APPENDIX A

COAL CONVERSION TECHNOLOGIES

Introduction. Many processes exist or are under development for the conversion of coal to synthetic gaseous, liquid, and solid fuels. The impetus for this development originates both from the need for alternatives to natural gas and oil and from the need for clean-burning fuels. Some of the technology is sufficiently advanced to be commercially applied, but much is still in the research or development stage. Fuels produced by these processes include high-, low-, and medium-Btu gas, liquid fuels of various grades, and clean-burning coal or char.

The conversion processes have the advantages of producing clean, ash-and sulfur-free coal from solid, contaminated coal, and of using plentiful domestic coal in place of imported foreign fuels or dwindling domestic gas and oil. Unfortunately there are some disadvantages to the conversion of coal to other fuels. Cost, both capital and operating, thermal efficiency, equipment complexity and reliability, raw material requirements, and potential air, water, and solid waste pollution all are factors which may act against use of specific processes in some applications. Generally, part of the coal is used to supply the required process heat, air or oxygen is needed, and the hydrogen needed to liquefy or gasify the coal is obtained from water.

Descriptive information for conversion technologies has been assembled from available sources and is presented in Appendices C through F. The individual process descriptions contain data reflecting the development program, characteristics of a commercially sized facility, narrative process description, and flow sheets. Background information includes the sponsors and developers, funding, current status, and restrictions on coal type. Following this is a listing of technical data relevant to a large-scale facility. This information is usually based upon conceptual design and presents available raw materials and product quantities, compositions, and characteristics of specific streams (where applicable), and identification of major ancillary operations. (Conceptual designs are plant designs prepared during research and develop-ment for the purpose of evaluating the technical and economic feasibility of proposed process systems. The convention has been adopted, by participants in synthetic fuels research and development, to use 250 MSCF per day and 50,000 Bbl per day as standard sizes for high-Btu gasification and liquefaction processes. These are approximately equivalent in Btu content.

No convention is used for low- and medium-Btu processes because the heating value of the fuel gas varies between processes). A brief narrative process description follows, and finally a process flow sheet is included.

Coal Gasification.   Natural gas is extensively used at military installations to heat individual buildings and domestic water and to generate steam for large-scale heating service. The gas is purchased from utilities, delivered to the installation by the utility pipeline, and distributed to the various points of use through a local pipeline distribution system. Natural gas is composed almost entirely of methane (CH_4) and has a nominal heating value of approximately 1000 Btu per standard cubic foot (SCF). Small amounts of nitrogen, carbon dioxide, water, and light hydrocarbons may also be present in natural gas.

Coal can be converted to fuel gas by reaction at high temperatures with steam and air or oxygen. Depending upon the pressure, temperature, use of air or oxygen, coal rank, and the reactor configuration, the resulting gas will have varying amounts of H_2, CO, CO_2, CH_4, H_2O, and N_2, and the heating value will range from 100 to 500 Btu/SCF. There are two options for using the coal-derived gas; it can be burned directly as low- or medium-Btu gas, or substitute natural gas can be produced from it by raising the heating value to 950 Btu/SCF or higher by increasing the methane content. In practice the composition of synthetic gas from any process would vary over some range as a result of the factors previously mentioned. The presence of high levels of nitrogen, introduced as a component of combustion air, makes the gas from air-fired processes unsuitable for upgrading to high-Btu gas (unless the combustion reaction is segregated from the gas-producing reactions as in CO_2 Acceptor, for example).

Some of the processes for gasifying coals are commercially available and operating in other countries. Others are under development, with some having pilot plants in operation.

The gaseous product from the gasifier has a higher hydrogen to carbon ratio than that in the coal itself, and to achieve this, hydrogen must be added. Hydrogen is supplied by steam, which is contacted, along with oxygen or air, with coal in the gasifier. Different methods of contacting solid with gaseous streams are used.

There are four types of gasifiers: moving-bed, fluidized-bed, entrained-bed, and molten-bath. Reaction rate and the conversion obtained depend upon factors such as coal characteristics, reactor configuration, operating temperature and pressure, and the oxidizing medium. All available commercial processes have been used to date to produce low- or medium-Btu gas. However, addition of a methanation step can produce high-Btu pipeline gas. Except for the Lurgi gasifier, which operates at a pressure of 20 to 30 atmospheres, commercial gasifiers operate at or near atmospheric pressure. Higher pressures are used in the developing processes. Gasifier operating temperatures vary from 1100 to 3600°F. It should be noted that higher pressures and lower temperatures result in higher methane content, and lower pressures and higher temperatures result in a higher H_2 and CO (synthesis gas) content in the product gas. Table A1 shows commercial processes and Table A2 shows typical processes under development along with the type of bed and the developer of each process. The first four processes in Table A1 have are commercial and addition of a methanation step in the Lurgi process can produce high-Btu pipeline gas.

Gasification Processes. Coal is used as a source of low- and medium-Btu gas in most parts of the world. In the United States, natural gas displaced coal-derived gas in the late 1940's when construction of transcontinental pipelines began. In many foreign countries gas is still being manufactured from coal. Various grade of gas for different purposes have been produced in the gas generators previously and presently in use.

Current development efforts on low- and medium-Btu gas processes are directed toward: producing a fuel gas for high temperature combined gas-steam turbine electric generators; producing fuel gas for captive industrial use; and producing synthesis gas for chemical processing. If low- or medium-Btu gas is substituted for natural gas, burner modifications will be required to allow for the higher volume of fuel needed to yield the same Btu content.

Production of low- and medium-Btu gas from coal basically involves reacting the coal with steam and oxygen, quenching to remove condensibles and solids, removing sulfur compounds, and finally either cooling prior to use or using the hot gas directly as fuel. Air may be the oxygen source. Depending upon process conditions and equipment, quenching and cooling

TABLE A1.   Commercial Gasification Processes

Processes	Developer	Type of Reactor	Btu Content
Lurgi	Lurgi Mineralotechnik Gmbh	Moving Bed	Low and High
Kopper-Totzek	Heinrick Koppers Gmbh	Entrained Bed	Low
Winkler	Davy Powergas, Inc.	Fluidized Bed	Medium
Wellman-Galusha	Wellman Engineering Co.	Moving Bed	Low and High
Babcock-Wilcox[1]	Babcock & Wilcox Co.	Entrained Bed	---
Riley-Morgan[1]	Riley Stoker Corp.	Moving Bed	---
Gas Inegrale/ Woodall Duckham[1]	Woodall-Duckham Co.	Moving Bed	---
Rummel/Otto[1]	Dr. C. Otto & Co.	Entrained Bed	---

(1) Data for these systems could not be obtained, and they are included for reference.

TABLE A2.   Developing Gasification Processes

Processes	Developer	Type of Reactor
1. BIGAS	Bituminous Coal Research, Inc.	Entrained Bed
2. HYGAS	Institute of Gas Technology	Fluidized Bed
3. Synthane	Pittsburgh Energy Research Center of ERDA	Fluidized Bed
4. CO_2 Acceptor	Conoco Coal Development Co.	Fluidized Bed
5. Hydrane	Pittsburgh Energy Research Center of ERDA	Entrained Bed
6. Molten Salt	M. W. Kellogg Co.	Molten Salt Bath
7. Agglomerating Burner Process	Battelle Memorial Institute	Fluidized Bed
8. Westinghouse	Westinghouse Research Laboratories	Fluidized Bed
9. Combustion Engineering	Combustion Engineering, Inc.	Entrained Bed

1-7: High Btu processes

  8: Low Btu processes

  9: Low Btu fuel gas processes used for electric power generation

may be optional. A general schematic is shown in Figure Al. Each process (commercially available and under development) has specific variations which affect the composition and heating value of the product, and the applicability of the process to individual uses. Coal rank and preparation requirements, supporting services and utilities, and equipment capacities are also affected. Several low- and medium-Btu processes can be used to produce high-Btu gas by using oxygen instead of air and including additional operations.

The major processing steps required for low-Btu gas production are:

- Coal Preparation: crushing and/or grinding, drying, and size classification.

- Gasification: reaction of the coal carbon with steam and oxygen to form H_2, CO, CO_2, and CH_4.

- Quench and Clean Up: cooling and removal of particulates, oils, and tars.

- Sulfur Removal: removal of H_2S, SO_2, and other sulfur compounds from the gas.

In addition to these operations, supporting services and utilities are required. These include steam generation, cooling water supplies, water and wastewater treatment, solid waste disposal, and sulfur recovery (conversion of H_2S to sulfur for sale or disposal).

Currently the commercial low- and medium-Btu processes of greatest interest are Lurgi, Winkler, and Koppers-Totzek. Descriptions of these and other processes as individual process descriptions are discussed in Appendix C.

