SECTION 4
GEOGRAPHICAL AREA CONSIDERATIONS

SECTION 4

GEOGRAPHICAL AREA CONSIDERATIONS

An objective of the study was to assess the projected relative performance/economics of the candidate processes in multiple areas of the country while supplying the local fuel markets. The goal was also to assess whether one process might be preferable in one geographical area while an alternate process would be preferable in another area.

To respond to these objectives, the study considered three production areas, three typical feed coal compositions, and four marketing areas; these are summarized in Table 4-1.

The synfuels plant designs/economics were based on plant sites in the coal producing regions using purchased clean washed coal to produce, in a manner environmentally acceptable to the area, a product slate responsive to the area's historical consumption pattern. Relative F.O.B. plant gate economics were developed for the separate processes. In addition, planning type estimates of transportation costs were developed for movement of the products to the four market locations listed in Table 4-1; "delivered cost" relative economics were then also developed.

In recognition of the practical restraints of time and resource allocation available for this study, a conceptual process design and economic evaluation was developed in most detail for the Eastern Region of the Interior Coal Province location — referred to in this report as the Base Case. Subsequently, adjustments to the Base Case were made to project process performance and economics for the other two production locations; experience developed during prior preparation of designs for multiple locations used.[2]

4.1 PRODUCT/MARKET SLATES

Target product market slates were selected based on historic fuels consumption profiles for each marketing location identified in Table 4-1. Profiles for these areas were developed using 1977 Monthly Petroleum Statistics Reports published by the Federal Energy Administration (FEA)/National Energy Information Center. Product supply/demand statistics in these reports are given by Petroleum Administration for Defense (PAD) Districts. Districts I, II, III, IV, and V were grouped as follows to approximate the locations listed in Table 4-1:

Defense Districts	States
PAD I - Eastern	All of New England, New York, Pennsylvania, New Jersey, Maryland, Delaware, West Virginia, Virginia, North Carolina, South Carolina, Georgia, and Florida
PAD II & III - Central	North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, Kentucky, Tennessee, Ohio, New Mexico, Texas, Arkansas, Louisiana, Mississippi, and Alabama
PAD IV & V - Western	Montana, Idaho, Wyoming, Utah, Colorado, Oregon. Washington, California, Nevada, Alaska, and Hawaii

Petroleum products reported by FEA include motor gasoline, aviation gasoline, naphtha-type jet fuel, kerosene-type jet fuel, kerosene, distillate fuel oil, No. 4 fuel oil, and residual fuel oil. For the purpose of this study, these liquids were realigned to produce LPGs gasoline, distillate fuel oils and residual fuel oil.

As a next step, energy consumption profiles were developed for each geographical area based on published statistics.[3,4] This provided the consumption ratios of natural gas to petroleum liquids by area. The target product slate as summarized in Table 3-2 was then developed using this ratio as a guideline.

Development of the Table 3-2 target product slates defined the specific products to be made and the level of coal derived liquid upgrading required to produce these products. It permitted the designers/evaluators to develop the process configurations presented in Section 5 of this report.

Table 4-1 - Geographical Factors

Production Location			Typical Feed Coal Composition		
Coal Region	Coal Province	Typical Site	Type	Reference	Marketing Location
Appalachian	Eastern	Moundsville, West Virginia	High Volatile Bituminous A Pittsburgh No. 8	Table 3-2	Delaware
Eastern	Interior	New Athens, Illinois	High Volatile Bituminous B Illinois No. 6	Table 3-2	Chicago Houston (secondary)
Powder River	Rock Mountain	Gillette, Wyoming	Subbituminous	Table 3-2	San Francisco

SECTION 5
DESCRIPTIONS OF HIGH POTENTIAL PROCESSES

SECTION 5

DESCRIPTION OF THE HIGH POTENTIAL PROCESSES

This section contains development status summaries, descriptions, operating conditions and estimated product yields for the four selected high potential processes; block flow diagrams are included. The sources of process data and cost information for each of the processes are also summarized.

Similar information for Mobil-M technology is contained in Appendix C.

Each process design is based on a production capacity of fuel products having a total HHV of 600 billion Btu/day; products include SNG, LPG, gasoline, distillate fuels and residual fuels. To increase the uniformity of product slates from the separate processes and provide as common a basis of comparison as possible, some process modifications and additions were incorporated. An example is the addition of hydrotreating, catalytic reforming, polymerization, additional LPG recovery and distillation units to the Fischer-Tropsch processes; these process steps convert the naphthas to gasoline product. An earlier design[5] produced light and heavy naphtha as part of the product slate.

The SRC II process, included in the high potential process group, is based on the results of Run 11 as presented in P&M's October 1977 monthly report. The configuration used is similar to Parsons Oil/Gas conceptual design.[6] Thus, the solids removal filtration step is included in the process. The process is of the SRC II mode wherein a slurry solvent is recycled to the dissolver as distinguished from the SRC I use of a solids-free distilled recycle solvent to slurry the feed coal. Subsequent to the beginning of this study, development efforts indicated elimination of the filtration step to be a practical improvement.[7,8] Since the development was not yet sufficiently defined at that time, the filtration mode was retained.

Assessments of eastern and western plant locations operating on Eastern Coal Province coal, and Rocky Mountain Coal Province coal, respectively, are also included for each of the high potential processes. The difference in coal compositions result in processing and cost variations from the base case operation. The three cleaned and dried feed coals' analyses involved were presented in Table 3-3.

5.1 SRC II BASED PROCESS

5.1.1 DEVELOPMENT STATUS

The SRC process has been under development using government funds in the U.S.A. for about 15 years. There are two pilot plants in operation; a nominal 50-ton-per-day DOE-sponsored unit at Tacoma, Washington and a 6-ton-per-day DOE/EPRI/Southern Services Corporation sponsored unit at Wilsonville, Alabama. The Tacoma pilot plant was designed to process approximately 50 short tons per day of coal when practiced in the SRC I mode. SRC I, in general, produces a solid product and removes ash and unreacted coal by filtration prior to product recovery. Depending on the composition of the feed coal and processing conditions, the SRC I may have a sulfur content of the order of 0.8% and contain about 0.15% solids. It is intended for boiler fuel use.

The Tacoma pilot plant has also been operated in the SRC II mode; in this mode a portion of the unfiltered reactor product is used to slurry feed coal. The result is a higher ash content and longer effective reaction time in the coal dissolver, causing a higher percentage of hydrogen addition to the coal and production of products which are more liquid than for the SRC I mode of operation.

The SRC pilot plant was mechanically completed in late 1974 and has operated since that time. It has successfully produced 3,000 tons of SRC I product which was then used in a boiler performance test to determine the functional performance of the product. Subsequently, the pilot plant has been operated in the SRC II mode successfully to obtain operating data and also to produce 5,000 barrels of liquids for product testing. It has had an onstream performance record of 85-plus percent in the SRC II mode vis-a-vis about 68 percent in the SRC I mode.[8]

The Tacoma pilot plant is now being returned to SRC I service. During future SRC I operations, new designs for equipment, including filters, will be tested. The Wilsonville pilot plant has operated successfully while testing a number of coal types in the SRC I mode.

5.1.2 DATA SOURCES AND FIXED CAPITAL INVESTMENT BASES

The data for the SRC II coal liquefaction process was obtained from reports submitted to the Department of Energy and its predecessor, The Energy Research and Development Administration, by Pittsburgh and Midway Coal Mining Company (P&M) under Contract No. EX-76-C-01-496. The design yields are based on a correlation of yields of gas and liquid products from MAF coal versus hydrogen consumption on MAF coal developed from eleven SRC II material balance runs, performed at the Tacoma Pilot Plant in 1977 (runs SR-1 through SR-11).[8] The dissolver operating conditions selected were those used for run SR-11. Pilot plant operations for this run included filtration. Subsequent runs have been made eliminating the filtration step.

Basic data and yields for the gasification unit originated from work done for the Office of Coal Research (OCR) by Bituminous Coal Research, Inc. (BCR) under Contract No. 14-32-0001-1207.[9] An independent design was developed by Parsons for the specific conditions of temperature, pressure and gas composition required for the SRC II process plant.

The basic information for the fixed capital investment estimate of the units shown in the block flow diagram R-01-FS-1 were obtained from:

1. A report prepared by Parsons for ERDA under Contract No. E(49-18)-1775 published in March 1977, entitled "Oil/Gas Complex-Conceptual Design/Economic Analysis", Report No. 114 - Interim Report No. 4.[6]

2. A report prepared by Parsons for DOE under contract No. EX-76-C-01-1775 published in December 1977, entitled "Project POGO - Coal Refinery Complex-Conceputal Design/Economic Analysis-Power-Oil-Gas-Other Products", R&D Report No. 114 - Interim Report No. 6.[2]

3. Parsons in-house information.

5.1.3 PROCESS DESCRIPTION

The SRC Process, as shown in the block flow diagram, Drawing R-01-FS-1, contains the following coal conversion units:

- A direct, pseudocatalytic hydroliquefaction unit (Coal Slurrying and Coal Dissolving and Product Let-Down) to convert coal to the primary products: SNG, LPG, naphtha and fuel oil;
- A two-stage, entrained-bed, slagging Process Gasifier to convert coal to methane, syngas and minor amounts of byproducts;
- A two-stage, entrained-bed, slagging Fuel Gas Gasifier to convert coal and filter cake to plant fuel gas.

In this process system, 95%-minus-20-mesh coal is combined with a filtered recycle solvent and unfiltered slurry recycle and fed to a coal slurrying unit. The coal slurry is continually pumped through the preheat furnace. Make-up plus recycle hydrogen is added at the furnace entrance; the resulting mixture is preheated, and then fed to the dissolver, which is operated at an outlet temperature of about 850°F and 2,000 psig. The temperature rise in the dissolver is controlled with a hydrogen-rich quench stream from the product let-down system.

The product mixture from the dissolver consists of a gas phase, a liquid phase and a solid phase.

The gas phase is separated in the product let-down system, treated to remove CO_2 and H_2S in the acid gas removal unit, and sent to drying and cryogenic separation. A hydrogen-rich gas is separated cyrogenically, compressed and recycled to the dissolver. The excess hydrogen and syngas is methanated to a methane-rich gas which is purified and compressed to produce pipeline quality SNG. The condensate from the Drying and Cryogenic Separation unit are fractionated to produce C_3 and C_4 LPG.

The liquefied coal products, containing undissolved coal and ash, are subjected to fractionation in the atmospheric distillation unit. The unit produces the following products:

1. Naphtha (C_5 to 400°F boiling range).
2. Light distillate (400°F to 500°F boiling range). Used as a constituent of the fuel oil products.
3. Heavy distillate (500°F to 650°F boiling range) used both as wash oil in the filters and as a constituent of the fuel oil product.
4. Atmospheric bottoms (650°F+) containing the solid residue consisting of undissolved coal and ash; used both as process solvent (slurry recycle) and filter feedstock.

