

CHAPTER 3 : OVERVIEW OF SELECTED SYNTHETIC FUEL CONVERSION PROCESSES

<u>Section No.</u>		<u>Page</u>
3.1	General Synfuel Processes.	3-1
3.2	Coal Gasification.	3-2
3.3	Coal Liquefaction.	3-8
	3.3.1 General	3-8
	3.3.2 Liquid Solvent Refined Coal (SRII)	3-11
	3.3.3 Exxon Donor Solvent	3-14
	3.3.4 H-Coal.	3-17
	3.3.5 Fischer-Tropsch Process	3-21
	3.3.6 Methanol Process.	3-26
3.4	Oil Shale Retorting.	3-31
	3.4.1 General	3-31
	3.4.2 Surface Retorting	3-31
	3.4.3 Modified In Situ Retorting.	3-36
3.5	Comparison of the various Synfuel Systems With Respect to Resource Requirements	3-40

Chapter 3: OVERVIEW OF SELECTED SYNTHETIC FUEL
CONVERSION PROCESSES

3.1 General Synfuel Processes

The General term "synfuel processes" applies to the following:

1. Upgrading of coal. to gaseous, liquid or solid products with improved characteristics.
2. conversion of the kerogen in oil shale to gaseous or liquid fuels or products.
3. Recovery of petroleum crudes from non-conventional oil resources such as heavy oils and tar sands.

Upgrading of coal by subjecting it to a reaction with steam at high temperatures and pressures in the presence of air or oxygen, or to hydrogen, with or without a catalyst, is called conversion. The coal can be converted to gaseous (gasification) or liquid (liquefaction) hydrocarbons. The products have a much lower content of sulfur than the original coal. Oil shale can be retorted by subjecting it to high temperature and pressure, also producing gaseous or liquid hydrocarbons. Catalysts are used in synfuel processes when there is need to accelerate the reaction rates and affect the product state.

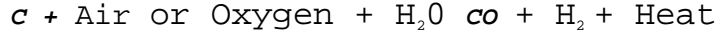
In this report, the following processes are included:

1. Coal gasification
 - to medium Btu gas: generic
 - to high Btu gas: generic
2. Coal Liquefaction
 - by pyrolysis (none included)
 - by solvent extraction: liquid solvent refined coal (SRC II)
Exxon donor solvent (EDS)
 - by catalytic liquefaction: H-coal
 - by indirect liquefaction: Fischer-Tropsch (FT) Methanol
3. Oil shale retorting using:
 - true in situ retorting (none included)
 - modified in situ: generic
 - surface retorting: generic

3.2 coal Gasification

The process by which coal is gasified involves reactions of devolatilization of coal with steam at elevated pressures and temperatures to produce CO and H₂O. Gasification of coal involves basically

the following reaction between steam and carbon:



There are many processes by which coal can be gasified producing low-, medium- or high-Btu gas. The definitions of the heat content of each of them are not rigorous. Low-Btu gas is a mixture of carbon monoxide, hydrogen and nitrogen. It has a heating value of less than 300 Btu per standard cubic foot¹ (Reference No. 25). This gas is of interest to industry either as a combustible fuel or as a raw material from which ammonia, methanol, and other compounds may be synthesized. Due to the low heating value, it cannot command high enough prices to justify long distance transport. Medium-Btu gas is a mixture of methane carbon monoxide, hydrogen, and other gases. It has a heating value between 300 and 700 Btu per standard cubic foot (Reference No. 25). It is suitable as a fuel for industrial consumers, but because of its low heating value, is not economic to transport over great distances. High-Btu gas consists essentially of methane. It has a heating value of ~~appro~~ approximately 1000 Btu per standard cubic foot, and is compatible with natural gas in that it can be substituted for natural gas in existing pipeline systems.

Coal gasification processes can be divided into three major process types according mainly to the way in which the feedstock coal, steam, and the product gases are contacted. They are:

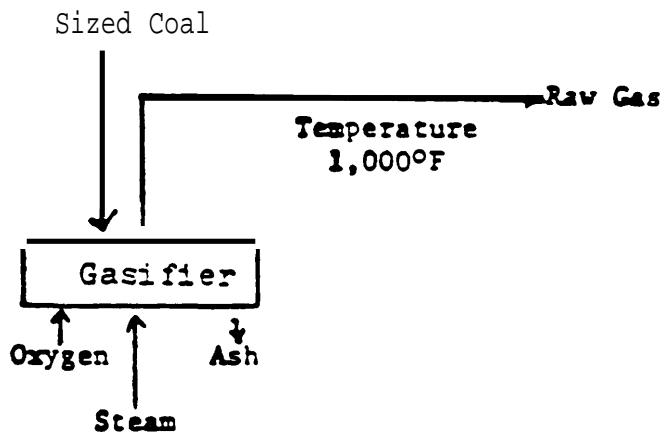
1. Fixed bed gasification in which the crushed, sized coal is fed from the top of the reactor vessel. Steam, air or **oxygen are** blown upwardly.
2. Fluidized bed gasification in which the finely sized coal particles are "fluidized" by the steam, air or oxygen, which are piped through them.
3. Entrained bed gasification: in which the even finer coal particles are blown into the reacting gas stream prior to entry into the reactor. The coal particles are suspended in the gas phase, and are filtered and recycled until a product gas with a suitable heating value is produced.

Figure 3.1 (Reference No. 31) describes the main features of these three processes.

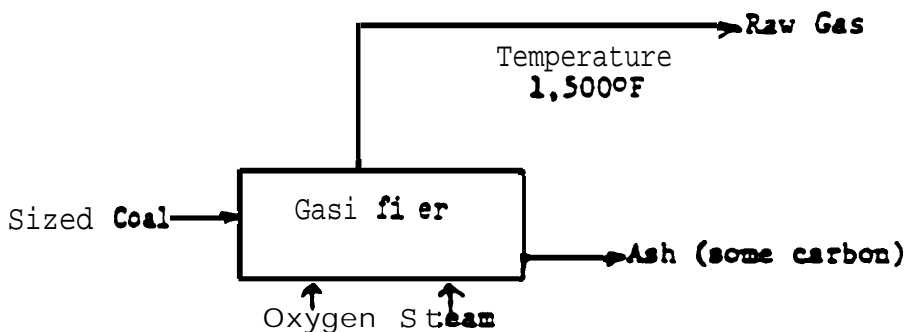
1

Usually, low-Btu gas has a heating value below 200 Btu per SCf; and medium-Btu gas ranges in heating value between 300 - 350 Btu per SCf .