High-Btu Gasification Processes. To date no commercial facility for producing high-Btu gas has been operated in the United States. Test production of high-Btu gas has been accomplished with American coals in a Lurgi gasifier in Europe, and several commercial plants based on Lurgi technology are in the planning stage by American industry. Pilot operations based on developing processes have been successful in yielding an acceptable product, and semi-commercial demonstration of one of these processes is likely in the near future.
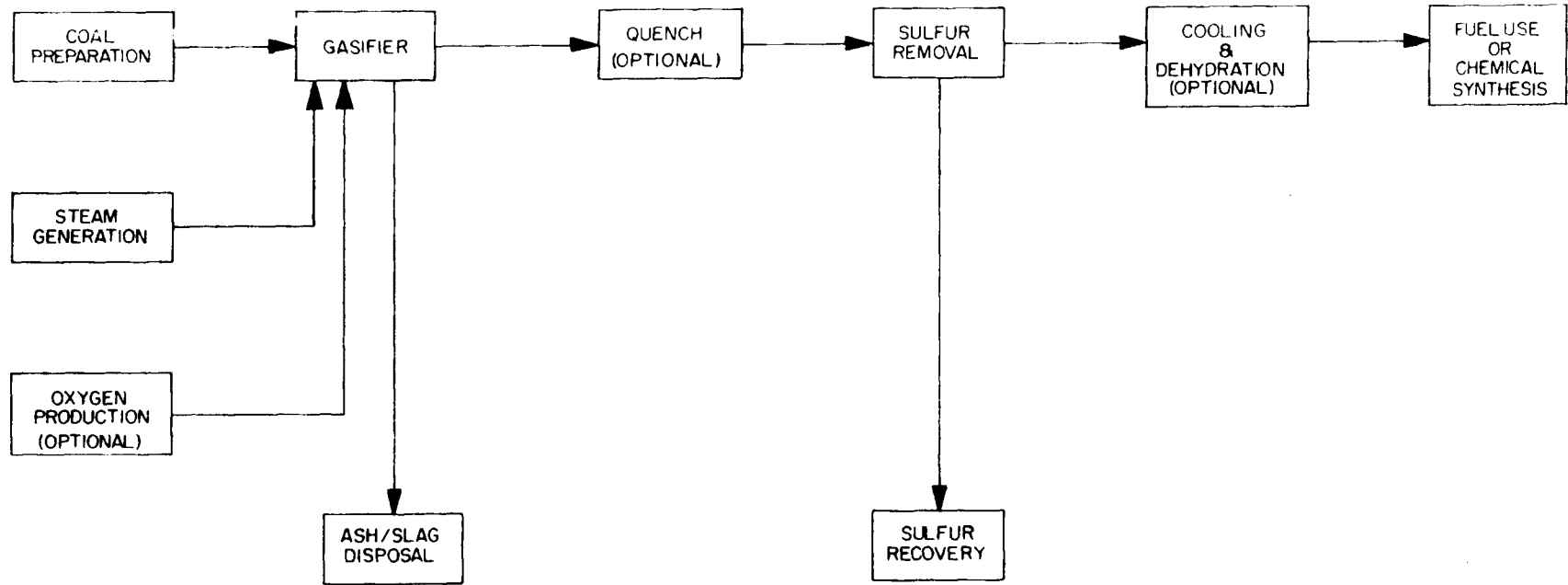
Figure Al.   Basic Features of Low-Btu Gasification Processes

Production of high-Btu gas from coal involves all of the operations needed for low-Btu gas production with the addition of several more steps. The final substitute natural gas is composed principally of methane and can be introduced into existing pipeline systems in place of natural gas. Existing equipment can be operated on substitute natural gas without modifications.

As with low-Btu gas, production of high-Btu gas is accomplished by reacting coal with steam and oxygen, removing particulates and condensibles when necessary, and removing sulfur compounds. In addition to these operations, it is also necessary to remove carbon dioxide, to adjust the hydrogen to carbon monoxide ratio to three to one, and finally to convert the hydrogen and carbon monoxide to methane. Figure A2 is a general schematic for high-Btu gasification.

In producing high-Btu gas, it is desirable to maximize the formation of methane in the gasifier. Coincident with this, the level of CO_2 should be as low as possible, while still yielding sufficient heat (from combustion of part of the coal) to carry out the gasification reactions. Most processes use oxygen as the oxidizer. This eliminates dilution of the gas with nitrogen, which precludes obtaining a heating value of 950 Btu/SCF. Two developmental processes (the CO_2 Acceptor and HYGAS) use air instead of oxygen to carry out the combustion portion of the reaction in a reactor that is separated from the gasifier and which obtains heat transfer indirectly.

High-Btu gasification requires more process steps than low-Btu gasification, although some are identical. The steps involved are:

- Coal Preparation: crushing and/or grinding, drying, and size classification.

- Gasification: reaction of the coal carbon with steam and oxygen to form H_2, CO, CO_2, and CH_4.

- Particulate Removal: most developmental systems utilize high temperature removal of entrained solids.
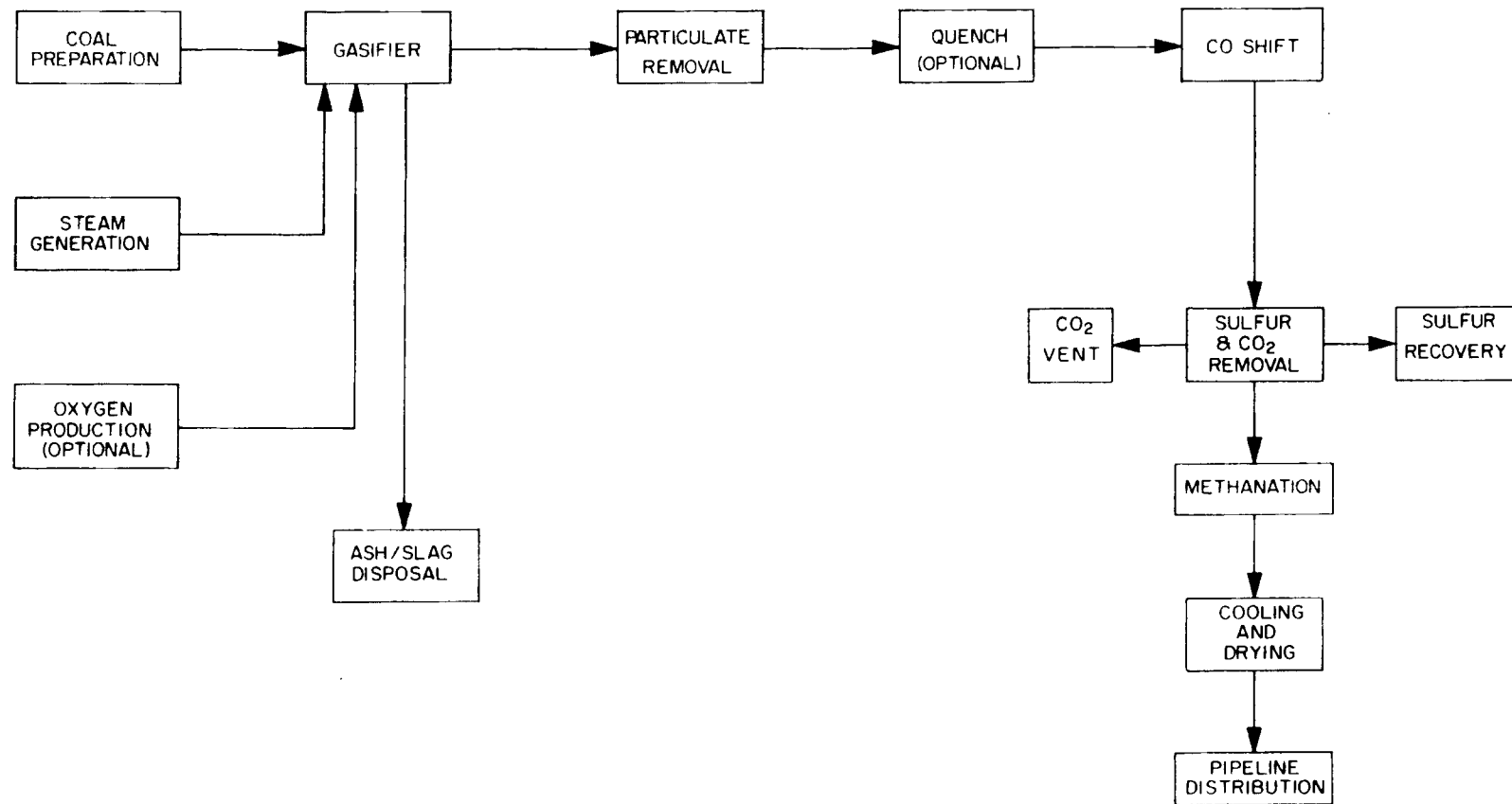
Figure A2.   Basic Features of High-Btu Gasification Processes

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- Quench: quenching of the gas is not usually necessary in high-Btu processes but steam may be added at this step.

- CO-shift: catalytic adjustment of the H_2:CO ratio to 3:1 by the reaction.

$$H_2O + CO \longrightarrow CO_2 + H_2$$

- Sulfur and CO_2 Removal: stripping of CO_2, H_2S, and other sulfur compounds from the gas.

- Methanation: catalytic formation of methane from H_2 and CO by the reaction.

$$3H_2 + CO \longrightarrow CH_4 + H_2O$$
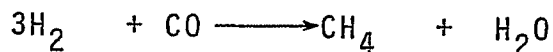
- Cooling and Drying: removal of water formed during methanation to meet pipeline specifications and cooling to pipeline conditions.

Supporting services and utilities are also necessary. Steam generation, oxygen production, cooling water supplies, water and wastewater treatment, solid waste disposal, and sulfur recovery are such services. High-Btu gasification processes in general require moderate to high quantities of process water. Because much of the water is used to generate high pressure superheated steam, water treatment facilities somewhat more extensive than those used for low-Btu gas are needed.