The fractionated naphtha is further hydrotreated and catalytically reformed to produce a high octane gasoline. A portion of the 650°F-plus liquids produced are combined with the net 400°-650°F liquids produced in the atmospheric fractioner to make a low-sulfur residual fuel oil.

The solids in the atmospheric bottoms (650°F-plus) consist of undissolved coal and ash and are recovered in the form of a filter cake in the filtration unit. The filter cake is dried to recover the wash solvent. The heating value of the dry filter cake is recovered by combining it with coal and gasifying it to produce plant fuel gas.

The plant is a self-contained facility producing all of its required electrical power, steam and fuel gas; the only import utility required is water.

5.1.4 ASSESSMENT OF PROCESSING OTHER COALS

Table 5-1 is presented here to compare SRC II yields for the Interior Coal Province (Illinois No. 6 Seam Coal) and the Eastern Coal Province (Pittsburgh Coal). The data in the table was developed using bench-scale equipment by P&M at their Merriam, Kansas laboratory[8] and is illustrated here for comparison purposes only. The data for the SRC II Case as shown in the block flow diagram originated from the Tacoma pilot plant as previously referenced and not from the Merriam laboratory data shown in Table 5.1.

Since the operating conditions for the Run GU-182R (Illinois No. 6 coal) and Run GU-181R (Pittsburgh seam coals) are almost identical, comparison between the two coals can be made.

The results indicate that Pittsburgh seam coal is at least equivalent to Illinois No. 6 coal as a feedstock for SRC II. This is evidenced by the following:

1. Pittsburgh coal has a higher total distillate (38.7% vs. 34.3%).

2. Pittsburgh coal has an equivalent MAF conversion (93.21% vs. 92.99%).

3. The Pittsburgh coal has a lower SRC, 850°F-plus, yield with more distillate liquids in the Residual Fuel Oil mix.

P&M reported a high iron content (2.5 weight per cent) for Pittsburgh coal, suggesting that this could be a factor in its high reactivity.

Yield data for SRC II processing of Rocky Mountain coal is sparse. Projected yields for processing Wyodak coal are presented in a report titled "Project POGO-Coal Refinery Complex-Conceptual Design/Economic Analysis," prepared by Parsons for DOE under contract No. EX-76-C-01-1775.[2] In this report, the yields for SRC I mode of operation on Rocky Mountain Coal were adjusted to reflect SRC II operation. The results indicate dissolver oil yields similar to those obtained from Illinois No. 6 coal when operating conditions are identical; however, MAF conversion for the Rocky Mountain coal is low compared to other coals.

Since it has a relatively high oxygen content, the hydrogen consumption required to remove the oxygen and produce water is expected to be high. Another inherent disadvantage to processing Rocky Mountain coal would be the high run-of-mine water content, approximately 25%, which would require extensive drying facilities. The net effect of processing the Rocky Mountain coal would be to lower the thermal efficiency compared to the Pittsburgh and Illinois No. 6 coal. This is primarily due to:

1. The higher drying load due to the high moisture content.

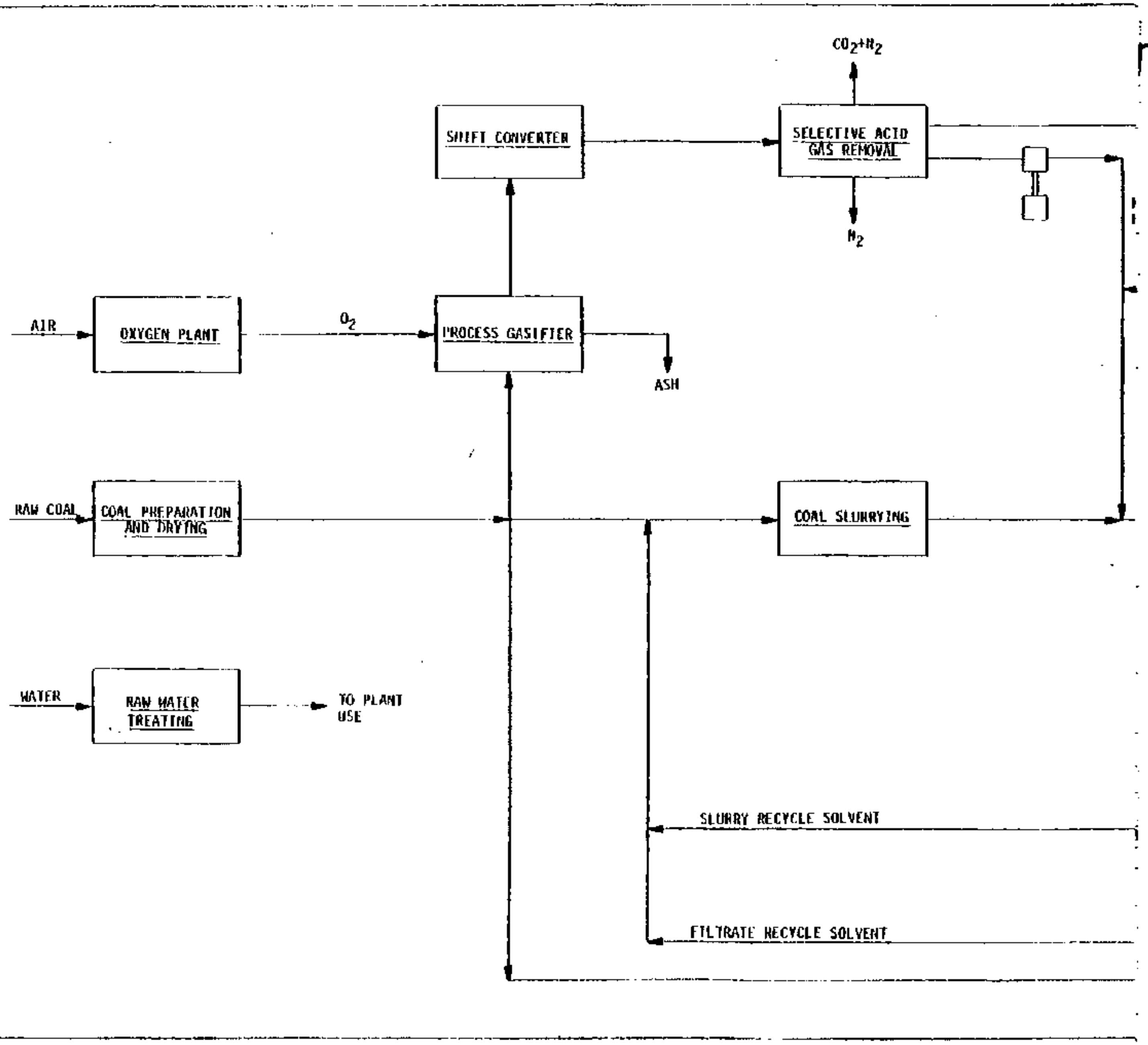
2. Additional hydrogen required to convert the oxygen to water.

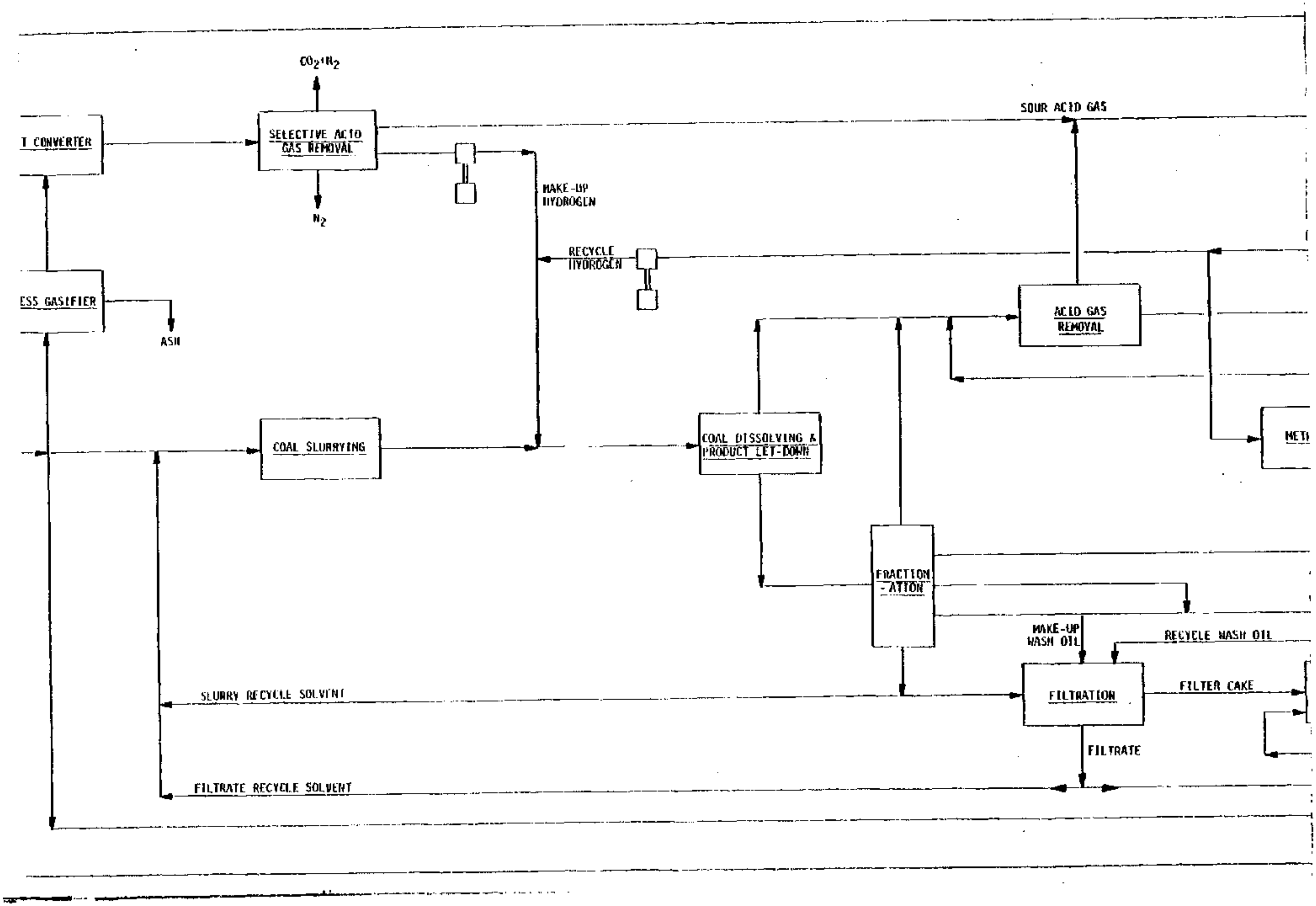
This would result in a higher fixed capital investment for the same quantity of fuel products in a commercially sized plant for the Rocky Mountain coal. However, the higher investment would tend to be compensated for by the significantly lower cost of Rocky Mountain coal when compared to the Appalachian and the Interior coals.