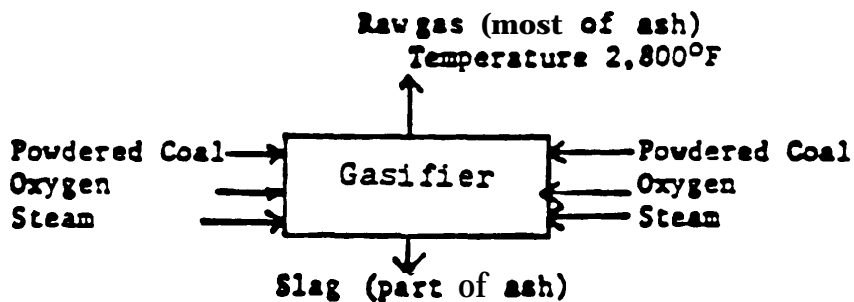
Figure 3.1: Basic Coal Gasification Processes



Fixed Bed Gasification e.g. Lurgi



Fluid Bed Gasification e. g. Winkler



Entrained Gasification e. g. Koppers-Totzek

SOURCE : Reference 31

Figure 3.2 (Reference No. 31) is a schematic diagram of coal gasification. It represents the whole coal gasification fuel cycle, including the production of low-, medium- or high-Btu gas. All of these gasification processes share a number of process steps. If high-Btu, pipeline-quality gas is desired, essentially all of the following process steps are required. In some cases, some of them may be omitted, depending on the type of coal being processed and the type of gas product desired. The process steps are as follows (Reference No. 25).

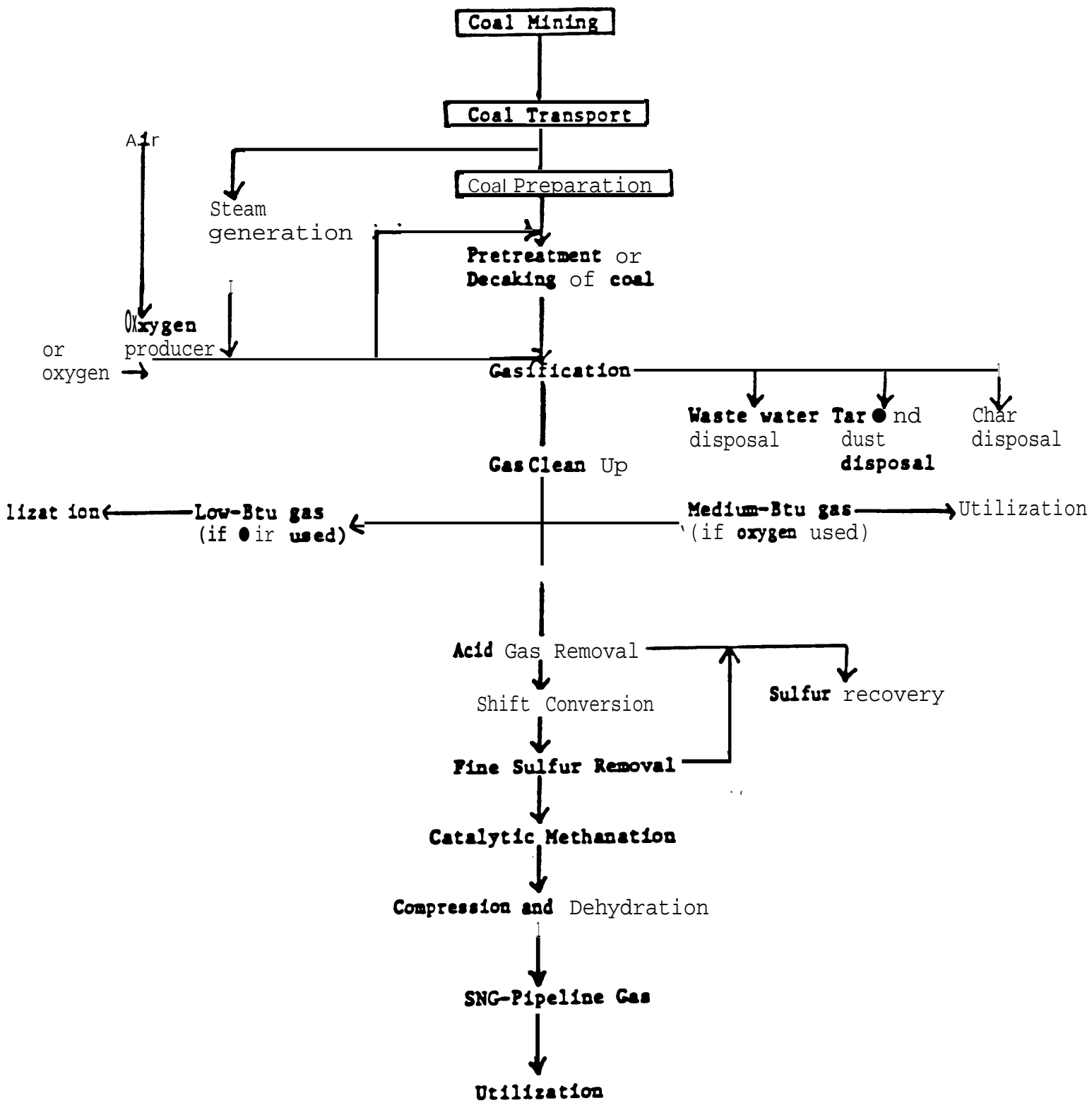
1. Pretreatment of coal² (if sizing or caking are problems) .
2. Primary gasification of coal.
3. Secondary gasification of carbonaceous residue from primary gasifier.
4. Removal of CO₂, H₂S, and other acid gases.
5. shift conversion for adjustment of the carbon monoxide/hydrogen mole ratio to the desired 1:3.
6. Catalytic methanation of the carbon monoxide/hydrogen mixture to form methane.

Pretreatment

The coal received at the plant must be further cleaned and crushed or ground before it can enter the gasifier. Extaneous materials such as shale, rocks, metal, etc. are removed by conventional cleaning methods. For fluidized or entrained gasification processes, the coal needs to be finely ground. Crushing and sizing may also be required for other processes. In the case of certain bituminous coals called caking coals, agglomeration of the material is observed when they are heated. Treatment is needed if they are to be gasified by fluidized or Moving bed processes, or even in fixed bed reaction. The caking characteristics are destroyed when the coal is heated to low temperatures in the presence of air or oxygen.

2 Pretreatment of coal by partial oxidation with air or oxygen is not in general a cost-effective approach to destroying the caking characteristics of certain coals, such as Eastern bituminous coals, because of the loss of Btu values of the coal in producing CO₂ & H₂O. The caking problem is a serious problem in the processing of such coals and limits the applicability of current commercial gasifiers such as the dry-bottom Lurgi to Western Subbituminous coals and lignite.

Figure 3.2: Schematic Diagram of Coal Gasification



SOURCE: Reference 31

Primary Gasification

This is the heart of the process, and is basically a pyrolysis process of the raw coal. The coal feed is contacted with synthesis gas (carbon monoxide and hydrogen). The coal is devolatilized according to the following general reaction (Reference No. 25).

COAL + HEAT (Pyrolysis) + Methane, water, tars, phenols,
hydrogen sulfide, hydrogen,
carbon dioxide, char, etc.

The pressures used for gasification range from atmospheric pressure to 1000 psi. The heat required to maintain the endothermic gasification reaction is supplied from burning coal. Air or oxygen are also needed to support the combustion reaction. If air is used, the product is low Btu gas ranging from essentially a carbon monoxide/hydrogen mixture (Koppers-Totzek process) to mixtures containing various proportions of carbon monoxide, carbon dioxide, hydrogen, water, methane, hydrogen sulfide, nitrogen, and typical products of pyrolysis such as tar, oils, phenols, etc. If oxygen is used, medium Btu gas results.

The bulk of the original coal is transformed into a solid char. Certain coals are more "reactive" to gasification than others. Thus the type of coal being processed determines to a large extent the amount of char produced, and the analysis of the gaseous products. The char is usually gasified by additional processing steps, or is marketed.