For high-Btu gasification the most promising commercially available process is based on Lurgi technology. The most advanced developmental processes are CO_2 Acceptor, Synthane, and HYGAS. CO_2 Acceptor has been successfully piloted using lignite, HYGAS has been tested on several coals, and the Synthane pilot plant is operational. Appendix D presents descriptions of these and other high-Btu processes.

Coal Liquefaction. The objective of converting coal to liquid fuels is three-fold: production of non-polluting utility fuels, production of synthetic crude for refining to distillate fuels, and/or production of petrochemical feed-stocks. Major efforts in the United States currently are directed toward developing processes for the production of utility fuels. The two routes applied for developing these processes are: (1) pyrolysis and hydrocarbonization, and (2) catalytic and non-catalytic hydrogenation. Using these technologies, the weight ratio of hydrogen to carbon in coal is increased from 1:(12-18) to 1:(5-10) in the liquid fuels. Table A-3 lists seven developing processes of major importance.

TABLE A3.   Coal Liquefaction Processes

Processes	Developer	Comments
Pyrolysis		
COED	FMC Corp.	Multistage pyrolysis in fluidized-bed reactors. Heat transfer by countercurrent flow of coal and gases produced from char.
COALCON	Union Carbide Corp.	Hydrocarbonization process. Heat transfer by circulating hot coal-ash agglomerates.
Catalytic Hydrogenation		
Consol Synthetic Fuel (CSF)	Consolidation Coal Co.	Dissolution of coal with hydrogen-donor solvent followed by extraction in a stirred vessel and catalytic hydrogenation of low ash coal extract
H-Coal	Hydrocarbon Research, Inc.	Slurry preparation with coal de-rived oil followed by hydrogenation in an ebullating-bed reactor.
Synthoil	Pittsburgh Energy Research Center, ERDA	Slurry of coal prepared with coal derived oil. Catalytic hydrogenation in a fixed-bed reactor.
Noncatalytic Hydrogenation		
Solvent Refined Coal (SRC)	The Pittsburgh and Midway Coal Mining Co.	Slurry preparation with coal derived solvent followed by dis-solution and hydrogenation with H_2.
Exxon Donor Solvent	Exxon Research and Engineering Co.	Hydrogenation with hydrogen-donor solvent which is prepared on a fixed-bed catalytic reactor.

N.B.   Fischer-Tropsch Synthesis (catalytic conversion of $CO+H_2$) is also a process used for liquefaction of coal. It is the only commercial process available in the world. It has not been used in the U.S.   This process requires, as a first step, that the coal be gasified.

Pyrolysis and Hydrocarbonization. Pyrolysis of coal
involves heating the coal in the absence of direct hydrogen
contact to about 800°F and higher to drive off the volatile
materials and naturally occurring oils. Partial combustion
of a portion of the coal is usually the source of heat in
pyrolysis processes. By-products obtained are gases (with
a higher H/C ratio than the feed coal) and char, both of
which are recovered for further use in the process. The oil
is hydrotreated to remove sulfur, nitrogen, and oxygen, and
to produce a higher-quality product. Hydrogen, for hydro-
treating, is obtained by reacting the by-product char with
steam and oxygen. The quantity of liquid product depends
on the coal rank, the mechanisms of heating, and the operating
pressure and temperature. At lower temperatures more char
and smaller amounts of gases and liquids are obtained. At
higher temperatures the liquid decomposes to gaseous products.
The liquid yield can be increased by minimizing the exposure
time to elevated temperatures. At increasing pressures less
liquid product is obtained with higher quantities of char
and gas resulting. At pressures above 25 atmospheres,
product distribution no longer is changed by pressure.

Hydrocarbonization differs from pyrolysis by using high-
temperature hydrogen-rich gas for devolatilization. In
addition to the effect of heat, in the presence of hydrogen
at high temperatures, coal components are hydrogenated. A
greater proportion of more hydrogenated hydrocarbons is
produced than by pyrolysis. Hydrogen is prepared by reaction
of the char with oxygen and steam. Generally the pyrolysis
and hydrocarbonization processes are similar except for the
product yield. Pyrolysis products usually require further
hydrogenation, while products from hydrocarbonization may not.
A schematic flow diagram for typical pyrolysis of coal is
shown in Figure A3.

The main process sequence consists of eight operations.
These are:

●   Coal Preparation: crushing, grinding, and drying.

●   Pyrolysis: devolatilization using hot flue gas
      or gases generated <u>in-situ</u> by the reaction of
      steam and air or oxygen with coal.

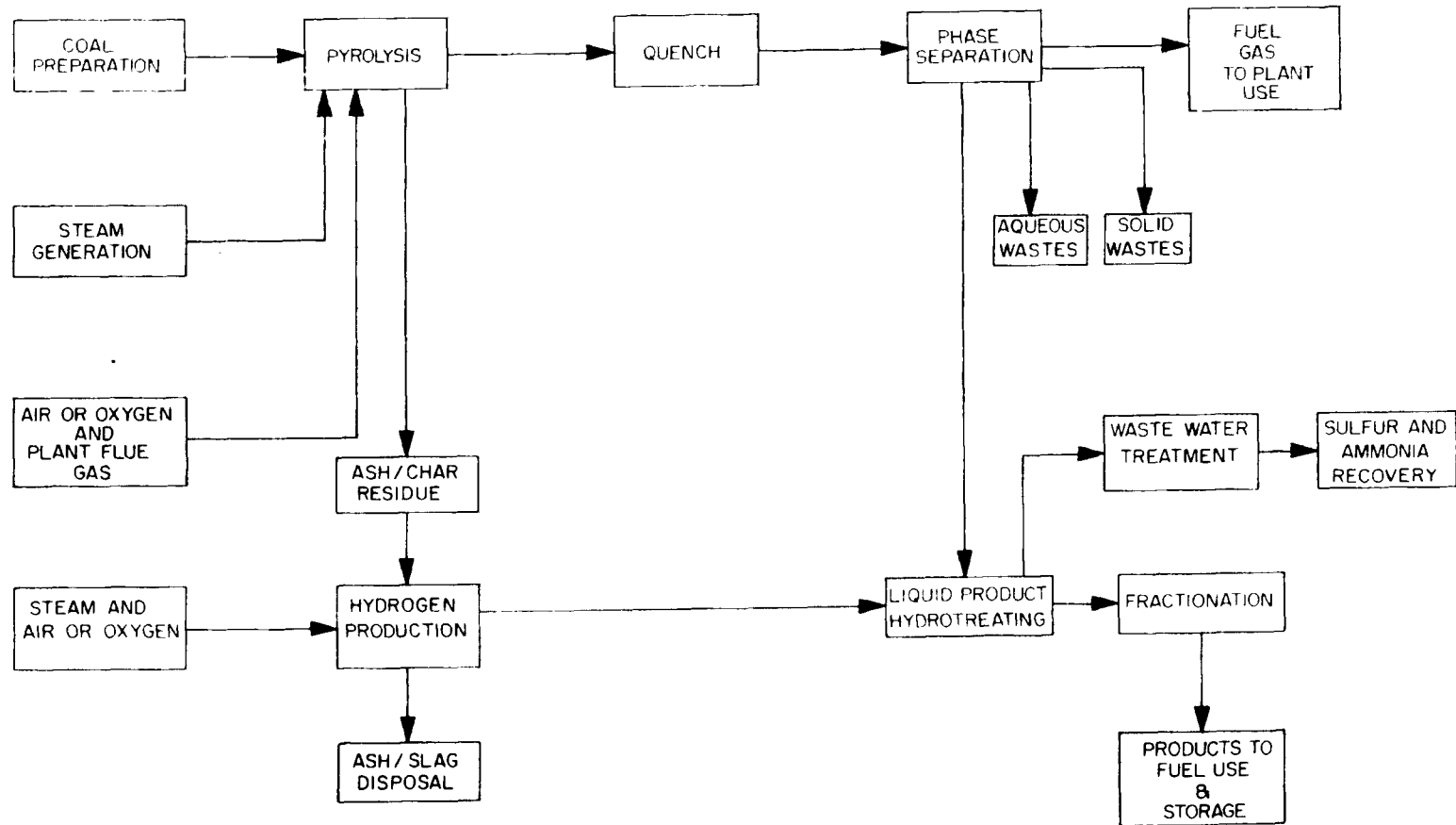●   Quench: cooling to condense liquid hydrocarbons.

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Figure A3.   Basic Features of Pyrolysis Processes

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- Phase Separation: separation of crude oil from gases, water, and solids.

- Hydrogen Production: generation of hydrogen from char, steam, and air or oxygen.

- Liquid Product Hydrotreating: Hydrogenation of the crude to upgrade the hydrocarbon content and to remove sulfur, nitrogen, and oxygen.

- Fractionation: distillation into product and by-product fractions.

- Product and By-Product Storage and Use: utilization of the main fuel product and disposition of by-products.

Electrical power, steam, air or oxygen, water and cooling water are required as utilities. Supporting operations include wastewater and solid waste disposal and by-product recovery.

Hydrocarbonization processes differ from the flow sheet shown for pyrolysis by introducing part of the hydrogen into the pyrolysis reactor in place of steam, oxygen, or air. In addition, less hydrogen is needed for hydrotreating because the crude product is more highly hydrogenated. Aside from these differences, the operations in the two technologies are quite similar.