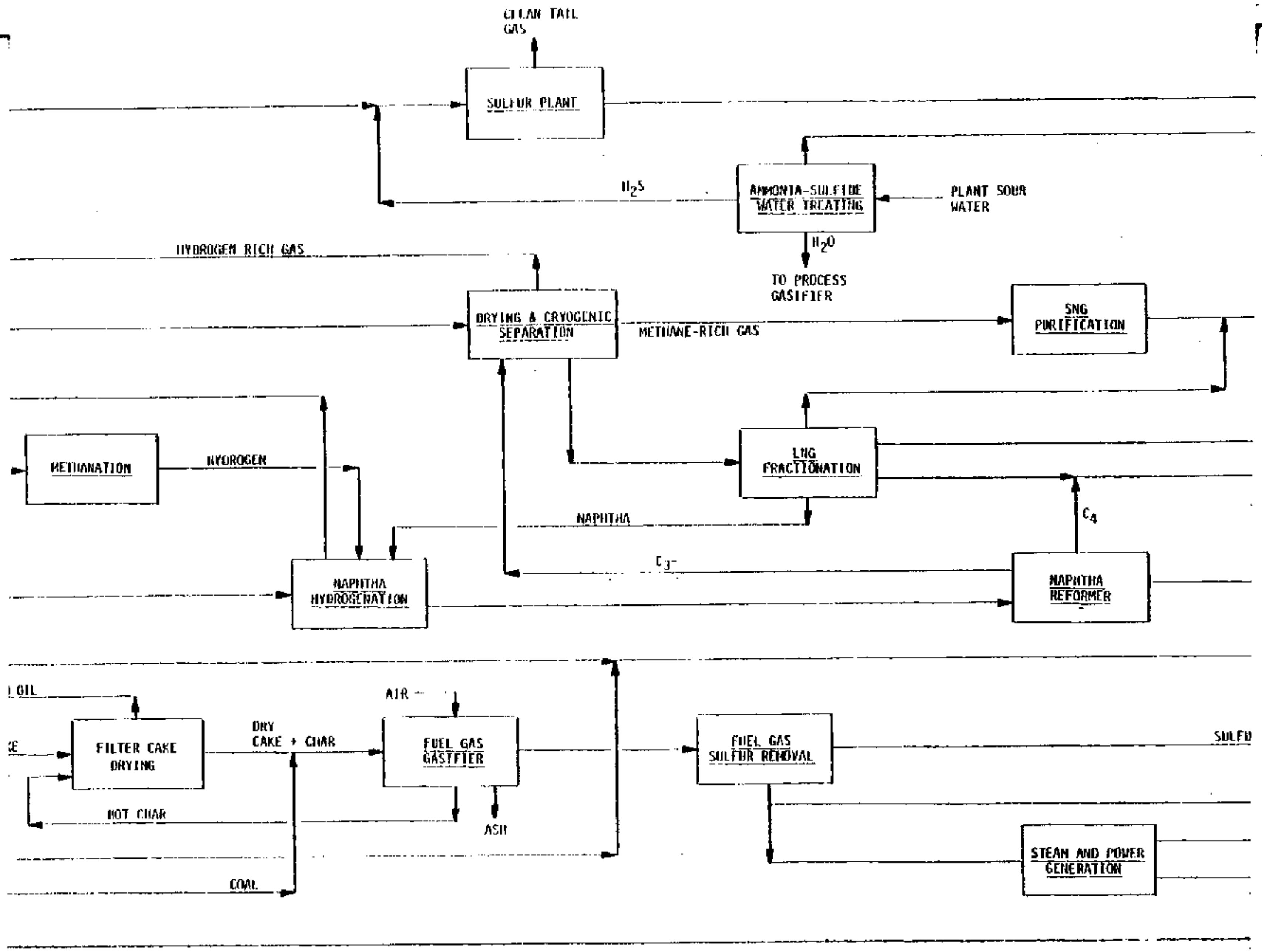
Table 5-1 - SRC II Laboratory Data For Several Coals[a]

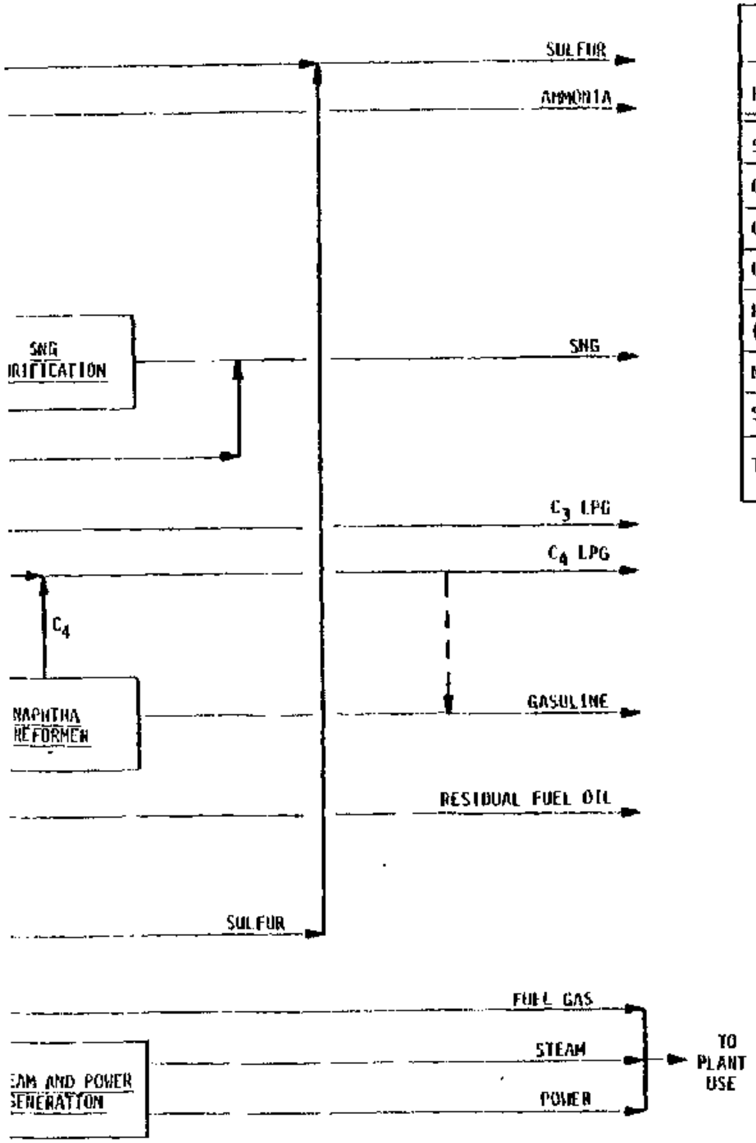
Item	Interior Coal Province (Illinois No. 6 Seam)	Eastern Coal Province (Pittsburgh Seam, Ireland Mine)
Merrian Lab Run No.	GU-182R	GU-181R
Yields: (Weight % Dry Coal)		
H_2O	8.2	5.7
Gas:		
C_1-C_4	10.8	12.9
Other Gases	4.3	4.6
Light Distillate	9.9	13.2
Heavy Distillate	24.4	25.5
SRC	27.4	22.1
IOM (Insoluble Organic Matter)	6.1	5.9
Ash	12.3	13.9
Total	103.4	103.8
H_2 Reacted (%)	3.4	3.8
MAF Conversion(%)	92.99	93.21
Total Gas Yield (%)	15.1	17.5
Total Distillate Oil Yield (%) (Light + Heavy Distillate)	34.3	38.7
Total Distillate Oil + SRC Yield (%)	61.7	60.8
Residual Fuel Oil (%) (Heavy Distillate + SRC)	51.8	47.6
Distillate Liquids in Residual Fuel Oil Mix (%)	47	54
Conditions		
Pressure (psig)	1900	1900
Nominal Dissolver Temperature (°F)	851	851
Nominal Residence Time (Hr)	0.98	0.99
Coal Space Rate (Lb/Hr/Ft^3)	22.0	21.8
Slurry Composition		
Coal (%)	30	30
Unfiltered Recycled Dissolver Product (%)	70	70

[a] P&M August 1977 Monthly Progress Report for ERDA Under Contract No. EX-76-C-01-496


AIR
OXYGEN PLANT
O_2
PROCESS GASIFIER
ASH
SHIFT CONVERTER
SELECTIVE ACID GAS REMOVAL
CO_2+N_2
N_2
RAW COAL
COAL PREPARATION AND DRYING
COAL SLURRYING
WATER
RAW WATER TREATING
TO PLANT USE
SLURRY RECYCLE SOLVENT
FILTRATE RECYCLE SOLVENT


T CONVERTER
ESS GASIFIER
ASH
CO2+N2
SELECTIVE ACID GAS REMOVAL
N2
MAKE-UP HYDROGEN
RECYCLE HYDROGEN
SOUR ACID GAS
ACID GAS REMOVAL
METI
COAL SLURRYING
COAL DISSOLVING & PRODUCT LET-DOWN
FRACTION -ATION
MAKE-UP WASH OIL
RECYCLE WASH OIL
FILTRATION
FILTER CAKE
FILTRATE
SLURRY RECYCLE SOLVENT
FILTRATE RECYCLE SOLVENT


CLEAN TAIL GAS
SULFUR PLANT
H2S
AMMONIA-SULFIDE WATER TREATING
PLANT SOUR WATER
H2O
TO PROCESS GASIFIER
HYDROGEN RICH GAS
DRYING & CRYOGENIC SEPARATION
METHANE-RICH GAS
SNG PURIFICATION
METHANATION
HYDROGEN
LNG FRACTIONATION
NAPHTHA
C4
C3-
NAPHTHA HYDROGENATION
NAPHTHA REFORMER
OIL
FILTER CAKE DRYING
DRY CAKE + CHAR
AIR
FUEL GAS GASIFIER
FUEL GAS SULFUR REMOVAL
SULFU
HOT CHAR
ASH
COAL
STEAM AND POWER GENERATION



	TONS/DAY	BPSD (MMSCFD)	MMMBTU/D (HHV)
FEED COAL	30,625	-	765
SNG	3,420	25,040* (140)	155
C_3- LPG	450	5,100	20
C_4- LPG	220	2,135	9
GASOLINE	1,380	10,335	56
RESIDUAL FUEL OIL (0.5 WT% SULFUR)	10,480	52,310	361
NH_3	100	-	-
SULFUR	990	-	-
TOTAL	17,040	95,720	600

*BARRELS FOE

THERMAL EFFICIENCY: $\frac{600}{765} \times 100 = 78\%$

REV NO	CKED APPR	DATE	REVISION	BY
0			ISSUE FOR REPORT	

COAL LIQUEFACTION PROCESS SURVEY
BLOCK FLOW DIAGRAM
SRC-II PROCESS

THE RALPH M PARSONS COMPANY PASADENA, CALIFORNIA	JOB NO 5658-1	DWG NO R-01-FS-1	REV 0

5.2 H-COAL BASED PROCESS

5.2.1 DEVELOPMENT STATUS

The H-Coal process has been under development by Hydrocarbon Research, Inc. (HRI), since the mid-1960s with funding from both private sector and public sector sources. Test facilities, consisting of a 25-lb/day bench-scale unit, and a 3 TPD process development unit (PDU) have been operated at Trenton, New Jersey. Construction is now in progress for a major pilot plant located at the Catlettsburg, Kentucky Ashland Oil Refinery, with construction scheduled to be complete in 1979. The design capacity of this pilot plant is 250 tons per day of feed coal when operated to produce syncrude and as much as 600 tons per day when operated to produce fuel oil. The project costs are projected to be in excess of $200 million U.S.A. dollars.