Secondary Gasification

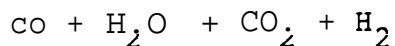
Secondary gasification involves the gasification of char from the primary gasifier. This is usually done by reacting the hot char with water vapor to produce carbon monoxide and hydrogen.

If the desired final product is either low- or medium-Btu gas, secondary gasification is usually followed by scrubbing and cleaning. Carbon dioxide and sulfur compounds are partially removed, and the resulting gas is used directly. If high-Btu gas is desired, shift conversion and methanation are further required.

Shift Conversion

In most gasification processes, a shift reaction is employed prior to methanation. Its purpose is to react

a portion of the carbon monoxide with steam to form more hydrogen.

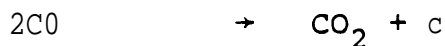
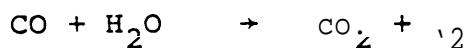
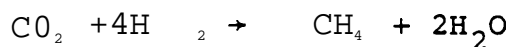
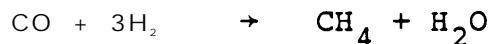


By this exothermic reaction the ratio of carbon monoxide to hydrogen may be increased to 1:3 mole ratio needed to produce methane. Otherwise, deactivation of the catalyst used in the methanation takes place.

The catalytic shift conversion reaction is a well-known process, but it has not been applied on the large scale required for commercial coal gasification. For coal gas shifting, conventional iron-chromium catalysts may be used; however, the coal gas stream must be purified prior to shifting (Reference No. 25).

Methanation

If carbon monoxide and hydrogen are present in the mole ratio of 1:3, the coal gas can be reacted in the presence of a catalyst to produce methane. Group VII transition elements such as iron, cobalt, nickel, ruthenium, rhodium, palladium, osmium, iridium, and platinum have been found to be effective catalysts. The following exothermic reactions occur simultaneously within the methanation unit (Reference No. 25).



Special care must be taken to prevent deactivation of the catalyst by temperatures above 750°F. It can also be poisoned by carbon deposition. These can be circumvented by ensuring that the mixture of carbon monoxide and hydrogen shall be fed to the methanator in the ratio of 1:3. Scrubbing of sulfur from the synthesis gas feed is employed to alleviate sulfur poisoning of the catalyst.

The final step to prepare high Btu gas for marketing is to remove water to specified levels. The product gas usually undergoes compression prior to storage or marketing.

3.3 Coal Liquefaction

303.1 General

Coal liquefaction processes are conversion processes in which liquids are the primary products. Some gases and solid char may also be produced.

There are two basic routes to coal liquefaction, namely direct and indirect liquefaction. In direct processes, slurried crushed coal is reacted directly with hydrogen at high temperature and pressure conditions to produce liquid hydrocarbons. In indirect liquefaction, coal is first gasified to produce a hydrogen-and carbon monoxide mixture. Further recombination with the aid of a catalyst produces liquid products.

Direct liquefaction is further broken down into three generic processes, namely: pyrolysis, solvent extraction, and catalytic liquefaction. The yields and physical properties of the produced liquid products depend directly on the reactor conditions and degree of hydrogenation.

Pyrolysis

In pyrolysis processes, coal is heated to temperatures above 750°F. It is converted into gases, liquids, and char. The latter accounts for more than 50 percent of the weight of the feed coal and requires hydrogenation. Some amount of solids remain in the raw gas and liquid products. They consist of unreacted coal and ash, and can be relatively easily removed from the gas stream. But the liquid requires filtration, distillation, or some other treatment to remove the solids.

Solvent Extraction

This process makes use of coal derived liquids known as "donor" solvents to increase the fraction of the coal that goes into solution. The "donor" solvents act as a source of hydrogen to the coal products, and are reacted together at temperatures up to 950°F. Hydrogen may be supplied under pressure in the extraction step, or it may be used to hydrogenate the solvent prior to recycle. In some processes the unreacted coal is used to generate the necessary hydrogen. In other processes, the hydrogen is generated from by-product gases or from additional raw coal.

Catalytic Liquefaction

In this process, pulverized coal is mixed with 1-1.5 parts of recycle solvent. A suitable catalyst is used to add hydrogen. Most processes of this type operate in the liquid phase with catalyst dispersed throughout or in a fixed bed. Some processes now in the development stage involve the injection of catalyst-impregnated coal into a stream of hot hydrogen at about 950° F for a very short time (Reference No. 25).

Indirect Liquefaction

Two stage conversion of coal typifies indirect liquefaction processes. Coal is first reacted with steam and oxygen to produce a gas composed primarily of carbon monoxide and hydrogen. This gas stream is subsequently purified to **remove sulfur**, nitrogen, and ash. The product gas is then catalytically reacted to yield liquid hydrocarbon products.

Figure 3.3 (Reference No. 31) presents a schematic diagram of the basic liquefaction processes. Each of them produces several types of products and some gas, which may be used within the plant.

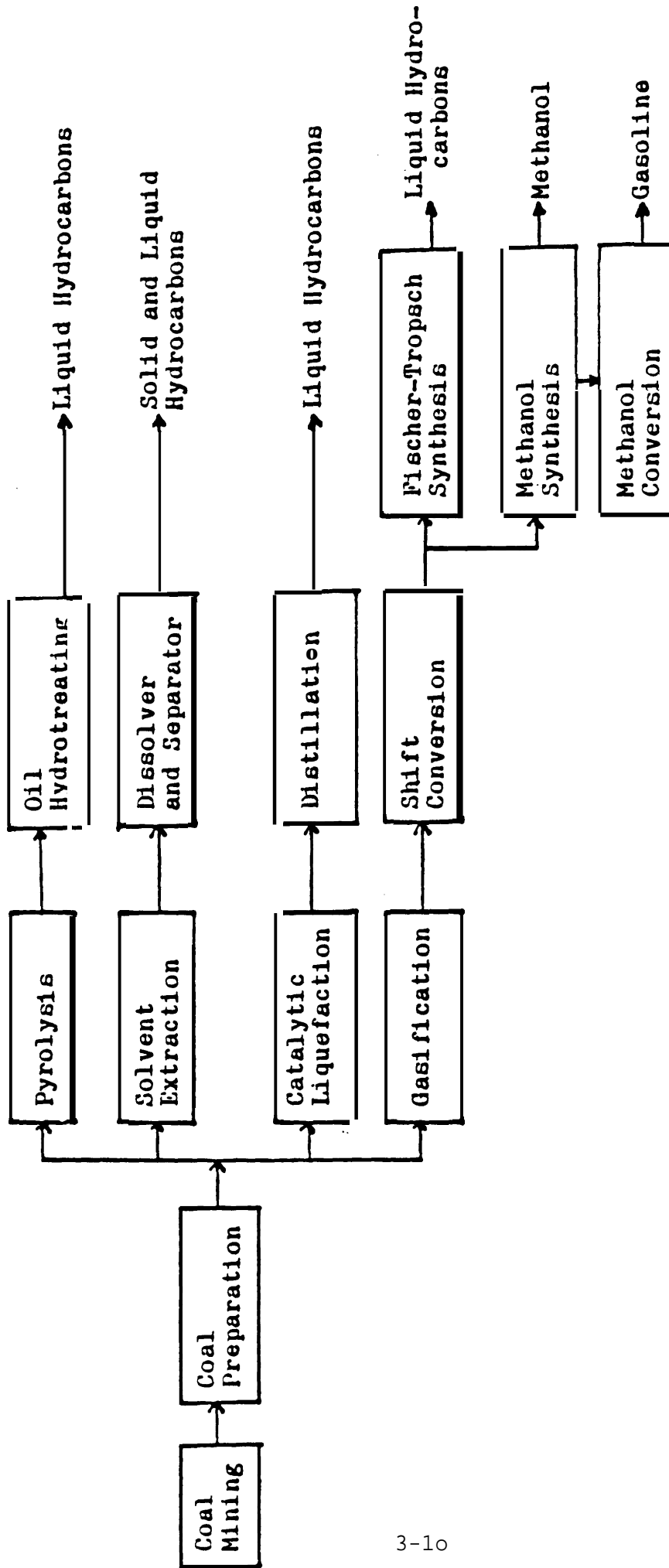
Removal of solids from coal liquids is a critical step in most of these liquefaction processes. Although there is currently a trend toward elimination of the solid-liquid separation step by the recovery of a solids-laden vacuum bottoms stream for gasification, most existing plant designs call for some type of physical/chemical solids removal system.³ The three processes receiving the most current interest are critical solvent deashing, antisolvent deashing, and pressure filtration (Reference No. 25).