At this time the two processes based on pyrolysis and hydrocarbonization of maximum importance are COED and Coalcon, respectively. The COED pilot program has been completed and the pilot plant has been dismantled. During 1973 a Navy destroyer was successfully operated for a short (several hours) run on fuel produced from COED crude. There are no current plans for implementation of COED technology, but future development may make the process economically competitive. A demonstration plant for the Coalcon process was planned for New Athens, Illinois. This project is jointly funded by ERDA, industry, and the State of Illinois. Coalcon is a hydrocarbonization process based on existing technology and equipment. While the major product is liquid fuel, gas and fuel-grade char also will be produced. Due to excessive cost increases Coalcon probably will be terminated by the end of 1977.

Process descriptions of the pyrolysis and hydrocarbonization technologies are included in Appendix E.

Catalytic and Non-Catalytic Hydrogenation. In contrast to pyrolysis and hydrocarbonization, hydrogenation of coal involves heating coal at elevated pressure and temperature with direct hydrogen contact. The properties of the liquids obtained depend upon the amount of hydrogen added. Liquids of lower boiling range are obtained when larger quantities of hydrogen are reacted. Catalytic and non-catalytic hydrogenation result in different end products, the former producing more liquid than the latter. If the hydrogen is reduced, a solid product (at ambient conditions) may be formed. Larger quantities of hydrogen yield a liquid product at ambient conditions.

Hydrogenation of coal is carried out in a coal-oil slurry phase. Coal is ground to the required size, dried, and mixed with an aromatic solvent, usually produced in the process itself. The coal slurry is heated to 675°F to 850°F and hydrogenated in a reactor at pressures of 200 to 4500 psig. At higher temperatures thermal cracking exceeds hydrogen transfer and results in coke formation and gas production. Catalytic hydrogenation allows higher temperatures, up to 950°F, without coke formation. The conventional catalysts used are cobalt and ammonium molybdate, nickel chloride, ferrous chloride, and similar materials.

Catalytic and non-catalytic hydrogenation processes basically use the same processing operations. Generally, differences are in conditions at which coal is liquefied. A generalized block flow sheet for typical hydrogenation process is shown in Figure A4. The main process stream includes operations as follows:

- Coal Preparation: crushing and drying.

- Slurrying and Preheating: mixing coal with recycled solvent, introducing hydrogen to the mix, and bringing the slurry to the necessary temperature and pressure.

- Liquefaction: either catalytic or non-catalytic reaction of hydrogen with coal components to produce liquid hydrocarbons.

- Phase Separation: removal of undissolved coal and mineral matter, and separation of liquid and vapor fractions:

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- Hydrogen Production: preparation of hydrogen for process use from undissolved carbon residue.

- Hydrotreating: further hydrogenation for non-catalytic processes to remove sulfur, nitrogen, and oxygen, and to upgrade the crude fuel.

- Fractionation: separation of the fuel components, recycle solvent, and by-products.

Utilities (steam, air, cooling, water, electrical power) are required as well as wastewater treatment, solid waste disposal, and by-product storage and disposal.

Solvent refined coal is the most advanced liquefaction process. Two pilot plants are in operation. One, a 6 TPD plant, is located at Wilsonville, Alabama and the other, having a 50 TPD capacity, is at Fort Lewis, Washington. H-Coal and the Donor Solvent Process are second in importance with pilot operations planned or beginning. Appendix F presents descriptions of hydrogenation processes for liquefaction of coal.

Streams denoted by dashed lines

(----) Maybe necessary with non-catalytic processes.

Figure A4.   Basic Features of Hydrogenation Processes

APPENDIX B

SELECTION OF COAL TECHNOLOGIES

Rationale and Criteria for Selection of Technologies For
Further Consideration. Obviously all of the technologies
described in this report are not practical and applicable to
Army bases. A limited number of suitable processes must be
selected from those described. This selection should not be
optimized to obtain a single process or even one process from
each technology, but rather to identify within the technologies
processes which appear applicable and to eliminate unqualified
technologies or processes.

Direct combustion of coal, conversion of coal to gas, and
conversion of coal to liquids must be considered individually
with respect to the capability to fulfill specific requirements.
Similarly, commercially available and developmental processes
within each technology must be considered separately. The
approach taken has been to evaluate first the technical factors
relevant to implementing a given process. After one or more
processes have been identified as technically acceptable,
economic factors then have been used to identify and eliminate
economically impractical processes.

Specific technical criteria considered in the selection
include process design factors, operability, capacity,
natural resource requirements, and environmental factors.
Economic considerations included manpower, retrofitting,
transportation, and by-product recovery costs. Table B1
identifies these criteria.

Direct Combustion Technologies. Every direct combustion coal
technology previously discussed conceivably could be applied
at Army bases. Advantages and disadvantages of each system
are shown in Table B2. The only advanced developmental
technology for direct combustion is the fluidized-bed system.

After evaluation of the different stoker technologies,
all stoker systems could be applied to Army facilities. Each
system is efficient and reliable, adaptable to burning
most types of coals, and compatible with required load demands
and variations. Environmental problems, stack gas emissions, or
ash disposal are manageable.

TABLE B1.   Factors Influencing Applicability of Technologies to Army Use

I.   Technical Criteria

A.   Process Factors

Product/Use Compatibility	Ability to utilize the product fuel for the end use application
Product Storage/Delivery	Need for product fuel storage and/or delivery system
Process Complexity	Compatibility of the level of technology sophistication with use for military bases
Process Reliability	Ability of process equipment to perform continously and on demand
Feed Stock Flexibility	Capability of equipment to function effectively using different coals
Conversion Efficiency	Amount of input energy recovered as useful heat
Process and Cooling Water Requirements	Water quantity and quality
Ability to Convert Waste Products	Compatibility of utilizing other fuel and later converting to coal

B.   Capacity Factors

Base Load   Comparison of process base load
                                             capacity with military post
                                             consumption

Peak Load   Ability of one or more producing
                                             units to meet peak requirements

Turndown Flexibility   Range of outputs over which a single
                                             process unit can efficiently and
                                             reliably operate and the ability to
                                             selectively operate multiple units.

Size Compatibility with Demand   Ability of process units to be
                                             scaled up or down to match
                                             production to consumption.

C.   Coal Supply Factors

Geography/Location   Regional availability of coal
                                             suitable for use

Coal Rank and Properties   Effect of coal rank and properties
                                             on equipment performance and com-
                                             patibility with the process requirements

Process Requirements   Flexibility of process to operate
                                             on range of coals

Long Term Availability   Ability of supplier(s) to provide
                                             coal of required properties for the
                                             projected life of the equipment.

Ash and Sulfur Content   Availability of methods to handle ash
                                             and sulfur compounds produced from coal

D.   Environmental Factors

    Ash Disposal   Facilities required for ash handling.

    Other Solid Waste   Amount and type of solid wastes presenting
                                           disposal problems

    Air Pollution   Necessary control system to prevent
                                         particulate, emissions to atmosphere

    Wastewater   Compatibility of wastewaters generated
                                         with existing treatment system and need
                                       for industrial wastewater treatment

    Local Environmental Regulations   Compatibility of process to efficiently
                                       perform in compliance with environmental
                                       laws, both local and federal

II.   ECONOMIC FACTORS

    Capital Costs   Cost of new equipment or modifications
                                       to existing systems, installation,
                                       engineering, and ancillary equipment

    Operating Costs   Maintenance, salaries, utilities and
                                       services, raw materials, replacement

    Manpower   Need for highly trained or unskilled
                                       labor to operate the system ability to
                                     automate equipment.

    By-Product Values   Need to dispose of or ability to
                                       profitability market by-products

    Transportation   Existing nearby transportation facilities

TABLE B2.   Summary of Factors in Direct Combustion Application

TECHNOLOGY	STATUS	CAPACITY	ECONOMICS	AIR POLLUTION	FUEL
Spreader Stoker	Highly reliable Requires minimal space, Efficient	Boiler Capacity: 75,000-400,000 lbs of steam per hour, Reponsive to variations in load demands		Dust collectors, SO$_2$ Control, and Ash Disposal Necessary	Can burn broad range of fuels including caking coals - no anthracite, Coal size segregation important
Underfeed Stoker	Efficient	Output: up to 500,000 Btu/sq ft hr, One can be designed to handle variations in load		Particulate, SO$_2$, and ash disposal necessary	Coal size affects capacity and efficiency, Can burn caking coals as well as others, Coal size segregation important
Water-Cooled Vibrating Grate Stoker	Become increasingly popular, Efficient	Output - up to 400,000 Btu/sq ft - hr		Especially adaptable to multiple fuel firing, Particulate and SO$_2$ removal equipment required, Ash disposal necessary	Low and high rank coals can both be burned, Can burn coals with high free swelling index
Chain Grate and Traveling Grate Stokers	Relatively high maintenance, Efficient	Output 350,000-500,000 Btu/sq ft hr		Minimum of fly ash carry-over, SO$_2$ and particulate control equipment necessary	Can burn nearly any solid fuel, Coal size segregation important
Pulverized Coal: Bin System	Pulverizer system required, More efficient than stokers, 400,000 lb/steam hr output, Requires more space than direct firing		No longer competitive with direct-firing	Danger of explosion during storage and pulverized coal, Requires SO$_2$ and particulate control equipment	Can burn all ranks of bituminous - anthracite with special preparation
Pulverized Coal Direct Firing System	Pulverizer system required, Must be operated continously, More efficient than stokers above 400,000 lb steamhr, Greater simplicity than bin system	Multiple pulverizers and burners permit adjustment to demand	Lower initial cost than bin system	Requires SO$_2$ and particulate control equipment	
Multi-cell Fluidized Bed	Most efficient method of direct combustion technology under developmental stage	Multiple modules permit adjustment to demand	Inexpensive due to fabrication potential	Reduced sulfur dioxide (up to 90%) and nitrogen oxide emissions, Ash is sintered and can be used as an aggregate	Can burn any coal and other solid fuels, No danger of slagging, Can burn high ash coals
Coal/Oil Slurry	Technology under development stage	Won't significantly affect Btu output when oil fired unit is converted	Increase in capital cost and operating costs	No significant affect on emissions	

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Pulverized coal combustion could also be effective at military installations. Despite the fact that coal pulverization equipment is necessary, energy efficiency, size compatibility, and turndown capability through use of multiple units make pulverized-coal-burning attractive. As with stokers, through proper preparation and control, environmental impact should be minimal.