5.2.2 DATA SOURCES AND FIXED CAPITAL INVESTMENT BASES

The process data for the H-Coal liquefaction process and its yields were taken from a report prepared by HRI for U.S. DOE under Contract No. EX-76-C-01-1544 entitled "H-Coal Integrated Pilot Plant", Volumes I and II, November 1977.[10] Minor adjustments to the yields were made to account for the use of Illinois No. 6 coal with a composition slightly differenct from that used in the referenced HRI report.

The H-Coal process catalytically converts coal to oil. At high severity conditions a liquid product called syncrude is produced. At low severity conditions, a low-sulfur, liquid fuel referred to as fuel oil is the product. This flexibility is achieved by varying the reactor space velocity which results in change of the hydrogen consumption per ton of coal. The yield of gas is reduced significantly when fuel oil is the primary objective rather than synthetic crude. However, the conversion of coal to liquids remains high even in the low severity fuel oil cases. The referenced HRI report presents data on yields and operating conditions from their PDU runs for both syncrude and fuel oil mode of operation. Anticipated yield and run conditions for intermediate severities of operation are also reported.

Yields for this report are based on the projected pilot plant yields - intermediate mode, for Illinois No. 6 coal.[10] The severity of operation for this intermediate mode is similar to the syncrude mode of operation and allows atmospheric distillation of the reactor effluent prior to the filtration step.

Basic data and yields for the gasification units originated from work done for OCR under Contract No. 14-32-0001-1207.[9] Independent designs were developed by Parsons for the specific conditions of temperature, pressure, and gas composition used.

The bases for the constructed costs of the units shown in block flow diagram R-02-FS-1 were taken from the following:

1. A report prepared by The American Oil Company (AMOCO) for OCR under contract No. 14-01-0001-1188, entitled "Evaluation of Project H-Coal", December 1967.[11]

2. A report prepared by Fluor Engineering and Construction, Los Angeles, California, in 1976 under Contract No. E(49-18)-2002 for ERDA entitled "H-Coal Commercial Evaluation-Conceptual Design and Economic Analysis for 25,000 TPD H-Coal Liquefaction Plant."[12]

3. A report prepared by Parsons for ERDA Under Contract No. E(49-18)-1775 published in March 1977, entitled "Oil/Gas Complex-Conceptual Design/Economic Analysis - Oil and SNG Production", R&D Report No. 114, Interim Report No. 4.[6]

4. A report prepared by Parsons for ERDA under Contract No. E(49-18)-1775 published in January 1977, entitled "Fischer-Tropsch Complex-Conceptual Design/Economic Analysis - Oil

and SNG Production," R&D Report No. 114, Interim Report No. 3.[5]

5. A report prepared by Parsons for OCR Under Contract No. 14-32-0001-1234 published in 1973 entitled "Demonstration Plant - Clean Boiler Fuels from Coal-Preliminary Design/Capital Cost Estimate", R&D Report No. 82, Interim Report No. 1.[13]

6. A report prepared by Parsons for DOE, under Contract No. EX-76-C-01-1775 published in December 1977 entitled "Project POCO-Coal Refinery Complex - Conceptual Design/Economic Analysis -Power-Oil-Gas-Other Products", R&D Report No. 114, Interim Report No. 6.[2]

7. Parsons in-house information.

5.2.3 PROCESS DESCRIPTION

The H-Coal process is shown schematically in block flow diagram R-02-FS-1. The heart of the process is the Dissolving and Separation unit which is a catalytic hydroliquefaction process. Here, a slurry of pulverized coal in a process-produced heavy recycle solvent made up of vacuum bottoms, filtrate and atmospheric bottoms is pumped to about 3,000 psig, then mixed with hydrogen. The coal slurry and hydrogen mix is preheated in a fired heater and then contacted with commercial catalyst[10] in ebullating-bed reactors, which are operated at about 800°F and 3,000 psig. The catalyst is kept in suspension by the upflow of reactants and an internal liquid recycle. Make-up catalyst is continually added to the reactor and an equivalent amount of spent catalyst is continually withdrawn.

The reactor effluent slurry is sent to the atmospheric distillation unit to:

1. Separate the C_4 and lighter gases from the C_5+ liquids.

2. Separate the C_5+ liquids into:

   A. Naphtha (C_5 to 400° boiling range). Used as a feedstock to the naphtha hydrogenation unit.

   B. Light distillate (400 to 500°F boiling range). Used as a constituent of fuel oil products.

   C. Heavy distillate (500°-650°F boiling range). Used both as wash oil in the filters and as a constituent of the fuel oil products.

   D. Atmospheric bottoms (650°F+ slurry). Used both as a recycle slurrying oil and vacuum filters feedstock.

The atmospheric bottoms are filtered to separate a filter cake, which contains unreacted coal and ash, from the liquefied coal products. The filtrate (650°F+) is split into recycle slurrying oil, filtrate product and vacuum distillation feedstock. The vacuum distillation unit produces: (1) vacuum bottoms (975°F+) which is used as a recycle slurrying oil and (2) vacuum distillate (650°-975°F boiling range).

The Vacuum distillate is combined with the filtrate product (650°F+) and part of the 400°-650°F distillate. The resulting residual fuel oil (400°F+) is projected to contain 0.3 Wt% sulfur and meet the commercially acceptable viscosity requirement of 180 SSF at 122°F. The remaining blend of light distillate (400° to 500°F) and heavy distillate product (500° to 650°F) meets the specifications of ASTM No. 4 fuel oil. The C_5-400°F naphtha is hydrotreated and catalytically reformed to produce high octane reformate.

The dissolving reactor product and recycle gases are combined with the atmospheric distillation gas and the naphtha hydrotreating of gas and sent to the high pressure acid gas removal unit.

After removal of H_2S and CO_2 the sweet gas is sent to the hydrogen recovery unit for separation and the acid gas is fed to the sulfur plant. The recovered hydrogen is recycled to the dissolver. The methane rich gas is sent to the SNG methanator for methanation of residual CO and inclusion in the SNG product. The C_2+ faction is fed to the LPG fractionation unit where C_3 and C_4 LPGs plus light hydrocarbons are separated, the light ends are added to the SNG while the C_3 and C_4 LPGs are sent to storage.

The reactor product undissolved coal and ash, which is separated as filter cake from the reactor liquids, is combined with coal and gasified in a two-stage entrainment slagging gasifier. A low-Btu fuel gas is produced; after H_2S removal, this is used for plant fuel gas.

The hydrogen required for the process is generated by producing syngas at 1,000 psig in a two-stage entrained slagging gasifier. The syngas is shifted, the acid gases are removed, and a hydrogen rich gas is cryogenically separated. Residual CO in this stream is methanated to produce a high purity hydrogen make-up stream.

Syngas and methane-rich gas are combined with the C_2 and lighter gases produced in the hydrogen recovery unit and fed to a methanation unit to produce a high-Btu pipeline quality SNG.

The plant is a self-contained facility producing all of its own power, steam, and fuel gas; the only import utility item required is raw water.

5.2.4 ASSESSMENT: PROCESSING OTHER COALS

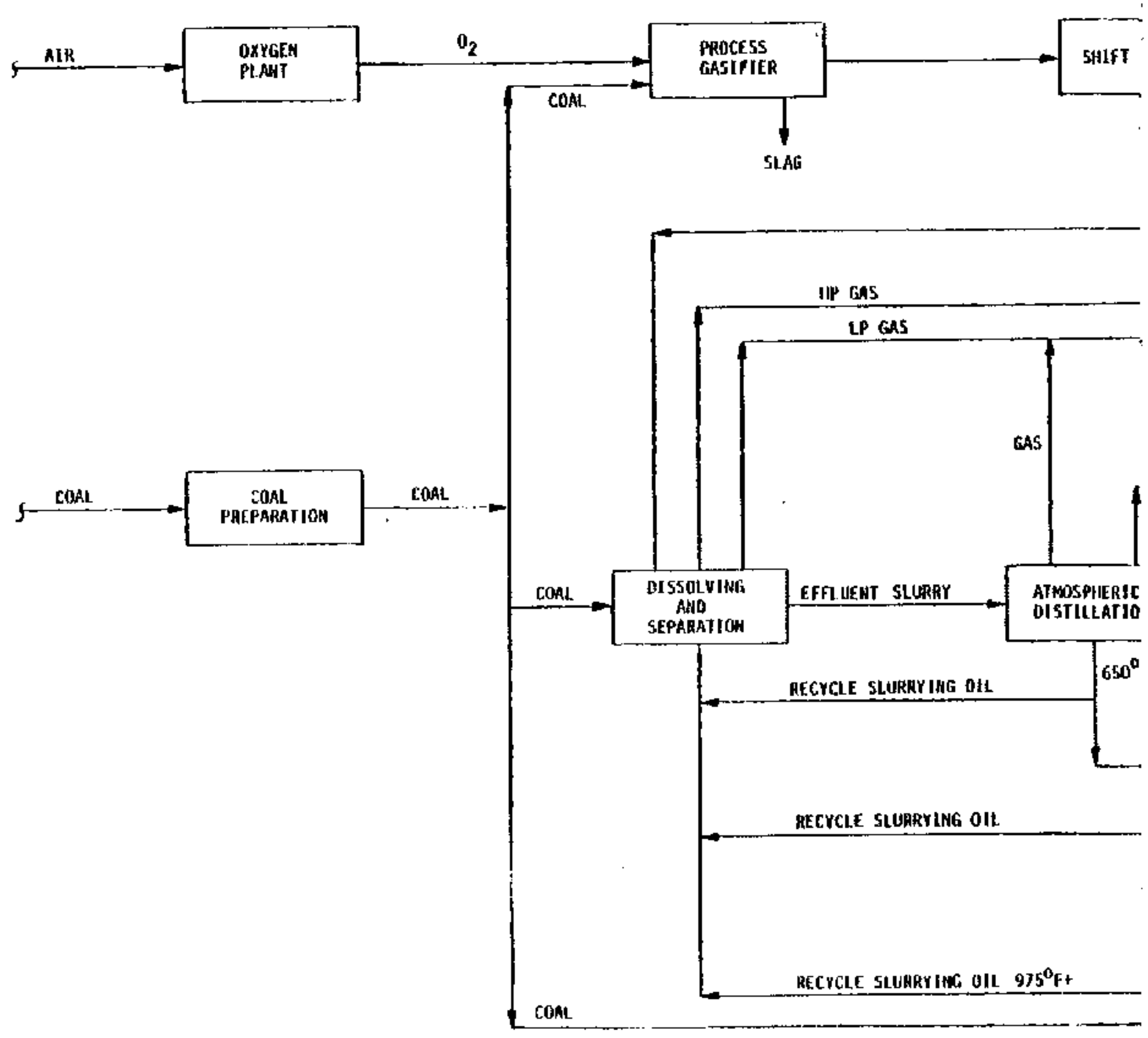
No information is available, at the time of this writing, on the yields from H-Coal when processing Eastern Coal Province (Pittsburgh) coal. Some information concerning its dissolving characteristics (under non-catalytic conditions) can be obtained from the bench-scale SRC II runs conducted by P&M at their Meriam Laboratory. The results from these runs indicate that the Pittsburgh Seam coal has MAF conversion similar to the