Separation of ash and unreacted coal particulate from coal liquids is difficult because of the small size and large quantity of the solid particles, the small density difference between solids and the liquid, and the high viscosity and melting point of the liquids. The Kerr McGee Corporation has been developing a separation technique which utilizes solvents such as benzene, toluene, xylene, pyridene, and cresols near their critical temperature and pressure, hence the term solvent deashing (Reference No. 25).

3

Solid\liquid separation is a critical step only in direct liquefaction process. Most modern coal hydroliquefaction processes in the pilot plant stage of development, such as SRCII, EDS, H-Coal (syncrude route) do not require a solid/liquid separation stage.

Figure 3.3: Schematic Diagram of the Basic Liquefaction Processes*



* Only major products are shown. The last process represents indirect liquefaction.

SOURCE: Reference 31

3.3.2 Liquid Solvent Refined Coal (SRCII)

The SRCI process was developed to convert high-sulfur, high-ash coals to low-sulfur and ash solid fuels. The SRCII is the same kind of process, except the product is a liquid rather than a solid. This is achieved by adding more hydrogen through the following steps:

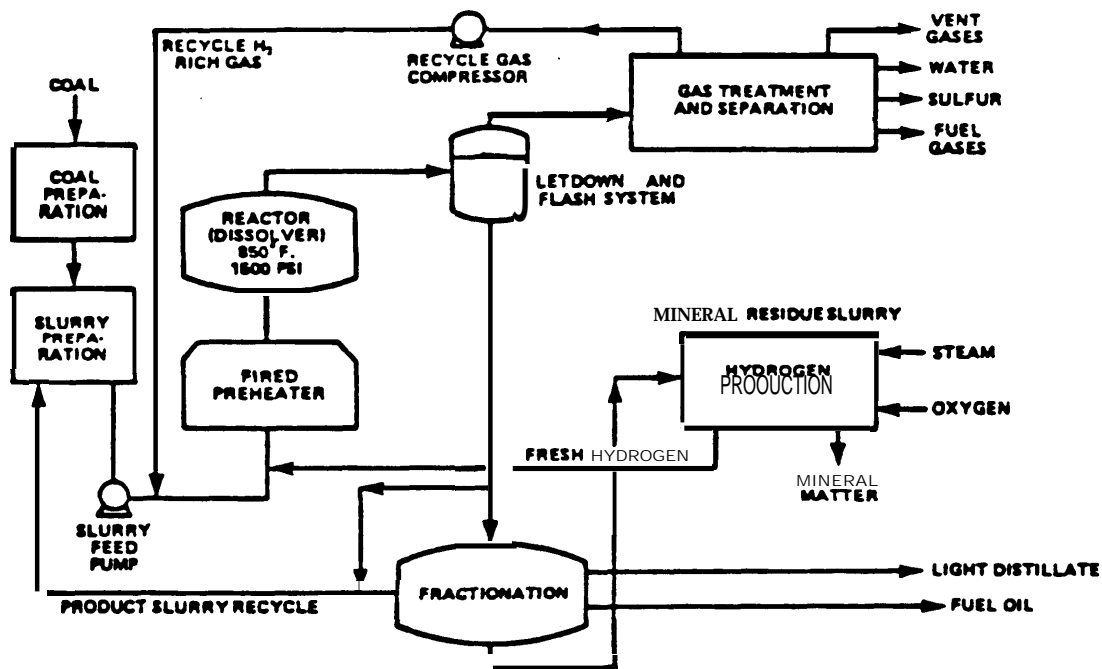
1. Recycling of a portion of the product slurry as solvent for the feed coal.
2. Higher residence time in dissolver.
3. Higher pressure.
4. Use, of vacuum distillation to separate solids from liquid, rather than the troublesome filtration step employed in SRCI .

Figure 3.4 is a schematic diagram of the SRCII process (Reference No. 35) . Table 3.1 summarizes the components, resource requirements, and potential impacts of this process (Reference No. 17) . The feed coal is first pulverized to less than 1/8" size, dried and mixed with process derived solvent in a slurry mix tank (Reference No. 35) . Feed coal is limited to those containing certain trace mineral elements which may be required to act as catalysts for the breaking of solids to liquids in the liquefaction reaction⁴(Reference No. 291. However, in cases where the problem is concentration rather than the presence of specific trace elements, a recycle of residue may broaden the allowable coal feeds (Reference No. 29) . The coal slurry is then mixed with hydrogen generated by gasification of the vacuum bottoms from the liquefaction step and reacting with steam and oxygen in a gasifier-converter. The slurry is pumped through a preheater (700 to 750°F) and passed through a dissolver (2000 psi, 820 to 870°F) to dissolve about 90 percent of the coal (Reference No. 35) . The following additional reactions take Place in the dissolver⁻ (Reference No. 35) .

1. The coal is depolymerized and hydrogenated.
2. The solvent is hydrocracked to form lower molecular weight hydrocarbons, ranging from light oil to methane.
3. **Much** of the organic sulfur is removed in the form of hydrogen sulfide.

The *slurry stream* from the dissolver is split into two. One is recycled to provide solvent for coal slurry mixing. The other is fractionated to recover the primary

⁴ **Opinions differ about the role of the trace minerals as catalysts.** The primary "catalyst" in the SRCII process may well be the pyritic mineral matter contained in the coal and not "trace mineral elements. "



SOURCE : Reference 35

Figure 3.4

A SCHEMATIC DIAGRAM OF THE
SOLVENT REFINED COAL (SRC-II) PROCESS

ENERGY SYSTEM:

- SIZE:** • 30,000 bbl/day (2)
 • 0.335 x 10¹² Btu/day (2)
 • 902 plant availability (2)
 • operation 318 days/year (2)
 • 110.22 x 10¹² Btu/year (2)
 • 31,353 tons per day ROM coal (a)
 • efficiency 64% (a)
 • plant life 30 years (a)
 • 6.7 x 10⁶ Btu/bbl (2)

DESCRIPTION:

Coal is crushed to about 200 mesh and dried to three percent moisture and slurried with a solvent. A 70 to 85 percent hydrogen mixture is added. This mixture is first preheated, then hydrogenated in the reactor. The temperature is 425 to 495°C; pressure 68 to 136 atmosphere. Liquefaction produces a mixture of gases, vapor, liquids, and solids. The gases and vapors are separated from the liquids and solids and the vapors condensed. The liquid is separated from the solids by filtration (SRC 11).