Fluidized-bed combustion (FBC) demonstration plants currently are being funded by ERDA. This technology promises to be an effective, efficient, economical, and environmentally sound method of burning coal. Variations in load demand and sizing also are easily met. A significant additional advantage of FBC is the elimination of the necessity for coal desulfurization and/or sulfur dioxide stack gas cleaning.

Coal Gasification Technologies

Commercial Processes. All commercially available gasification processes yield low- and medium-Btu gas. There are no proven commercial high-Btu systems in operation, although high-Btu gas has been produced experimentally during tests at Westfield, Scotland. Plans to use the oxygen-fired Lurgi system for producing substitute natural gas are being implemented but no plants have yet been constructed. Any immediate effort to convert coal to gas will of necessity be based on one or more of the low-Btu processes.

Tables B3, B4, and B5 summarize the characteristics which will have greatest influence on military applications of the four most advanced commercial low-Btu processes. On the basis of these summary tables the two most promising processes for near-term Army use are Lurgi and Koppers-Totzek.

For low-Btu production, Koppers-Totzek based systems have the advantages of accepting any type of coal, operating at sufficiently high temperatures to minimize formation of oils and tar, and not requiring high-pressure operation. The need for an oxygen plant to supply the gasifier with oxygen is a disadvantage. Lurgi has the advantages of being able to produce low-Btu gas using either air or oxygen as the oxidizing medium and of having a high thermal efficiency. Its prime disadvantage is the lower temperature operations leading to formation of oils, tars, and phenols which must be separated from the raw gas and then disposed of. (Lurgi gasification appears to have lower capital costs than Koppers-Totzek.)

TABLE B3.   Product Factors Affecting the Low-Btu Gas Applicability to Army Bases

Gasifier	Oxidizer (1)	Typical Gas Compositions, Mole Percent (2)				Suitability for Upgrading to High-Btu Gas	Need For Pressurization Before Distribution	Volume Ratio of Gas Relative to Natural Gas (3)
		CO	CH_4	H_2	H_2/CO			
Lurgi	A	9.2	4.7	20.1	2.2	No	No	5.6
	O	13.3	5.5	19.6	1.5	Yes	No	3.1
Koppers-Totzek	O	50.4	0.0	33.3	0.7	No	Yes	3.3
Winkler	A	25.7	0.7	30.3	1.1	No	Yes	8.3
	O	19.0	2.5	13.9	0.7	No	Yes	3.3
Wellman-Galusha	A	29.6	2.4	32.3	1.1	No	Yes	5.9
	O	26.0	0.5	11.7	0.6	No	Yes	3.6

(1) A: Air, O: Oxygen
(2) CO_2, N_2, H_2O and other constituents are not listed.
(3) Natural Gas, 1000 Btu/scf.

TABLE B4. Equipment Factors Affecting Applicability of Low-Btu Gas to Army Use

Gasifier	Gasifier Description			Gasifier Performance								
	Type	Coal Feed Capabilities	Gasifying Medium	Operating Pressure atm.	Gasifier Diameter ft.	Unit Capacity Billion Btu/Day	Heating Value Btu/scf	Turn-down	Overall Efficiency, Percent Hot[2]	Cold[3]	Steam Requirement lb/MM Btu	Units Required for Army Scale Use
Lurgi	Fixed/ agitator	Needs sized low caking and non-caking coals	A) Steam-air and B) Steam-oxygen	20	12 16 (planned)	7 to 9 12 to 16	180 (air) 320 (oxygen)	50	91	82	150 to 180	2 to 10
Koppers-Totzek	Entrained slagging	Needs pulverized coals Can accept all types	A) Steam-oxygen B) Air cannot be used	1	2 burners(1) 4 burners	7 to 9 14 to 18	300	35 65	86	67	40 to 65	1 to 3
Winkler	Fluidized	Needs crushed low caking and non-caking coals	A) Steam-air B) Steam-oxygen	1	18	8 to 10	120 (air) 300 (oxygen)	53	75	65	20 to 30	2 to 3
Wellman-	Fixed/ agitator	Needs sized low caking and non-caking coals	A) Steam-air B) Steam-oxygen	1	10	15 to 20	170 (air) 280 (oxygen)	90	95	82	60 to 75	10 to 15

(1) Not cylindrical, 25 ft Ellipsoid

(2) Overall thermal efficiency with fuel gas at discharge temperature.

(3) Overall thermal efficiency with fuel gas at ambient temperature (70°F) and no sensible heat recovery.

TABLE B5.   Product, By-Product, and Waste Factors

Process	By-products	Environmental Considerations	Remarks
Lurgi	Tar, oil, phenols, ammonia, steam	The facility will require a gas cleanup and wastewater treatment facility	Suitable for industrial heating Combined-cycle operation is not simple Instrument control simple
Koppers-Totzek	Steam	Purification system is less complicated since only trace amounts of tar, oil, and phenols are present in the gas	Suitable for combined-cycle operation Instrument control sophisticated
Winkler	Steam	Purification system is less complicated since only trace amounts of tar, oil and phenols are present in the gas.	Suitable for industrial heating and combined-cycle operation Instrument control sophisticated
Wellman-Galusha	Tar, oil, phenols ammonia, steam	The facility will require a gas cleanup and wastewater treatment facility.	Suitable for industrial heating Combined-cycle operation simple Instrument control simple

Developing Processes.   While there are several low-Btu and medium-Btu processes under development, the objectives of this technology are combined high-temperature gas and steam turbine electric power generation.   The scale of these units is not compatible with Army needs.   Developmental low- and medium-Btu processes are not considered to be of interest for military applications.

All high-Btu processes must be considered developmental. Tables B6, B7, and B8 summarize the relevant characteristics of the most promising and most advanced of these.   Oxygen-fired Lurgi is the only fixed-bed system, and HYGAS and CO_2 Acceptor are processes not requiring oxygen.

The latter two processes suffer the disadvantage of extremely complex solids transfer in a high-temperature environment.   High concentrations of methane are produced in the gasifier.   Problems of scaledown to requisite size from commercial scale are probable.   Pilot plant sizes, however, could conceivably be scaled up, or pilot-sized units replicated, to produce gas in quantities required by Army facilities, although costs may be prohibitive.

All high-Btu processes require steam (the source of hydrogen), carbon dioxide and hydrogen sulfide removal, and methanation.   For military uses, production of high-Btu gas may require excessive sophistication when compared to other available options.

Among the processes shown in Tables B6, B7, and B8, Lurgi is closest to commercialization for production of high-Btu gas. It is also the least "high technology" system, but requires (as does the low-Btu version) fairly extensive waste control. Shift, gas cleanup, and methanation all are necessary processing steps to upgrade the raw gas to a high-Btu product.

Synthane, BIGAS, HYGAS, and CO_2 Acceptor are considered second-generation technologies.   Oxygen is required by Synthane and BIGAS and hydrogen is obtained from steam by the CO shift reaction.   Hydrogen must be supplied separately to HYGAS, while sufficient hydrogen can be generated in the CO_2 Acceptor reactor to avoid this.   All four require methanation but the highest concentration of methane, and therefore the least additional methanation reaction, is obtained with HYGAS.   BIGAS and CO_2 Acceptor are the "cleanest" of the processes.