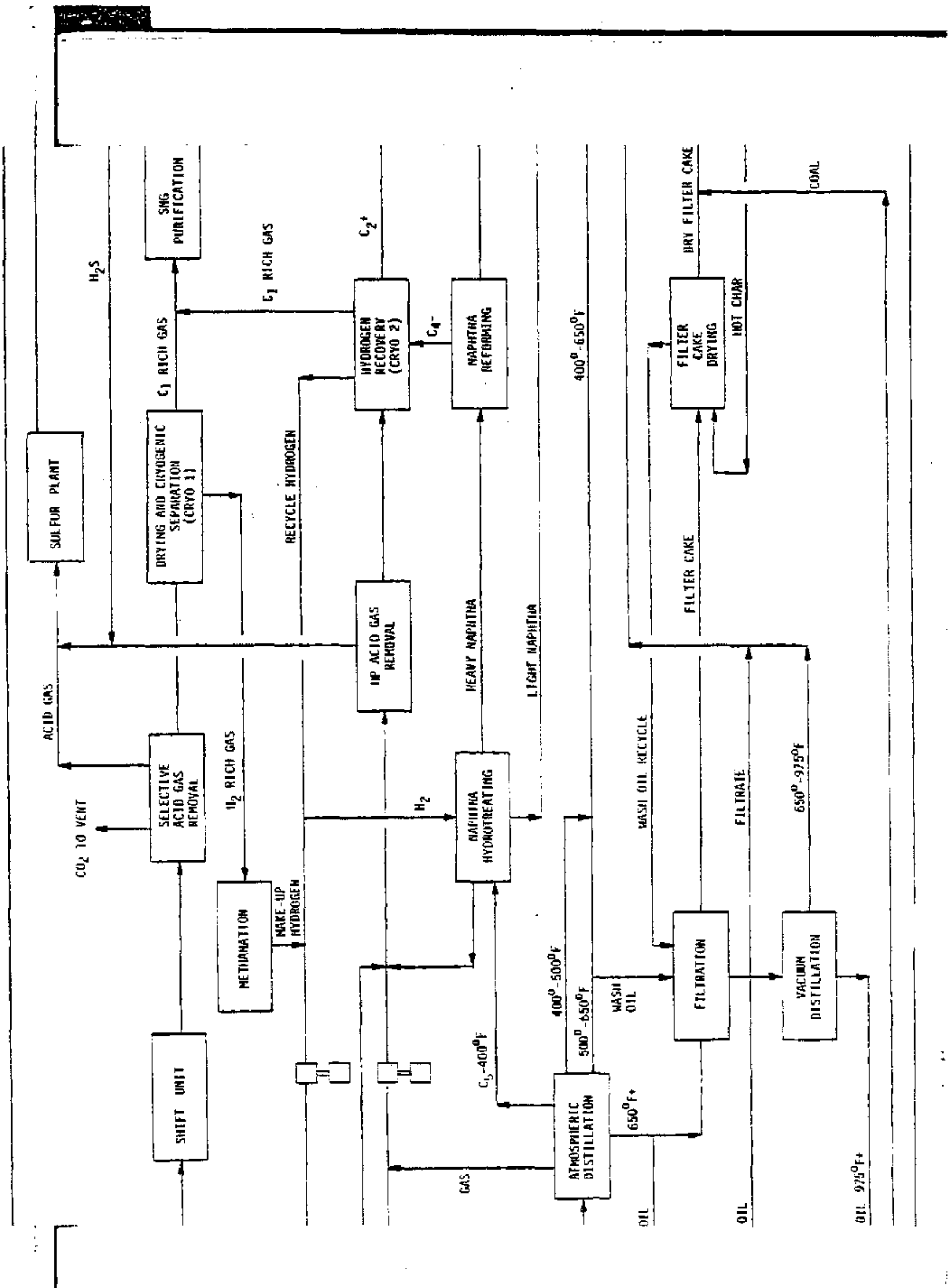
Illinois No. 6 coal; in addition, under similar reaction conditions it results in a higher hydrogen consumption, higher distillate yield and a lower SRC (650°F+) yield. Although the dissolver of the H-Coal process operates at a higher pressure and under catalytic conditions, it is reasonable to expect a similar change of the H-Coal yields when Pittsburgh is used instead of Illinois No. 6.

The net effect of this change would be a decreased coal and coal-surplus hydrogen feed rate to the dissolver. This change is due to the higher heating value of the feed coal while maintaining the total product energy output of the plant at 600 MM Btu/day. The decreased coal-sourced hydrogen feed rate will be offset by a higher molecular hydrogen consumption.

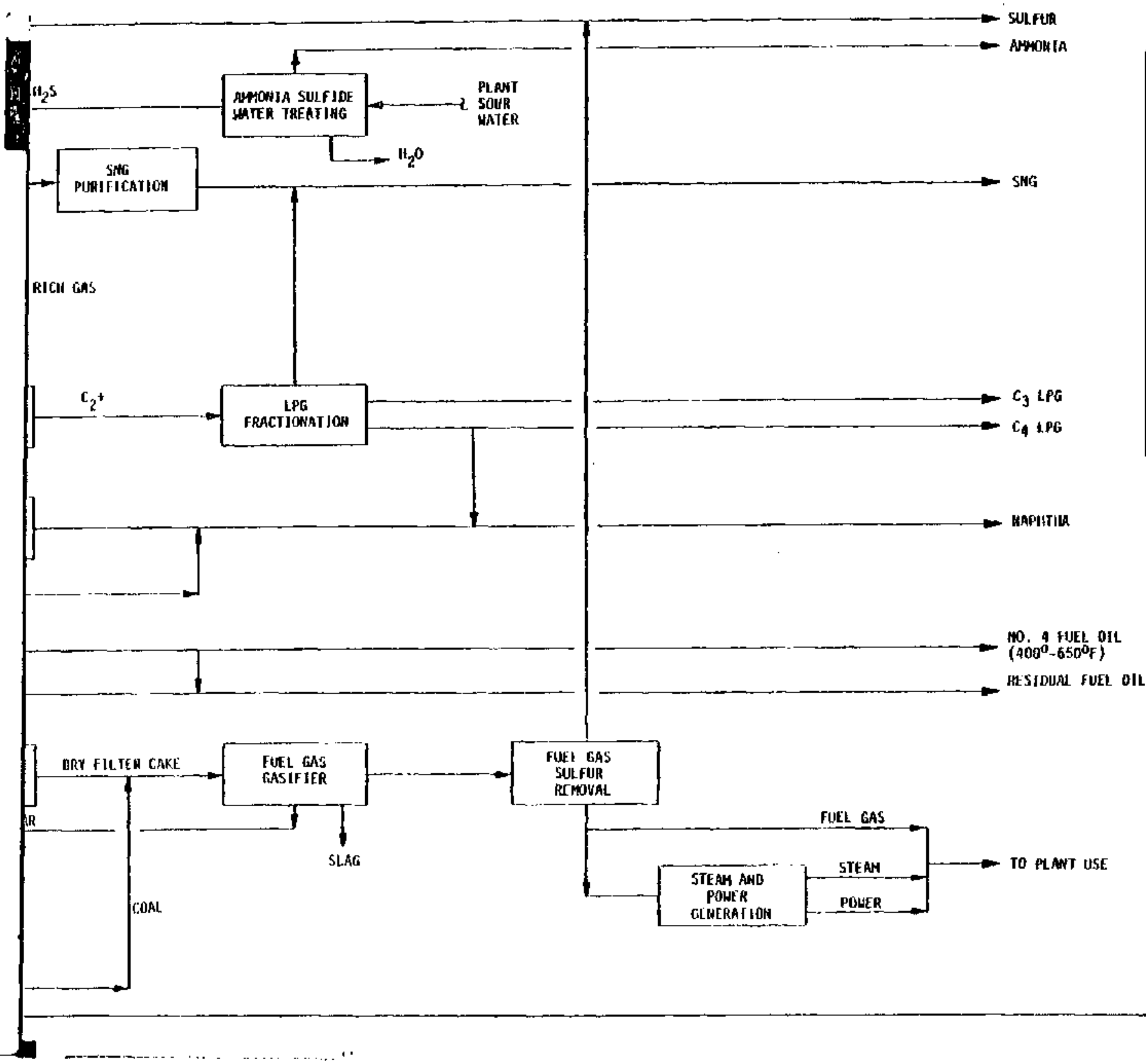
The results of gasifier elemental balances performed for several coals (in-house information) indicate that the process gasifier for the Eastern Coal Province coal would require less coal and oxygen in order to produce the same quantity of hydrogen and carbon monoxide in the syngas as that produced in the Illinois No. 6 (Interior Coal Province) case. The above changes would result in a decrease of the capital cost since the coal preparation unit, the coal dissolving unit and the oxygen plant would be smaller. There should be little change in the thermal efficiency since the decreased coal feed rate would be offset by the higher HHV of the Eastern coal.