EQUIPMENTS:

- crushers
- SRC reactor
- drying unit
- pre-heaters
- gas recovery plant
- filtering unit

ENVIRONMENTAL CONCERNS:

- air emissions
- water pollution from runoff and leachates
- solid waste
- occupational hazards and health effects
- noise pollution
- odor

RESOURCES USED:
(Per 10¹² Btu Produced)

FUEL (DAF) (c)
 coal: 100,000 tons
 energy content: 12,021 Btu/lb

COAL ANALYSIS (DAF) (a)
 moisture: 2.70%
 volatile matter: 35.09%
 fixed carbon: 51.70%
 sulfur: 1.18%
 ash: 7.13%

LAND (c)
 plant facilities: 3.5 Acres
 solid waste: 0.21

WATER (c)

cooling towers: 84.5 Acres-Ft.
 plant use: 11.0
 steam: 13.1
 miscellaneous: 0.9
 total: 89.5

COSTS
 construction: MA
 operation: MA

PERSONNEL
 construction: MA
 operation & maintenance: MA

RESIDUALS AND PROBLEMS:
(Per 10¹² Btu Produced)

AIR POLLUTANTS (c)

particulates: 2.6 Tons
 SO₂: 0
 NH₃: 36.7
 hydrogen sulfide: 1.0
 CO: 1.0
 arsenic: 1.8 x 10⁻⁶
 cadmium: 1.7 x 10⁻⁶
 mercury: 2.9 x 10⁻⁶
 silver: 1.3 x 10⁻⁶
 chromium: 2.7 x 10⁻⁶
 nickel: 5.9 x 10⁻⁶
 lead: 6.2 x 10⁻⁶
 polynuclear organic material: 1.3 x 10⁻⁶

WATER POLLUTANTS

no direct discharge to any watercourse

SOLID WASTE (c)

dry ton equivalent: 36.16 (11) Tons

EMERGENCY PHENOMENA

average (SRC 11) (energy content = 6.7 x 10⁶ Btu/bbl)
 Equivalent Barrels: 149,734

*The data presented are based on a conceptual design of a commercial facility. The data will be updated when more current data become available. The data should not be used directly for comparison with other coal liquefaction processes.

(1)After coal preparation includes solid waste from mine burial and tailings pond.
 (2)Representative values selected for analysis purposes.

SOURCE:

- (a) Bitumin Associates, Inc., Standards of Practice Manual for Solvent Refined Coal Liquefaction Process, 1978.
- (b) Bitumin Associates, Inc., Environmental Assessment of Coal Liquefaction, 1978.
- (c) EPA, Characterizations and Data in the Area of Coal New Environmental Data Book, Volume IV, 1978.
- (d) Flack and Kuyper, Boiler Fuel and Building Blocks, 1978.

SOURCE: Reference 17

products which consist of naphtha, low sulfur fuel oil, and a vacuum residue which is separated from the solution in a filtration unit. The residue consists of heavy oil, ash and undissolved organic material from the coal (Reference No. 25).

The gases from the dissolver are treated to remove hydrogen sulfide and carbon dioxide. Liquid petroleum gases and pipeline gas are separated in a cryogenic separation unit. Unreacted hydrogen is recovered and recycled.

Recent developments have resulted in increased efficiency of the SRCII process. A combination of solid and liquid products are produced. A wide range of products can be obtained depending on the severity of recycling. Table 3.2 (Reference No. 25) shows the properties of a typical mix of products.

3.3.3. Exxon Donor Solvent (EDS)

The process is similar to SRCII, except that the major portion of the hydrogen supplied as part of the solvent is chemically combined rather than in the form of a free dissolved gas (Reference No. 29). A schematic diagram of the process is illustrated in Figure 35 (Reference No. 35). Crushed coal is liquefied in a reactor at 800-880°F and 1500 - 2000 psig (Reference No. 25). The reaction is non-catalytic, in the presence of molecular hydrogen and the hydrogen-donor solvent, which transfers hydrogen to the coal. The product from the liquefaction reactor is separated into two portions. One part is sent to the solvent hydrogenation unit to produce donor solvent. It is a catalytically hydrogenated recycle stream which is fractionated from the middle boiling range of the liquid product, and has a boiling range of 400 - 850°F (Reference No. 25). After hydrogenation, the solvent is mixed with fresh coal feed, heated in a furnace, and pumped into the liquefaction reactor.

The other portion from the product liquefaction reactor is a slurry. It is separated by distillation into gas, naphtha, middle distillate, and a bottom product that contains heavy liquid, untreated coal and mineral matter. The vacuum bottoms slurry is cooked to produce additional liquids.

The major advantages of the EDS process are:

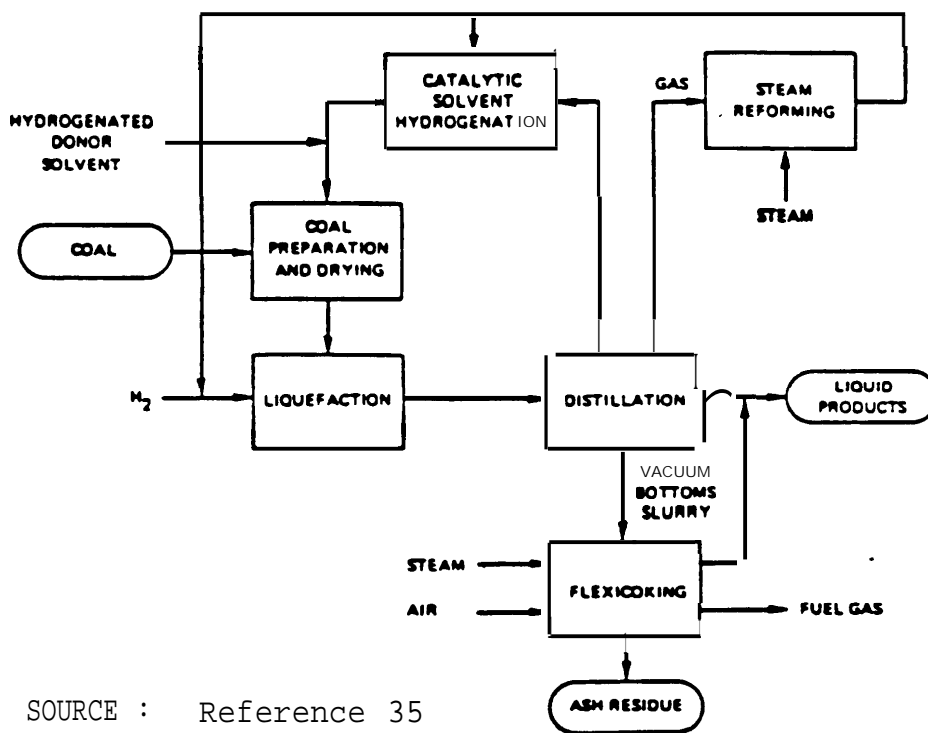
1. High yields of low sulfur liquids are obtained from bituminous and sub-bituminous coals or lignites (Reference No. 25). A yield

TABLE 3.2
TYPICAL PROPERTIES OF SRC FUELS
USING RECYCLE SRC II PROCESS

	<u>Solid Fuel</u>	<u>Distillate Fuel</u>
Gravity: 'API	-18.3	5.0
Approximate Boiling Range: 'F	800+	400-800
Fusion Point: 'F	350	
Flash Point: 'F		168
Viscosity: SUS at 100°F		50
Sulfur*: Percent	0.8	0.3
Nitrogen*: Percent	2.0	0.9
Heating Value: Btu/lb.	16,000	17,300

* Assuming Western Kentucky coal feed with 4% Sulfur and 2% Nitrogen.