TABLE B6. Product and Process Factors Affecting Applicability of
High-Btu Gas to Army Use

	Typical Raw Gas Compositions, Mole Percent			Ratio of H_2/CO	Quench and Heat Recovery	Gas Cleanup System	Shift Reaction
	CH_4	CO	H_2				
Lurgi	4.7	9.2	20.1	2.2	Gas washed with gas liquor	Not required prior to shift reaction but required prior to methanation step	About 50% of the gas bypasses shift reaction
Synthane	15.4	10.5	17.5	1.7	Gas washed with water	Not required prior to shift reaction but required prior to methanation step	Part of the gas bypasses shift reaction
BIGAS	8.1	22.9	12.7	0.6	Gas washed with hot condensate	Not required prior to shift reaction but required prior to methanation step	All the crude gas goes to shift reaction
HYGAS	32.8	11.6	37.6	3.1	Gas washed with water or oil	Required prior to methanation step	Not required as H_2/CO ratio after gas cleanup is 3.1 Ratio adjusted by hydrogen addition if required
CO_2 Acceptor	17.3	14.1	44.6	3.2	Gas washed with water	Smaller system required due to H_2S and CO_2 react with the acceptor	Not required as raw gas contains enough hydrogen

Process	Bed Type	Coal Feed Capabilities and Pretreatment	Feed System	Pressure atm	Exit Gas Temperature °F
Lurgi	Fixed/Agitator	Limited to non-caking or low caking coals. Fine coal sizes must be briquitted for use.	Pressurized lock-hopper system	20 to 30	700-1100
Synthane	Two stage fluid bed	Caking coal pretreated in a separate high pressure fluidized bed. Wide range of coal including lignite can be used.	Pressurized lock-hopper system	70	1400
BIGAS	Entrained/ Slagging	All types of coals can be used without prior treatment.	Coal water slurry	100	1700
HYGAS	Three stage fluid bed	Caking coal pretreated in a separate atmosphere fluidized bed.	Coal oil slurry	70	1200
CO_2 Acceptor	Single stage fluid bed	Caking coal pretreated in a separate fluidized bed. Limited to more reactive lignite and subbituminous coals.	Lock-hopper system	10-20	1500

TABLE B7. (continued) Equipment Factors Affecting Applicability of High-Btu Gas to Army Use

Process	Methanation and Dehydration	Oxygen Plant	Process Water Requirements Gal/Million Btu	Thermal Efficiency Percent	Heating Value Btu/SCF
Lurgi	Methanation larger than HYGAS process	Required	3.4	67	980
Synthane	Methanation smaller due to high percent of methane produced on the gasifier	Required Oxygen requirements due to high CO_2 production in the gasifier	4.3	65	927
BIGAS	Methanator of large size will be required due to small H_2/CO ratio	A large oxygen plant is required	6.4	69	943
HYGAS	Methanator smaller due to high percent of methane produced in hydrogasifier	Not required	7.6 (Steam-oxygen)	57 (Steam-Iron) 71 (Steam-Oxygen)	941 (Steam-Iron) 947 (Steam-Oxygen)
CO_2 Acceptor	Large size, methanator required as amount of methane produced directly is low	Not required	6.3	62.5	953

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The process most likely to be compatible to Army utilization for the near (but not immediate) future, is Lurgi. For consideration at a later time, CO_2 Acceptor and HYGAS, the two most advanced second-generation processes, may be considered but with reservations due to equipment complexity.

Coal Liquefaction Technologies. There are at present no commercial coal liquefaction processes in the United States. All processes in this technology are under development and will not become commercial in the near future.

These developing liquefaction processes are characterized by complex unit operations and unit processes. New technology is required in the initial breakdown of coal into liquid components. Subsequent processing steps resemble oil refining operations and the nature of the processing equipment and the technology dictates that large-scale facilities will be necessary to economically produce liquid fuels from coal. In general, a minimum economic capacity is nominally 50,000 barrels per day of product produced from 18,000 to 25,000 TPD of coal. This is far in excess of the consumption of any individual Army facility. Even the major energy-consuming bases use only one-twentieth to one fortieth the Btu equivalent of this amount of oil.

On the basis of size, none of the coal liquefaction technologies under development can be selected for further study due to the large capacities required for economic operation. Additional factors in eliminating these processes are the production and disposal of multiple by-products and the complexity of the technology. For practical purposes, a small petrochemicals plant would be operated if the processes were to be scaled down to requisite size. Except for the capacity restriction, Solvent Refined Coal (SRC), H-coal, and Coalcon processes would be the most promising liquefaction processes. It is possible that future developments may result in liquefaction processes compatible with Army facilities' fuel needs in terms of capacity. At this time, however, no such processes have been identified.

One alternative to on-site production of liquid fuel from coal is the operation of a regional facility. A full-scale plant could be located to serve a number of military facilities. The plant location could be chosen to minimize transport of coal and product. Product fuel would be delivered to the facilities served by the plant in tank trucks or by rail. Regional facilities, however, are not within the scope of this effort.

APPENDIX C

LOW- AND MEDIUM-BTU GASIFICATION PROCESSES

Descriptions of the major low-Btu gasification processes follow.

COAL GASIFICATION

LURGI PROCESS

Low-Btu Gas

BACKGROUND

Sponsor:	Proposed Demonstration Plant sponsored by ERDA
Developer:	Lurgi Mineraloltechnik g.m.b.h.
Contractor:	Commonwealth Edison Co./ Electric Power Research Institute (EPRI)
Contract Value:	ERDA - $62.2 million Others - $42.7 million
Status:	600 tons/day demonstration plant scheduled for operation in June 1978. Plant design and construction will be done by Fluor Engineers. American Lurgi will furnish the gasifier. Plant site Located at Pekin, Illinois.
Compatible Coal Type:	Non-caking coals.

CONCEPTUAL DESIGN

Plant producing 307 MSCFD low-Btu gas.

Coal Preparation

Coal Type: Navajo Subbituminous

Coal Analyses:

Proximate, wt%		Ultimate (MAF), wt%	
Fixed Carbon	35.0	Carbon	76.72
Volatile Matter	31.2	Hydrogen	5.71
Ash	17.3	Nitrogen	1.37
Moisture	16.5	Sulfur	0.95
		Oxygen	15.21

Heating Value, Btu/lb: 8872 (MAF)
7340 (As Received)

Preparation: Coal is dried and ground
to 1-3/4" x 3/16"
Caking coals are to be
pretreated.

Feed System: Lock hopper

Gasification Reactor Description and Operating Conditions

Type: Counter-current moving
bed

Temperature: Top: 1100-1400°F
Bottom: 1700°F

Pressure: 285 psig

Input to Gasifier Reactor:

Coal	440,000 lb/hr
Steam	258,060 lb/hr
Air	184 MSCFD (dry)
(including water)	3,679 lb/hr

Output from Gasifier Reactor:

Product gas	307.2 MSCFD
Heating Value	230 Btu/SCF
Acid gas	40.3 MSCFD

By-product	lb/hr
Ash	80,224
Tar	21,846
Gas liquor	231,165

Analysis of Char, wt% Dry

Not specified

Heating value: Not specified

Other Information

Type of acid gas removal: Hot carbonate (Benfield)

Type of sulfur recovery: Stretford

Thermal efficiency: 80 to 85% (gasifier only)

Process Description

Coal can be converted to a low-Btu gaseous product in the
Lurgi gasifier (see Figures C1 and C2) by reaction with steam and
air at about 250-300 psi. The gasifier is a moving-bed-type
reactor with sized coal entering the top through a distributor
and a mixture of steam and air entering the bottom through
a rotary-grate. The coal is fed through a lock hopper
system. The gasifier consists of a double-walled pressure
vessel; the double wall forms a water jacket which protects
the outer pressure wall from high-reaction temperatures.
As the coal charge travels downward, the coal is dried,
devolatized and gasified. Resulting ash is removed by the
rotating grate through a lock hopper system. The maximum
temperature is reached in the combustion or oxidation zone,
where the highly exothermic oxidation reactions provide the
necessary heat and temperature for the endothermic reactions
and vaporizations which occur in the upper portions of the
reactor. Ash leaving the combustion zone is cooled by
incoming steam and air before being discharged. The crude
gas is washed and cooled by generating low-pressure steam
followed by air and water quench cooling. The gas is then
purified by passing it through the hot carbonate acid gas-
removal unit. The Stretford unit is used for sulfur recovery.

