in New Orleans recently conducted successful tests involving the burning of methanol in a boiler.
- The combustion properties of methanol lead to improvements in the efficiency and output of gas turbines. This can be used advantageously for peak shaving electrical loads, reducing fuel use by as much as 20 percent.
- The same qualities make methanol potentially attractive in the general fuel market and as a possible jet fuel. Another use would be in the automobile, where a relatively simple carburetor modification would allow methanol to replace gasoline as a fuel. The clean burning characteristics of methanol would lead to less loss of efficiency due to antipollution equipment than burning of gasoline. There is little question that a methanol-fueled car, equipped with a simple oxidizing catalyst, could meet the original 1975-1976 federal emission standards.
- Methanol could also be used in place of LPG or heating oil for remote energy users such as farms and trailer homes.