SOURCE: Reference 15



SOURCE : Reference 35

Figure 3.5
A Schematic Diagram of the
Donor Solvent Liquefaction Process

of 2.6 barrels of liquids per ton of dry coal is typical for an Illinois bituminous coal (Reference No. 25).

2. The only by-products of significance are ammonia and elemental sulfur (Reference No. 25).
3. There is wide flexibility in product distribution by varying liquefaction conditions or adjusting solvent properties (Reference No. 25).

The typical properties of the products from the EDS process are shown in Table 3.3 (Reference No. 25). An estimated heat balance is given in Table 3.4 (Reference No. 35).

3.3.4 H-Coal

The H-coal process converts coal to hydrocarbon liquids by hydrogenation with a cobalt-molybdenum catalyst. An ebullated bed reactor is employed. The liquid products may range from a heavy boiler fuel to a synthetic crude product (Reference No. 25).

Figure 3.6 (Reference No. 35) is a schematic diagram of the H-coal process. Coal is first crushed to minus 60 mesh, dried, and then slurried with recycled oils at pressures of approximately 200 atmospheres (Reference No. 25). Mixing of the slurry with compressed hydrogen follows, and the mixture is preheated. The material is pumped to the bottom of the ebullated bed reactor, with the-upward flow of slurry through the reactor maintaining the catalyst in a fluidized state (i.e. random motion). The catalyst needs periodic additions of fresh catalyst and withdrawals of spent portions. Typical temperatures of the slurry entering the reactor are 650 - 700°F (Reference No. 25). The finely divided coal and ash particles flowing through the ebullating bed are removed with liquid and vapor products.

The reactor effluent is separated into recycle and net product streams. Conventional processing equipment is used. The liquid stream is distilled to produce a mixture of light distillate and a heavy distillate product. Gaseous products composed of hydrocarbon gas, hydrogen sulfide and ammonia are separated. A portion of the heavy distillate is recycled as the slurring medium.

The operating conditions of the H-Coal process can be altered to produce various types of primary products. For

TABLE 3.3

DONOR SOLVENT PRODUCT ANALYSES

	Heavy Naphtha ¹		200°C+ Fuel Oil	
	Raw Liquid	Hydrotreated Liquid	Raw Liquid	Hydrotreated Liquid
Nominal Boiling Range, °C	70/200	70/200	200/540	200/540
Distillation, 15/5°C				
10 wt. %	106	92	247	239
50 wt. %	180	157	368	347
90 wt. %	199	182	433	412
Density (g/cm ³)	0.87	0.80	1.08	1.01
Elemental Analysis, Wt. %				
c	85.60	86.80	89.40	90.80
H	10.90	12.90	7.70	8.60
o	2.82	0.23	1.83	0.32
N	0.21	0.06	0.66	0.24
s	0.47	0.005	0.41	0.04
Higher Heating Value MJ/kg	42.6	44.9	39.8	42.1

¹Excludes C₆/70°C naphtha cut

SOURCE: Reference 25

Tab I e 3.4

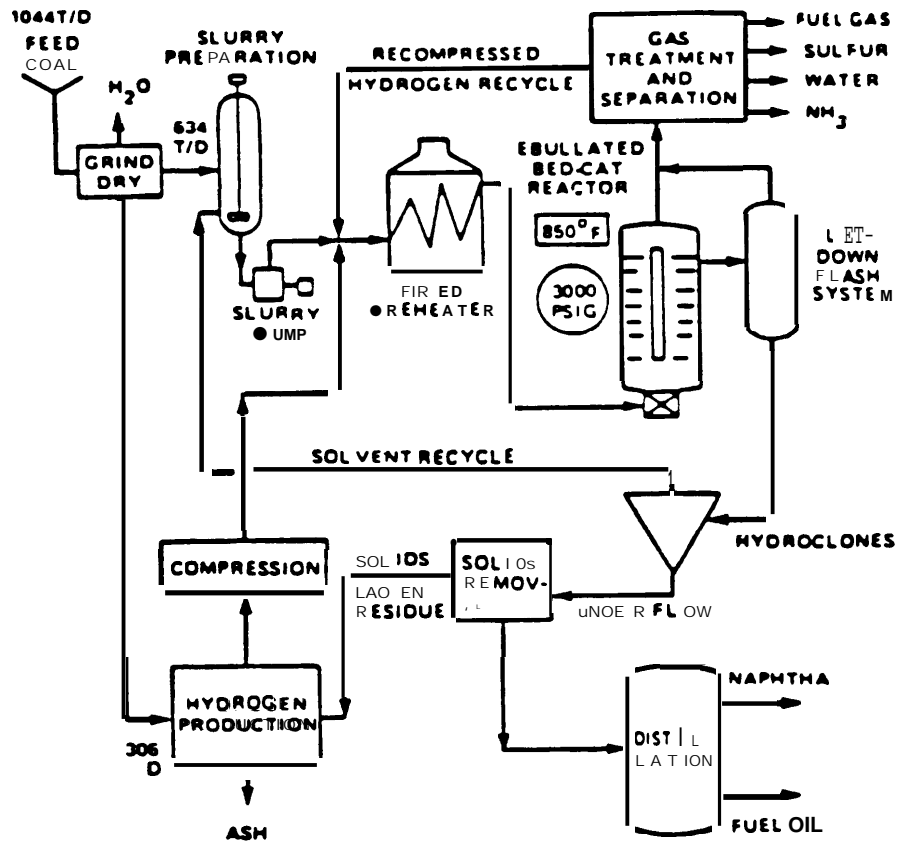
Estimated Heat Balance for a Commercial Scale EDS Plant

	Btu/day (10 Btu's)	Percent of Total Energy Input
<u>System Products</u>		
Liquids	323,071	61.72
Sulfur, ammonia	8,309	1.59
<u>System Losses</u>		
Ash, combustibles and sensible heat	26,082	5.13
Stack losses	20,039	3.83
Energy losses via water and air	136,853	26.14
Liquefaction and solvent hydrogenation (9.80%)		
Flexicoking (6.44%)		
Hydrogenation and recovery (6.72%)		
" By-product recovery, offsites, and miscellaneous (3.18%)		
Other miscellaneous	8,309	1.59
<u>Energy Input</u>		
Coal (cleaned)*	488,761	93.37
Electrical power**	34,702	6.63

* Coal - Illinois No. 6; 10,574 Btu/lb as received prior to cleaning

** Power based on 8,500 Btu/kwh to generate

SOURCE: Reference 35



SOURCE : Reference 35

Figure 3.6

SCHMATIC DIAGRAM OF THE
H-COAL PROCESS

example, relatively high temperatures and high hydrogen partial pressures are used to produce a synthetic crude products. Vacuum distillation is used to separate the solids from the liquid phase. If gas and oil are desired, lower temperatures and pressures are used (Reference No. 25) . Conversion and yield structure are determined by reactor conditions, catalyst replacement rate, and recycle slurry oil composition (Reference No. 29) .