Although this proven process has been used commercially
since 1936, it does have certain operating limitations.
It is restricted to noncaking coals; hence only lignite,
subbituminous coals, and noncaking and weakly caking bit-
uminous coals can be used directly. Pretreatment is
necessary for caking coals. The size of coal fed must be
closely regulated, with all fines eliminated. Several
gasifier units must be operated in parallel for commercial
production, due to size limitations. The maximum size of
the Lurgi is about 12 feet in diameter. Operational problems
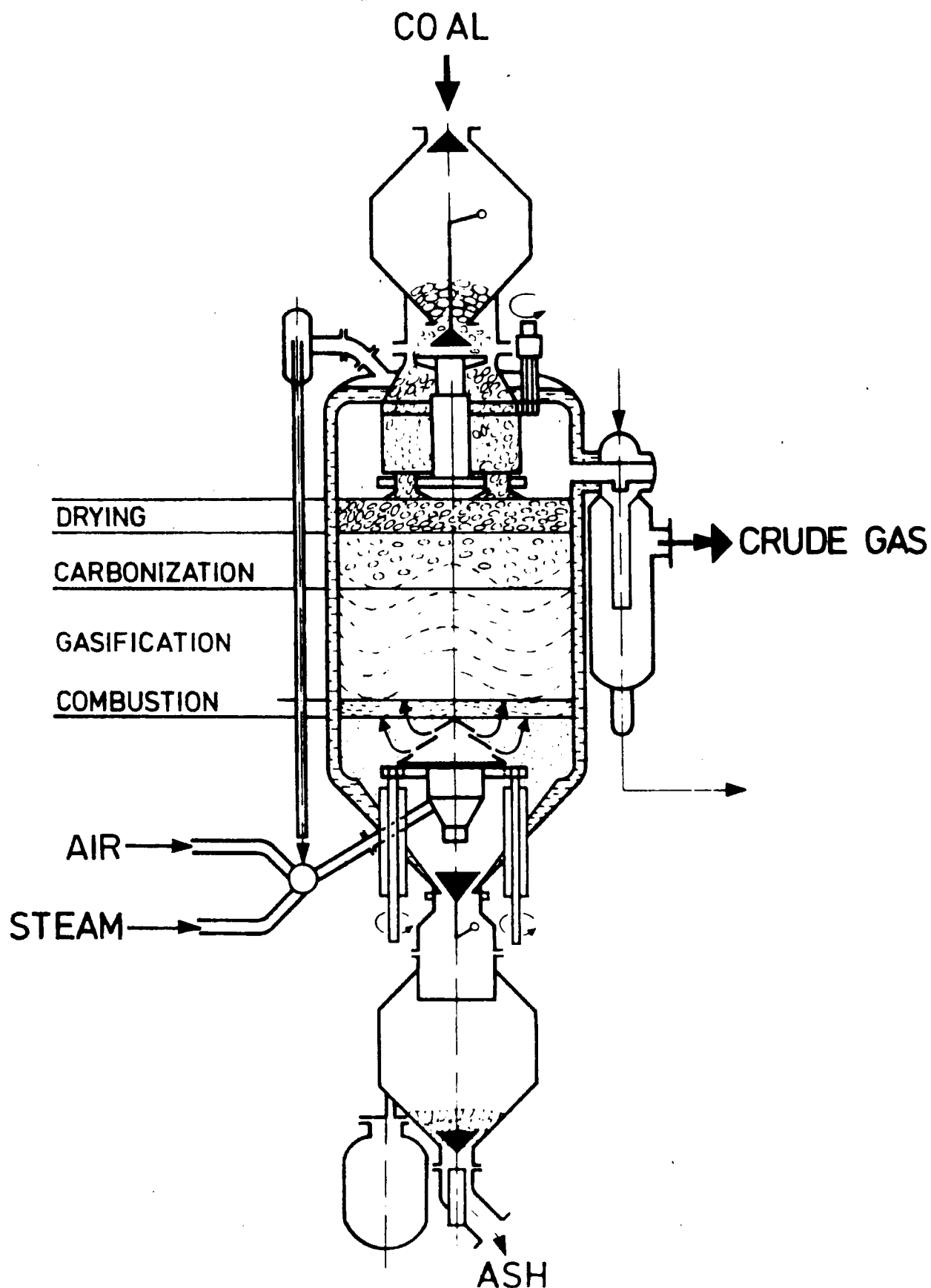are mechanical wear of moving parts.

COAL

DRYING

CARBONIZATION

GASIFICATION

COMBUSTION

CRUDE GAS

AIR

STEAM

ASH

Figure C1.   Lurgi Low-Btu Gasifier

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TO
ATMOSPHERE ◄──────────────────────────────► TO INCINERATOR

SULFUR
PLANT ──────► ELEMENTAL SULFUR

AIR

COAL──► COAL
PREPARATION ──► AIR
BLOWN COAL
GASIFIERS ──► QUENCH ──► GAS
PURIFICATION ──► LOW BTU GAS

──► TO POWER &
STEAM PLANT

ASH
DISPOSAL

GAS
LIQUOR
SEPARATION ◄──── ──► NAPHTHA

WET ASH
TO MINE

TAR AND
TAR OIL

GAS LIQUOR &
EFFLUENT
WATER
TREATMENT ──► RECLAIMED WATER
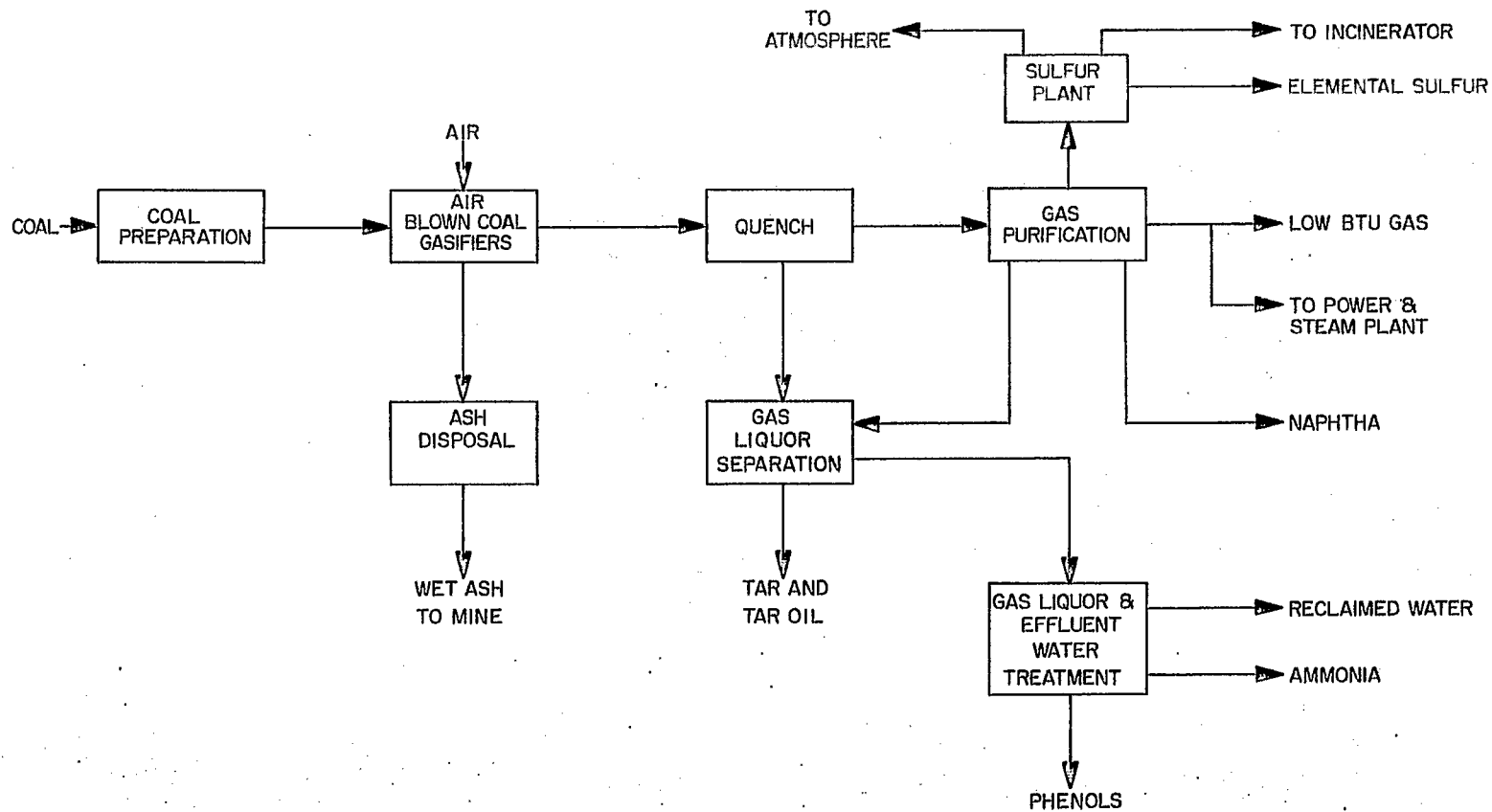
──► AMMONIA

PHENOLS

Figure C2. Lurgi Low-B.tu Process Flow Sheet

COAL GASIFICATION

KOPPERS-TOTZEK PROCESS

Low-Btu Gas

BACKGROUND

Developer: Koppers Company

Status: Commercial plants in existence
                      around the world

Compatible Coal
 Types: Bituminous and Subbituminous

CONCEPTUAL DESIGN   Plant produces 290 MSCFD of medium -
                      Btu Gas

Coal Preparation Operation:

    Coal Type: Navajo Subbituminous

    Coal Analyses:

Proximate, wt %		Ultimate (MAF), wt %	
Fixed Carbon	35.0	C	76.72
Volatiles	31.2	H	5.71
Ash	17.3	N	1.37
Moisture	16.5	S	0.95
		O	15.21
		Other	0.04

Heating Value, Btu/lb: 8830 (MAF)
                            7300 (As Received)

Size of Coal Feed:

Pretreatment   Drying and grinding, 10% (less
                            than 200 mesh)

Feed System: Screw feed mixed with steam
                            and oxygen

Gasifier Description and Operating Conditions:

Type: Entrained slagging

Oxidant Supplied: Oxygen

Temperature: 2700°F

Pressure: 15 psig

Input to Gasifier:

    Coal: 479,300 lb/hr (2% moisture)
    Steam: 84,700 lb/hr
    Oxygen: 326,000 lb/hr

Output from Gasifier:

Raw, dry gas from gasifier and quench:

CO	575,300 lb/hr
H_2	22,200 lb/hr
CO_2	88,900 lb/hr
CH_4	600 lb/hr
H_2S	3,400 lb/hr
COS	700 lb/hr
N_2	11,000 lb/hr
Higher Hydrocarbon	0 lb/hr

By-products from Gasifier:

Ash	111,500 lb/hr
Tar & Oil	Negligible
Phenols	Negligible
NH_3	Negligible
Hydrocarbon liquids	Negligible

Net dry product gas:

Volume of Product Gas   290 MSCFD

Heating Value: 303 Btu/SCF

Pressure of Product Gas: 166 psia (after compression)

Gas Analysis (Volume %):

CH_4	0.1
H_2	32.6
N_2	1.2
CO_2	5.2
CO	60.9
H_2S+COS	0.03

Other Information:

Net Process Water Consumption: 0.4 MGD

Type of Acid Gas Removal: Methyl diethanolamine

Sulfur Recovery:

        Type: Claus
        Total Produced: 3,330 lb/hr

Thermal Efficiency: 53.0% to 69.0%

Process Description

Coal is pretreated by drying and then pulverized to about 70 per-
cent through 200 mesh. The drying medium, which is either
hot flue gas or Koppers-Totzek gas burned with air, is
circulated through the mill. The resulting coal dust is
conveyed continously by fluidization to service bins above
the gasifier. From each bin, coal passes to a feed bin from
which the coal is screw fed to the mixing head. At the
mixing head a combination of steam and oxygen entrain the
coal particles and transport the dust at velocities greater
than the speed of flame propagation. Low-pressure steam
produced in the gasifier jacket is used as the process steam
in the gasifier.