Yield data for H-Coal processing of the Rocky Mountain coal were taken from a report entitled "H-Coal Integrated Pilot Plant" Volume II, 1977, prepared by Hydrocarbon Research, Inc. for DOE under Contract No. EX-76-C-01-1544.[10] The data indicates that for similar conditions in the dissolver the MAF conversion of the Rocky Mountain Coal is lower (less than 90%) when compared with the Interior coal (95-95%). The relatively high oxygen content results in higher water and CO_2 yields. In order to maintain the plant product HHV output of 600 MMM Btu/day, more coal and more hydrogen will have to be fed to the dissolver. The gasifier elemental analyses also indicate that the Rocky Mountain feed rate, as well as the oxygen feed rate, would have to be higher in order to produce the same quantity of (H_2 + CO) in the syngas as produced in the Interior case. Another disadvantage when processing Rocky Mountain coal is the high run-of-mine water content, which would require extensive drying facilities. The changes listed above will result in an increased capital cost for the Rocky Mountain coal compared to the Interior coal, due to the greater capacities of the units handling the increased coal, hydrogen and filter cake rates. Another effect of H-Coal processing of Rocky Mountain coal would be a lower thermal efficiency when compared to the Interior case. Economically, these factors tend to be offset by the lower cost of the western coal.


AIR
OXYGEN PLANT
0_2
PROCESS GASIFIER
SHIFT
COAL
SLAG
COAL
COAL PREPARATION
COAL
HP GAS
LP GAS
GAS
COAL
DISSOLVING AND SEPARATION
EFFLUENT SLURRY
ATMOSPHERIC DISTILLATIO
650°
RECYCLE SLURRYING OIL
RECYCLE SLURRYING OIL
RECYCLE SLURRYING OIL 975°F+
COAL



SHIFT UNIT
SELECTIVE ACID GAS REMOVAL
CO2 TO VENT
ACID GAS
SULFUR PLANT
H2S
METHANATION
MAKE-UP HYDROGEN
H2 RICH GAS
DRYING AND CRYOGENIC SEPARATION (CRYO 1)
C1 RICH GAS
SNG PURIFICATION
RECYCLE HYDROGEN
HP ACID GAS REMOVAL
HYDROGEN RECOVERY (CRYO 2)
C1 RICH GAS
C2+
C4-
H2
NAPHTHA HYDROTREATING
HEAVY NAPHTHA
NAPHTHA REFORMING
LIGHT NAPHTHA
GAS
ATMOSPHERIC DISTILLATION
C5-400°F
400°-500°F
500°-650°F
400°-650°F
650°F+
WASH OIL
FILTRATION
WASH OIL RECYCLE
FILTER CAKE
FILTER CAKE DRYING
HOT CHAR
DRY FILTER CAKE
COAL
FILTRATE
VACUUM DISTILLATION
650°-975°F
OIL
OIL
OIL 975°F+



	TONS/DAY	BPSD (MMSCFD)
FEED COAL	32,[illegible]35	-
SNG	3,700	27,600*
C_3 LPG	420	4,795
C_4 LPG	115	1,115
GASOLINE	2,940	21,965
NO. 4 FUEL OIL	480	3,005
RESIDUAL FUEL OIL (0.3 WT% SULFUR)	7,725	40,150
SULFUR	1,075	-
AMMONIA	130	-
TOTAL	16,585	98,630

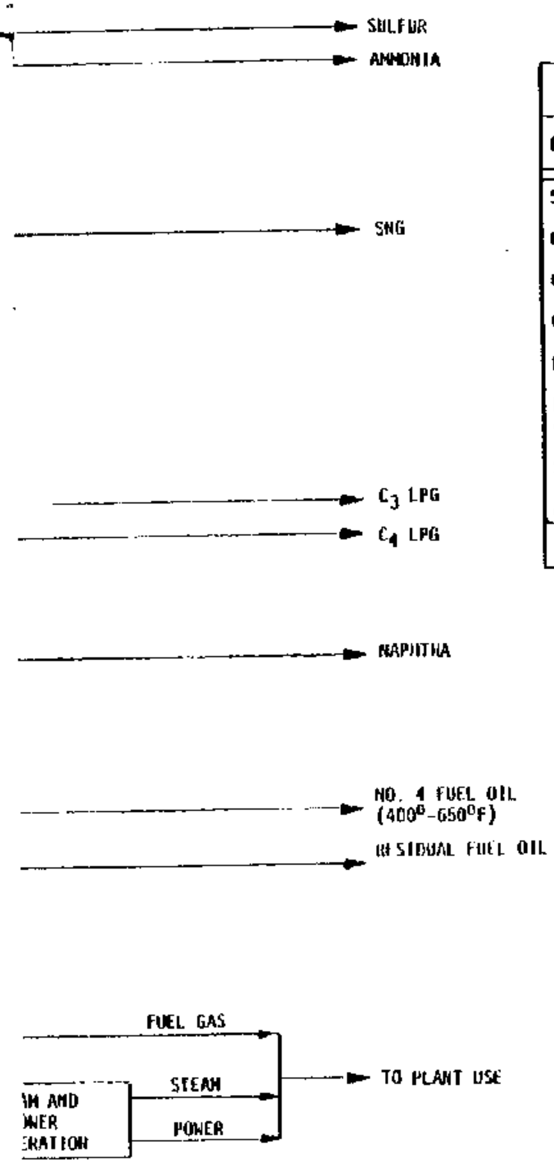
*BARRELS FOE

THERMAL EFFICIENCY: $\frac{600}{810} \times 100 = 74\%$

0			ISSUED
REV NO			

COAL LIQU
BL

THE RALPH M PARSO
COMPANY
PASADENA, CALIFORN



	TONS/DAY	BPSD (MMSCFD)	MMMBTU/D
FEED COAL	32,756	-	810
SNG	3,700	27,680* (155)	166
C_3 LPG	420	4,795	18
C_4 LPG	115	1,115	5
GASOLINE	2,940	21,965	118
NO. 4 FUEL OIL	480	3,005	19
RESIDUAL FUEL OIL (0.3 WT% SULFUR)	7,725	40,150	274
SULFUR	1,075	-	-
AMMONIA	130	-	-
TOTAL	16,585	98,630	600

*BARRELS FOE

THERMAL EFFICIENCY: $\frac{600}{810} \times 100 = 74\%$

0			ISSUED FOR REPORT							
REV NO	CLNT APPR	DATE	REVISION	BY	PROC ENGR	CHECK	CHIEF PROC ENGR	CHIEF OPER ENGR	PROJ DIR	

COAL LIQUEFACTION PROCESS SURVEY
BLOCK FLOW DIAGRAM
H-COAL PROCESS

THE RALPH M PARSONS COMPANY PASADENA, CALIFORNIA	JOB NO 5658-1	DWG NO R-02-FS-1	REV 0

5.3 CSF BASED PROCESS

5.3.1 DEVELOPMENT STATUS

Extensive bench-scale testing and research work was conducted by Consolidation Coal Company prior to 1963. The Office of Coal Research and Consolidation Coal entered into a contract in September 1963 for development of the CSF process. A 20-TPD pilot plant was designed, utilizing Consol's data, and built.

The pilot plant was operated for approximately 40 months during the 1966-1970 period and then was taken out of service. During this operating period, a number of equipment and mechanical problems were defined.

5.3.2 DATA SOURCES AND FIXED CAPITAL INVESTMENT

The CSF plant configuration used is illustrated by the block flow diagram shown in drawing R-03-FS-1. The process data and yields for the CSF process were taken from the DOE report entitled "Conceptual Design for Advanced Coal Liquefaction Commercial Plant," prepared under Contract No. EX-76-C-01-2251.[14] That design/economic evaluation was adjusted to show projected performance when feeding Illinois No. 6 coal as an alternate to the Pittsburgh No. 8 seam coal used in the reference design. The reactor yields for the extraction, extract hydrogenation and low temperatures carbonization sections were concluded to be similar for the two coals. The percent heteroatom (N, S, O) removal in the extraction and extract hydrogenation sections was judged to be the same.

The data and yields for the gasification units originated from work done for OCR by BCR under Contract No. 14-32-0001-1207[9] and Contract No. 14-01-0001-324.[15] Independent designs were developed by Parsons for the temperature and pressure conditions specified for the CSF case.

The constructed costs of the units shown in the block flow diagram R-03-FS-1 were based on information from the following:

1. A report prepared for DOE under Contract No. EX-76-C-01-2251 published in October 1977, entitled "Conceptual Design for Advanced Coal Liquefaction Commercial Plant".[16]

2. A report prepared by Parsons for ERDA under Contract No. E(49-18)-1775 published in March 1977, entitled "Oil/Gas Complex -Conceptual Design/Economic Analysis - Oil and SNG Production", R&D Report No. 114 - Interim Report No. 4.[6]

3. A report prepared by Parsons for DOE under Contract No. EX-76-C-01-1775, published in December 1977 entitled "Project POGO - Coal Refinery Complex Conceptual Design/Economic Analysis", R&D Report No. 114 - Interim Report No. 6.[2]

4. Parsons in-house information.

5.3.3 PROCESS DESCRIPTION

The heart of the CSF coal liquefaction process includes the following process steps:

- Extraction
- Solids separation
- Low temperature carbonization
- Solvent recovery
- Extract hydrogenation

Minus-½-inch coal is slurried with recycle solvent and recycle donor solvent and the resultant mixture is pumped to the preheater. The mixture is heated and fed to the extraction reactor, which is a stirred reactor operated at about 700°F and 575 psig and serves to extract coal liquids from the feed coal. The hydrogenated donor solvent serves as a hydrogen carrier. After extraction, the solids are removed from the coal liquids in the solids separation unit which consists of several parallel gravity settling tanks.

Extraction solids, contained in the settler underflow stream, are sent to the low temperature carbonization (LTC) unit which is operated at about 400 psig and 900°F. Heat is supplied by partial oxidation of the undissolved coal with oxygen. Solvent contained in the settler underflow and LTC produced tar is recovered after separation from the LTC gases. Tar and recovered solvent rejoin the settler overflow. The LTC gases are sent to the H_2S removal unit to be subsequently used for plant fuel gas and the LTC char is blended with extract hydrogenation vacuum residue in the process gasifier to produce the plant hydrogen and fuel gas requirements.

Extraction liquids, as settler overflow, are fractionated in the solvent recovery unit to produce a distillate which is sent to fuel oil distillation, recycle solvent which is returned to the extraction, and extract as bottoms which is forwarded to the extract hydrogenation unit.

In the extract hydrogenation unit, the extract is reacted with hydrogen in a catalytic ebullating bed reactor at about 3,000 psig and 800°F. The gas phase is separated and sent to the acid gas removal unit and the resulting sweet gas is sent to the fuel gas cryogenic separation plant for separation into final products — SNG, C_3 LPG and C_4 LPG. The liquid phase, including the solids, is fractionated in atmospheric and vacuum columns to produce naphtha, light distillate, heavy distillate and vacuum bottoms. The vacuum bottoms, which contains the solids, is sent to the process gasifier to produce syngas. The light and heavy distillate are combined with the light oil from solvent recovery and sent to fuel oil distillation to produce the No. 4 and heavy fuel oil products. The naphtha is further refined by hydrodesulfurization and catalytic reforming to provide a high octane gasoline.