Table 3.5 (Reference No. 25) summarizes the properties of both the fuel oil syncrude products from H-coal.

Table 3.6 (Reference No. 17) summarizes the components , resources and potential impacts from H-coal process. It requires between 14,000 and 20,000 standard cubic feet of hydrogen for each ton of coal produced. Hydrogen consumption depends on the type of product produced, with less hydrogen required during the production of residual oil (Reference No. 25) .

3.3.5 Fischer-Tropsch Process

A commercial plant using a modification of this process is currently operating in South Africa (Reference No. 36). This is the only commercial sized plant producing synfuels. Table 3.7 (Reference No. 35) is an overview of this plant.

In the Fischer-Tropsch process the coal is initially gasified (for description of gasification see section 3.2 of this report) . The synthesis gas is then converted to largely aliphatic hydrocarbons using an iron or cobalt catalyst.

Figure 3.7 (Reference No. 35) is a schematic diagram of the SASOL I plant, which utilizes the Fischer-Tropsch process. Thirteen high pressure gasifiers convert coal in the presence of steam and oxygen to medium Btu gas containing mainly carbon monoxide, tars and oils. The product gas is then cleaned of carbon dioxide, hydrogen sulfide, organic sulfur, ammonia, and phenols. The cleaned gas is then subjected to the catalytic Fischer-Tropsch reaction which produces a mixture of gases, liquid hydrocarbons, and an aqueous chemical mixture that must be further processed to set the desired plant output .

The cleaned gas from the Lurgi gasifiers is partitioned into two streams . One stream is reacted in a fixed bed catalytic reactor to produce straight chain and medium boiling oils, diesel oil, LPG, and some alcohols. Operating conditions are 450°F and 360 psig (Reference No. 35) . The other stream is combined with reformed product gas to increase the hydrogen to carbon ratio. It is reacted in a fluidized bed reactor

TABLE 3.5

 PROPERTIES OF H-COAL DISTILLATES
 FROM ILLINOIS NO. 6 COAL LIQUIDS

<u>Property</u>	<u>Fuel Oil</u>		<u>Syncrude</u>	
	<u><203°C</u> <u>distillate</u>	<u>>203°C</u> <u>distillate</u>	<u><197°C</u> <u>distillate</u>	<u>>1970C</u> <u>distillate</u>
Specific gravity, 60° /60°F	0.864	0.979	0.838	1.025
Gravity, 'API	32.3	13.0	37.4	6.6
Pour point, ASTM D-97, F	<5	<5	<5	<5
Color, ASTM D-1500 or (BuMines description)	NPA6	Brownish black	NPA4-1/2	Brownish black
Kinematic viscosity @ 100°F, ASTM D-455, C _s	1.08	3.87	0.96	14.90
Saybolt viscosity, SUS, 100°F		39		77
Sulfur (Bomb) ASTM D-129, wt-pet	0.13	0.29	0.06	0.35
Nitrogen, Kjeldahl, Wt-pet	0.420	0.446	0.212	0.871
Carbon residue (Conradson) ASTM-524, Wt-pet	0	2.33	0	5.44

SOURCE: Reference 25

TABLE 3.6

H-Coal

ENERGY SYSTEM:	RESOURCES USED: (Per 10 ¹² Btu Produced)	RESIDUALS AND PRODUCTS: (Per 10 ¹² Btu Produced)
SIZE <ul style="list-style-type: none"> • 50,000 bbl/day • .32 x 10¹² Btu/day • 105.12 x 10¹² Btu/year • 90% plant availability • operates 328.5 days/year • efficiency 70% • plant life 30 years 	FUEL coal: bituminous 57,756 tons energy content 11,900 Btu/lb COAL ANALYSIS % (by weight) moisture 2.7 volatile matter 35.5 fixed carbon 51.7 sulfur 3.0 ash 7.1 LAND ⁽¹⁾ plant facility 3.9 solid waste disposal 0.31 CONSUMPTIVE WATER USE Accr-Pt. process water 9.3 cooling water 101.6 waste water 7.0 potable .3 other (utility, quench, etc) 2.8 Total 121.8 COSTS Dollars (1973) construction ⁽²⁾ 6,700,000 operation 3,700,000 PERSONNEL construction NA operation & maintenance 4.1	AIR POLLUTANTS Tons particulates 4.4 SO ₂ 20.2 NO _x 48.9 hydrocarbons 0.6 CO NA organic 0.1 cadmium 1.1 x 10 ⁻² mercury 6.2 x 10 ⁻³ Pb 5.9 x 10 ⁻² chromium 0.1 U ²³⁵ 3.3 x 10 ⁻³ lead 1.1 x 10 ⁻² polynuclear organic material NA WATER POLLUTANTS no direct discharge into any water source SOLID WASTE ⁽³⁾ Tons dry ton equivalent 5,785 ENERGY PRODUCT Barrels liquid fuel 156,250 (energy content Btu/bbl) 6.4 x 10 ⁶
DESCRIPTION <ul style="list-style-type: none"> • Coal is crushed to about 3/4 inches and then ground to minus 60 mesh and mixed with recycled oil. The slurry is then preheated and fed to the reactor and hydrogenated as it comes in contact with the abulating bed of catalyst. Reaction temperature is about 350°C. Gases and vapors are then withdrawn from the top of the reactor and passed through condensers for product separation. The heavier product is withdrawn as a side-stream from the reactor and pumped to an atmosphere distillation unit. 		
COMPONENTS <ul style="list-style-type: none"> • crushers • drying unit • hydrogen plant (gasifier) • H-coal reactor • gas recovery plant • distillation unit 		
ENVIRONMENTAL CONCERNS <ul style="list-style-type: none"> • air emissions • solid waste • water pollution from runoff and leaching • occupational hazards and health effects • noise • odor 		

*The data presented are based on a conceptual design of a commercial facility. The data will be updated when more current data become available. The data should not be used directly for comparison with other coal liquefaction processes.

(1) This represents land committed to use over the lifetime of the plant, divided by the annual output of the plant, expressed in trillion Btu., (405 acres x 105.12 = 3.9 acres)

(2) This represents total cost of constructing the plant, divided by the annual output of the plant, expressed in trillion Btu. (\$650 million x 105.12 = \$6.2 million).

(3) Does not include solid waste from mine burial and tailings pond.

SOURCES: Nittman Associates, Inc., Environmental Assessment of Coal Liquefaction, 1978.

TBW, Characterizations and Data in the Area of Coal Based Environmental Data Book, Volume IV, 1978.