The hydrogen and fuel gas required for the process are produced by generating syngas from the gasification of LTC char and extract hydrogenation vacuum residue. The fraction of syngas used for hydrogen production is shifted, the acid gases removed, and cryogenically separated into a hydrogen-rich stream plus feed streams to the SNG and LPG purification units.

The required fuel gas is produced by processing a portion of the process gasifier product to remove hydrogen sulfide. This fuel gas is then used to produce the steam and electrical power required to operate the complex.

The plant is a self-contained facility producing all of its own power, steam, and fuel gas. The only purchased utility is raw water.

5.3.4 ASSESSMENT OF PROCESSING OTHER COALS

The projected performance of the CSF process when feeding Appalachian and Rocky Mountain coals is summarized in Table 5-2. The data source for these projections are bench-scale and pilot plant experimental programs. The coal compositions are presented in this table to indicate the differences in compositions from those similar areas, listed in Table 3-3, used in this study. Although they differ, the coals are from the same geographical area and, assuming similar liquefaction tendencies, are useful for comparison.

As indicated in the table, the MAF conversions are very similar for both the extraction and the extract hydrogenation steps. The MAF conversion for all three coals is defined as:

$$\frac{\text{(MAF feed - the unconverted residue)}}{\text{MAF feed}} \quad \text{X 100.}$$

However, the hydrogen consumption is significantly higher for the Montana coal, 4.6 % versus 4.0% and 3.8% for Pittsburgh No. 8 and Illinois No. 6 coals, respectively. Most of this can be attributed to the high oxygen content of the Montana coal which is typical of Western sub-bituminous coals.

A comparison of the yields indicated the Pittsburgh coal to have the higher liquid yields and lowest total gas yield. However, all of the coals have acceptable oil yields to be candidates for a commerical plant.

As previously stated for the SRC II case, the net effect of processing Rocky Mountain coal compared to the Pittsburgh No. 8 and Illinois No. 6 coal would be a lowering of thermal efficiency due to:

1. The higher drying load because of high moisture content in Rocky Mountain coal.
2. Additional hydrogen required to convert the oxygen to water due to the relatively high oxygen content.

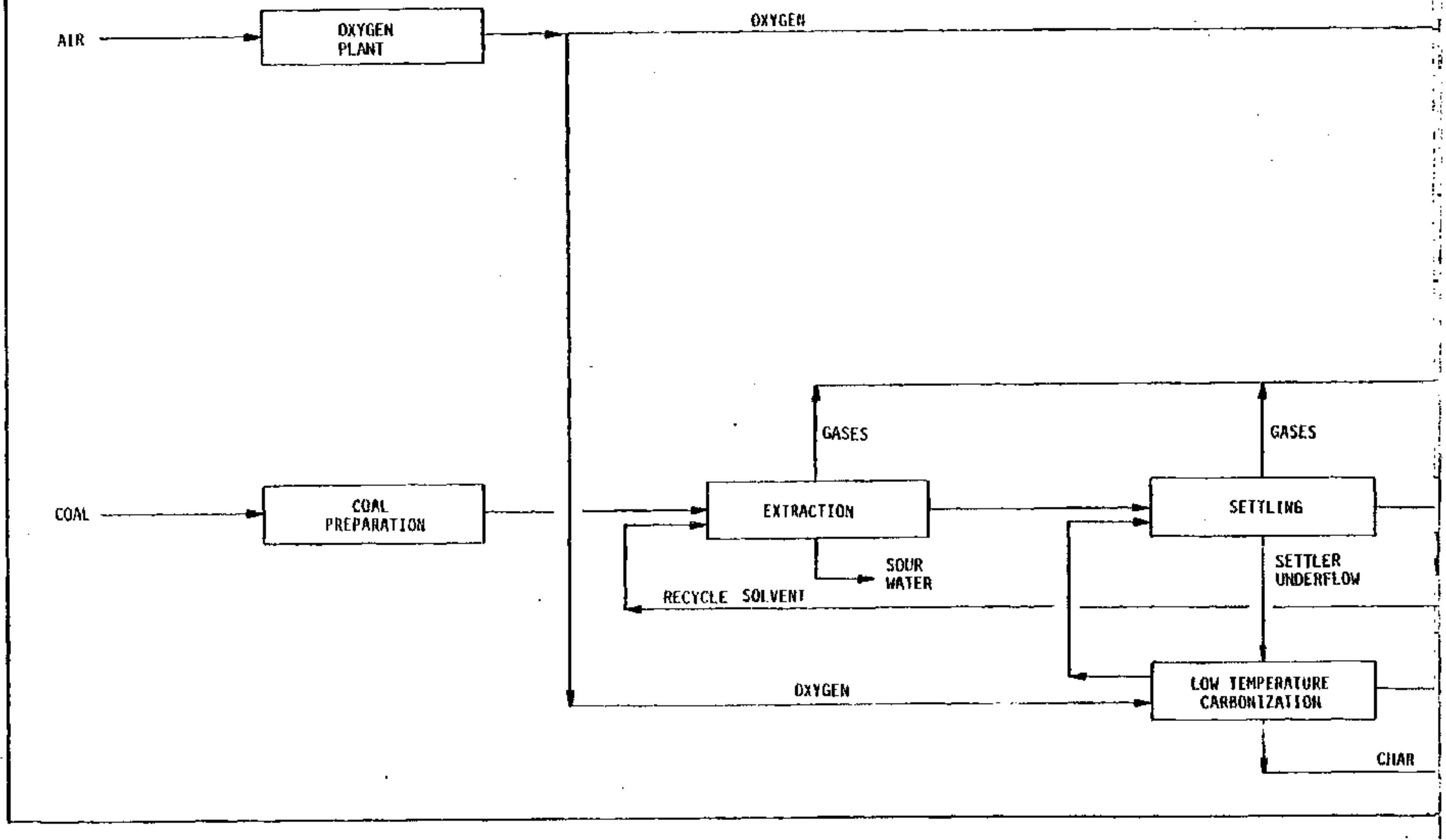
This would result in a higher capital investment for the same quantity of fuel products in a commercially sized plant for the Rocky Mountain coal. However, the higher investment would tend to be compensated for by the significantly lower cost of Rocky Mountain coal compared to that for Eastern and Interior coals.

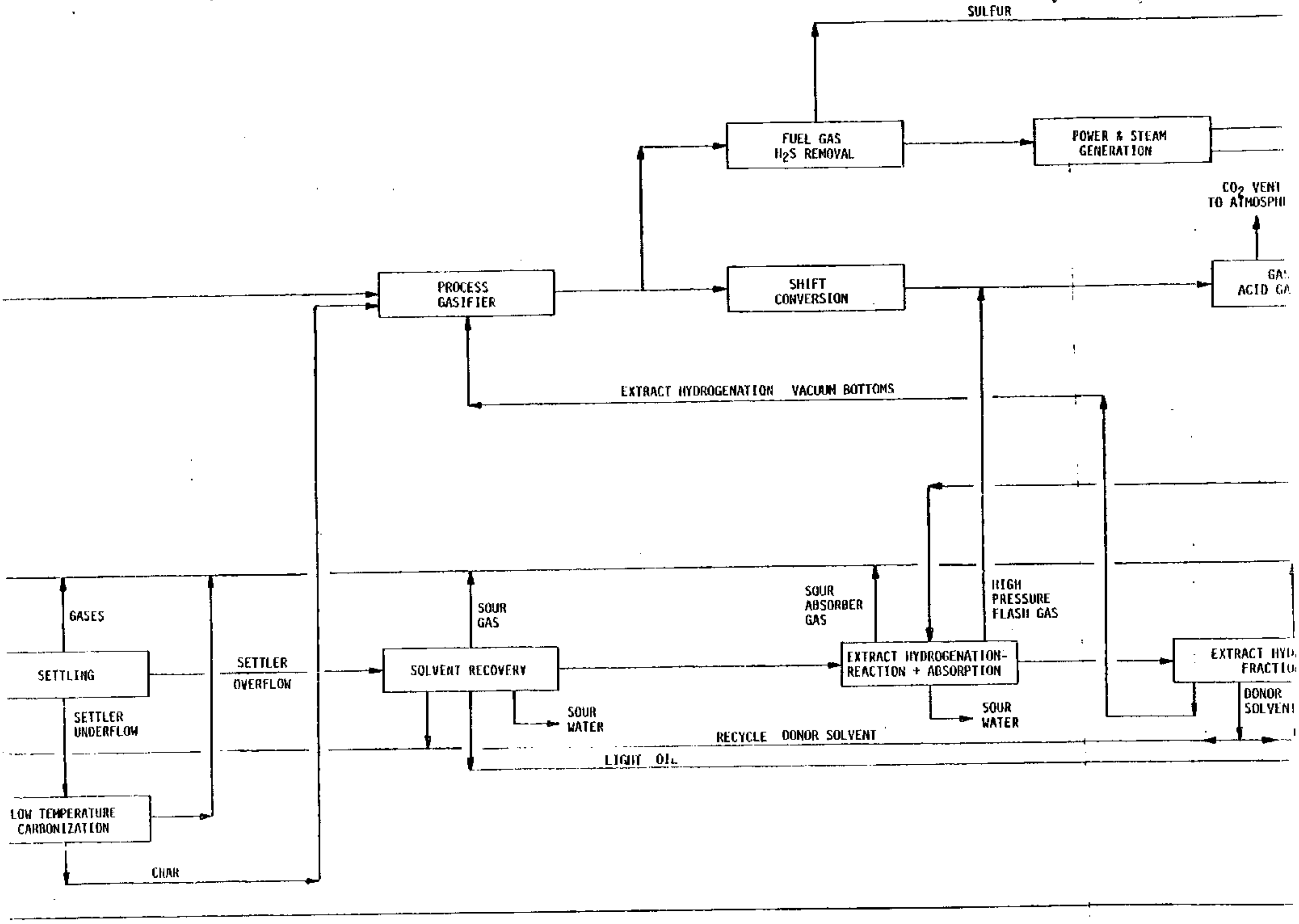
Table 5-2 - CSF Process Yields For Several Coals