U.S. Energy Research and Development Administration, Synthetic Liquid Fuels Development: Assessment of Critical Factors, ERDA 76-129/2.

Piner Engineers and Constructors, Inc., H-Coal, Commercial Evaluation FE-2007-12, March 1976.

SOURCE: Reference 17

TABLE 3.7

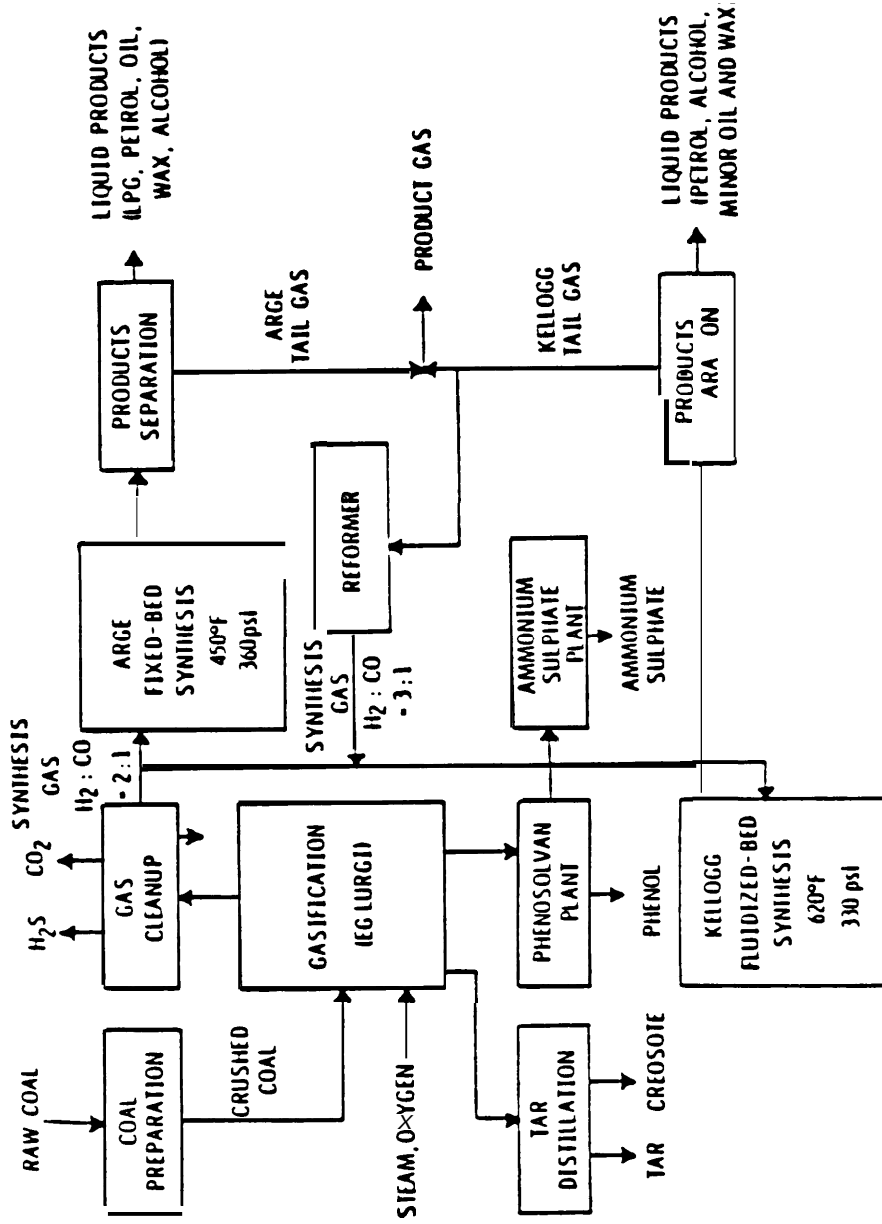
Overviews on SASOL I and SASOL II, based on reference 8, follow:

SASOL 1

LOCATION: Sasolburg, South Africa
 DESCRIPTION: Gasification in Lurgi gasifiers
 Two Fischer-Tropsch synthesis units;
 1) ARGE fixed-bed unit, temp. 230°C;
 press. 23 atm.; catalyst, pelleted
 precipitated iron.
 2) Kellogg SYNTHOL process, high-
 velocity entrained-flow reaction
 using a doubly promoted iron
 catalyst.
 SIZE: 10,000 bpd
 STATUS: in commercial production since 1956
 YEARS OPERATION: 24
 COAL TYPE: Subbituminous
 MAJOR PRODUCTS: Liquid fuels, chemicals, and fuel gas.

SASOL II

LOCATION: Secunda, South Africa
 DESCRIPTION: Gasification in Lurgi gasifiers,
 Fischer-Tropsch synthesis unit using the
 Kellogg SYNTHOL process
 SIZE: Nominal 40,000 bpd
 STATUS: Anticipate ready for commissioning in 1980
 COAL TYPE: Subbituminous
 MAJOR PRODUCTS: Liquid fuels (gasoline is the major product).
 SOURCE: Reference 35



SOURCE: Reference 35

Figure 3.7

Fischer-Tropsch Synthesis

at 620%⁵ and 330 psig, (Reference No. 35). The main products are gasoline, fuel oil fractions, and various chemical products. The gasoline has a lower octane rating than the one derived from petroleum crude. The products produced do not fit well into existing markets. However, Mobil Oil Corporation has developed catalysts that improve the quantity and quality of gasoline (Reference No. 29).

3.3.6 Methanol Process

The production of methanol from synthesis gas is a specialized application of the Fischer-Tropsch reaction. Whereas the F-T process produces liquid fuels and chemical products, the Mobil methanol process produces gasolines. The schematic outline of this process is given in Figures 3.8 and 3.9 (Reference No. 35). Table 3.8 (Reference No. 35) presents a comparison of the thermal efficiencies of the Fischer-Tropsch and the Mobil methanol-to-gasoline process.

In the Mobil methanol liquefaction process, synthesis gas is produced from coal by any of the medium-Btu coal-gasification processes. The synthesis gas is converted to methanol by a number of catalytic processes. The reaction is exothermic. The yield of methanol is optimized by using high pressures and low temperatures, optimum type and shape of catalysts, and of recycling of the unreacted gases.

The conversion of methanol to gasoline is a separate catalytic conversion process. The Mobil conversion process dehydrates methanol, then rearranges the carbon and hydrogen atoms. The zeolite catalysts employed in the process (called ZSM-5 class catalysts) have a unique ~~channel~~ ^{channel}. The pore openings are of the right size to limit the size of the product molecules that can pass through them. The conversion proceeds to conventional high quality gasoline (Reference No. 25).

Table 3.9 (Reference NO. 25) summarizes the overall material and energy balances of the methanol-to-gasoline conversion process.

Table 3.9 (Reference No. 25) shows typical product yields produced from methanol by this conversion process.

⁵ Even though no commercial demonstration plants of the "indirect" coal-methanol-gasoline process has been built as of this date, this route is considered by many authorities to be a very promising way to get gasoline from coal. There are several proposed studies and plants under instruction in the U.S. using this process (see Appendix chart). Also, New Zealand Liquid Fuels Trust Board (Report No. LF 5502, 10/31/79) has a large Mobil-M gasoline plant under construction (expected to become operational by 1983-5).