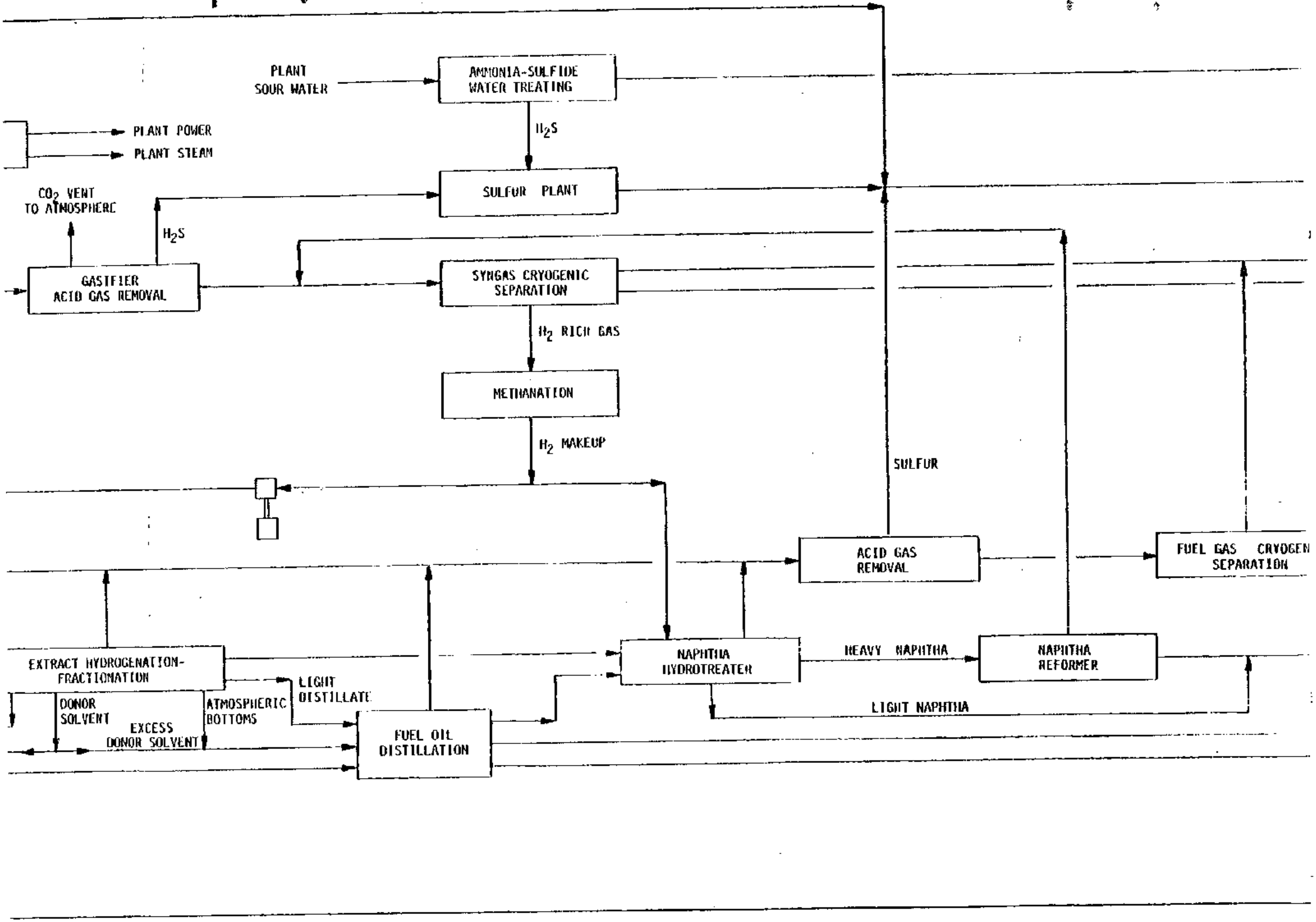
Item	Eastern Coal Province[a] (Pittsburgh No. 8 Seam Ireland Mine)	Interior Coal Province[b] (Illinois No. 6)	Rocky Mountain Coal Province[b] (Montana Sub-bituminous)
Coal Composition (Dry Wt %)			
Carbon	69.0	64.8	69.8
Hydrogen	4.9	4.4	4.5
Nitrogen	1.3	1.2	1.0
Sulfur	4.3	5.8	0.9
Oxygen	7.3	8.3	14.4
Ash	13.2	15.5	9.4
	100.0	100.0	100.0
Yields (Wt % Dry Coal)			
H_2O	5.7	7.4	11.5
C_1-C_3	9.1	7.7	9.5
Other Gases	7.1	12.7	10.9
Light Distillate (Naphtha)	6.2	8.7	9.2
Heavy Distillate	30.0	24.3	25.8
Hydro Extraction Residue (750°F+)	10.9	8.8	9.4
LTC Char	34.5	36.8	29.8
Dry Wt % H_2 Consumption	3.5	3.2	4.2
MAF Wt % H_2 Consumption	4.0	3.8	4.6
MAF Conversions			
Extraction (Wt % of MAF Coal)	70	68	69
Extract Hydroconversion (Wt % of MAF Feed)	81	83	82
Total Gas Yield (Wt % Dry Coal)	16.8	20.4	20.4
Total Distillate Oil Yield (Wt % Dry Coal)	36.2	32.0	35.0
Total Distillate Oil + Residue Yield (Wt & Dry Coal)	47.1	41.8	44.4
Residual Fuel Oil Yield (Heavy Distillate + Residue) (Wt % Dry Coal)	40.9	33.1	35.2

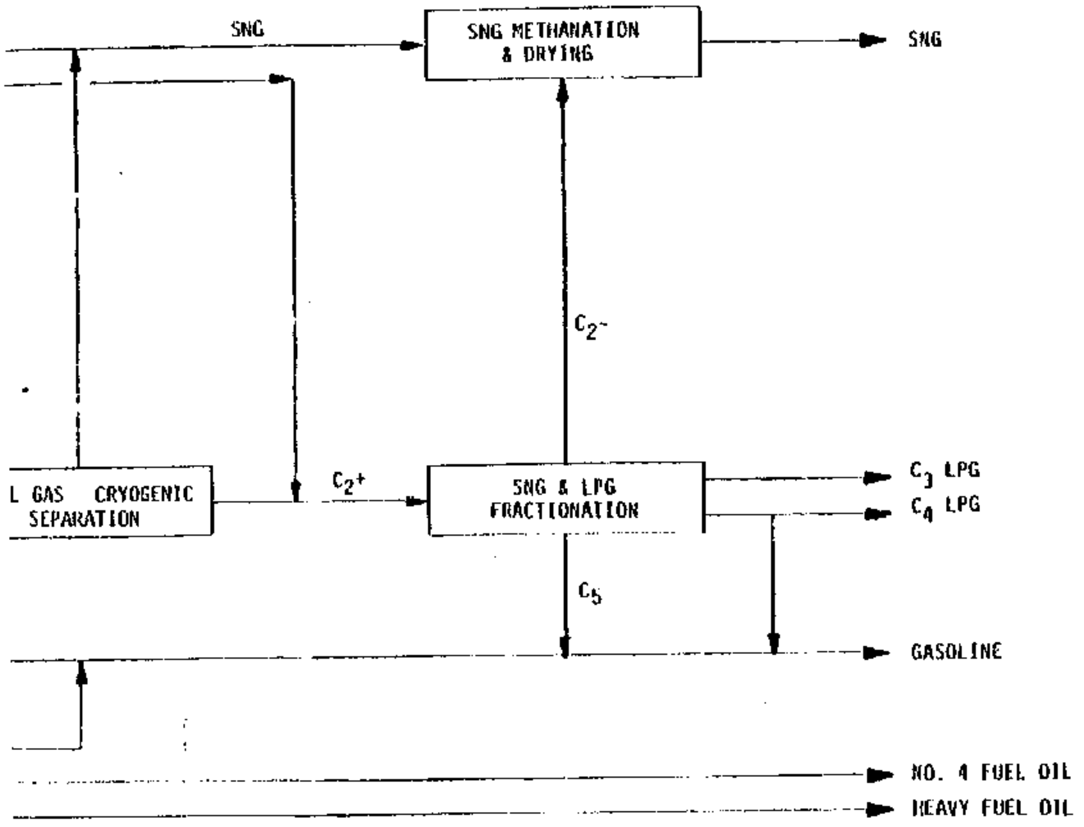
[a] Foster Wheeler Report[17] for OCR, R&D Report No. 70, 1972

[b] Consolidation Coal Co. Report for OCR, R&D Report No. 39, Vol I, 1969[18]


AIR
OXYGEN PLANT
OXYGEN
COAL
COAL PREPARATION
GASES
EXTRACTION
SOUR WATER
RECYCLE SOLVENT
GASES
SETTLING
SETTLER UNDERFLOW
OXYGEN
LOW TEMPERATURE CARBONIZATION
CHAR


SULFUR
FUEL GAS
H_2S REMOVAL
POWER & STEAM
GENERATION
CO_2 VENT
TO ATMOSPH
PROCESS
GASIFIER
SHIFT
CONVERSION
GA
ACID GA
EXTRACT HYDROGENATION VACUUM BOTTOMS
GASES
SETTLING
SETTLER
OVERFLOW
SETTLER
UNDERFLOW
LOW TEMPERATURE
CARBONIZATION
CHAR
SOUR
GAS
SOLVENT RECOVERY
SOUR
WATER
SOUR
ABSORBER
GAS
HIGH
PRESSURE
FLASH GAS
EXTRACT HYDROGENATION-
REACTION + ABSORPTION
SOUR
WATER
EXTRACT HYD
FRACTIO
DONOR
SOLVEN
RECYCLE DONOR SOLVENT
LIGHT OIL


PLANT SOUR WATER
AMMONIA-SULFIDE WATER TREATING
H_2S
PLANT POWER
PLANT STEAM
CO_2 VENT TO ATMOSPHERE
SULFUR PLANT
H_2S
GASIFIER ACID GAS REMOVAL
SYNGAS CRYOGENIC SEPARATION
H_2 RICH GAS
METHANATION
H_2 MAKEUP
SULFUR
ACID GAS REMOVAL
FUEL GAS CRYOGEN SEPARATION
EXTRACT HYDROGENATION-FRACTIONATION
DONOR SOLVENT
EXCESS DONOR SOLVENT
ATMOSPHERIC BOTTOMS
LIGHT DISTILLATE
FUEL OIL DISTILLATION
NAPHTHA HYDROTREATER
HEAVY NAPHTHA
NAPHTHA REFORMER
LIGHT NAPHTHA



	TPD	BPD OR (MMSCFD)	HHV MMBTU/D
COAL FEED	35,715	-	895
PRODUCTS			
SNG	3515	25,265* (135)	151
C_3 LPG	1040	11,725	45
C_4 LPG	280	2,475	12
GASOLINE	2820.0	20,975	114
FUEL OIL (0.2 WT% SULFUR)			
400°-650°F	4870	-	-
650°F+	3220	-	-
FUEL OIL SUBTOTAL	8090	46,980	278
NH_3	180	-	-
SULFUR	1200	-	-
TOTAL	17,125	107,420	600

*BARRELS FOE

THERMAL EFFICIENCY: $\frac{600}{895}$ X 100 = 67%

REV NO	CUST APPR	DATE	REVISION	BY	PROC ENGR	CHECK	SUPV PROC ENGR	CHIEF OPER ENGR	PROC MGR
0			ISSUED FOR REPORT	LDS	RW				

COAL LIQUEFACTION PROCESS SURVEY
BLOCK FLOW DIAGRAM
CSF PROCESS

THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA
JOB NO 5658-1
DWG NO R-03-FS-1
REV 0

DC- S-27 DT-