Carbon is oxidized by the steam and air entering the gasifier
and hydrogen is produced. The high temperature of operation
causes slagging of the ash. Over half the slag flows down
the gasifier walls into quench tanks. The remainder of
the ash leaves the gasifier as a fine fly ash entrained in
the exit gas. Water sprays remove the heavy particles
and cool the gas. Final gas cleaning is accomplished by
two Thesen disintegrators arranged in series. After com-
pression the gas is scrubbed with amine to remove H_2S
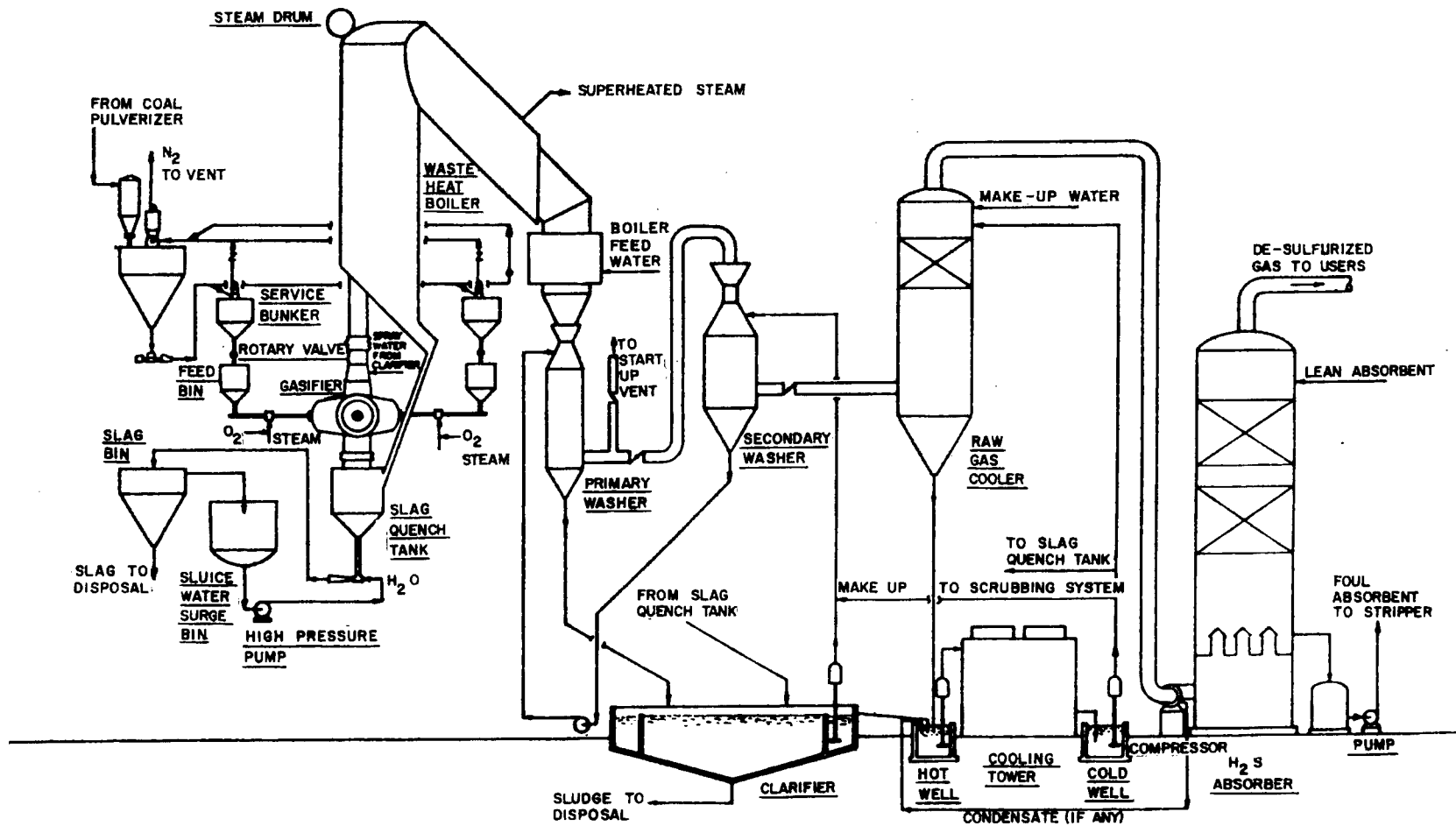for sulfur recovery (see Figure C3).

Figure C3. Koppers-Totzek Gasification Process

COAL GASIFICATION

WINKLER PROCESS

Medium-Btu Gas

BACKGROUND

Developer:	Davy Powergas, Inc.
Status:	The process has been in successful commercial operation at 16 plants in a number of countries, using a total of 36 generators. Some plants are still operating, with the largest having output of 26.4 MSCFD. The last installation was in 1960.

CONCEPTUAL DESIGN

Plant producing 886 MSCFD medium-Btu gas.

Coal Preparation

Coal Type: Lignite

Coal Analyses:

Proximate, wt%		Ultimate (MAF), wt%	
Fixed Carbon	N.R.	Carbon	71.2
Volatile Matter	N.R.	Hydrogen	5.4
Ash	14.5	Nitrogen	0.8
Moisture	13.3	Oxygen	18.3

Heating Value, Btu/lb: 9320 (MAF)
7970 (As received)

Preparation: Coal is dried and ground to minus 1/4 in. Pretreatment necessary for caking coals.

Feed System: Variable speed screw feeder.

Gasification Reactor Description and Operating Conditions

Type: Fluidized Bed

Temperature: 1700°F

Pressure: 30 psia

Input to Gasifier Reactor:

	lb/hr
Lignite	1,675,000 (8.7% moisture)
Steam	820,800
Oxygen	961,300

Output from Gasifier Reactor:

Raw Dry Gas	lb/hr	Vol%
CO	1,094,800	35.2
H_2	85,700	38.6
CO_2	1,066,500	21.8
CH_4	32,000	1.8
H_2S	51,250	0.4
COS	10,000	0.2
N_2	34,000	1.1

By-Products	lb/hr
Char	372,500
Tar and Oil	-------
Phenols	-------
NH_3	-------
Higher Hydrocarbons	-------

Analysis of Net Dry Product Gas, Vol%

CH_4	2.0
H_2	42.7
N_2	1.2
CO_2	15.1
CO	38.9
H_2S+COS	0.08

Heating Value: 282 Btu/SCF

Pressure: 15 psia

Analysis of Char, wt% Dry

    Not specified

    Heating value: 4,810 Btu/lb

Other Information

Net process water consumption: 3.9 MGD

Type of acid gas removal: Hot carbonate (Benfield)

Type of sulfur recovery: Claus

Thermal efficiency: 66.8 - 68.9%

Process Description

The Winkler fluidized-bed gasifier is shown in Figure C4. Crushed coal (minus 1/4 in.) is dried and fed by a screw feeder into the side of the reactor. Coal reacts with oxygen and steam to produce offgas rich in carbon monoxide and hydrogen. The fluidized bed operates at 1,500°-1,850°F depending on coal type. Pressure is approximately atmospheric.

Because of the high temperatures, all tars and heavy hydrocarbons are reacted. About 70 percent of the ash is carried over by gas and 30 percent of it is removed from the bottom of the gasifier by the ash screw. Unreacted carbon carried by the gas is converted by secondary steam and oxygen in the space above the fluidized bed.

As a result, maximum temperature occurs above the fluidized bed. To prevent ash particles from melting and forming deposits in the exit duct, gas is cooled by the radiant boiler section before it leaves the gasifier. Raw gas leaving the gasifier is passed through an additional waste-heat recovery section. Fly ash is removed by cyclones, followed by a wet scrubber, and finally an electrostatic precipitator. Gas is then compressed and purified.

Oxygen consumption for the Winkler process is intermediate between that of the moving-bed Lurgi and the entrained-bed Koppers-Totzek. While the Winkler does not produce the tars, phenols, and light oils that the Lurgi does, like Koppers-Totzek, it has been operated commercially only at atmospheric pressure. Studies of estimated results under conditions of 1.5-atm pressure have been made.
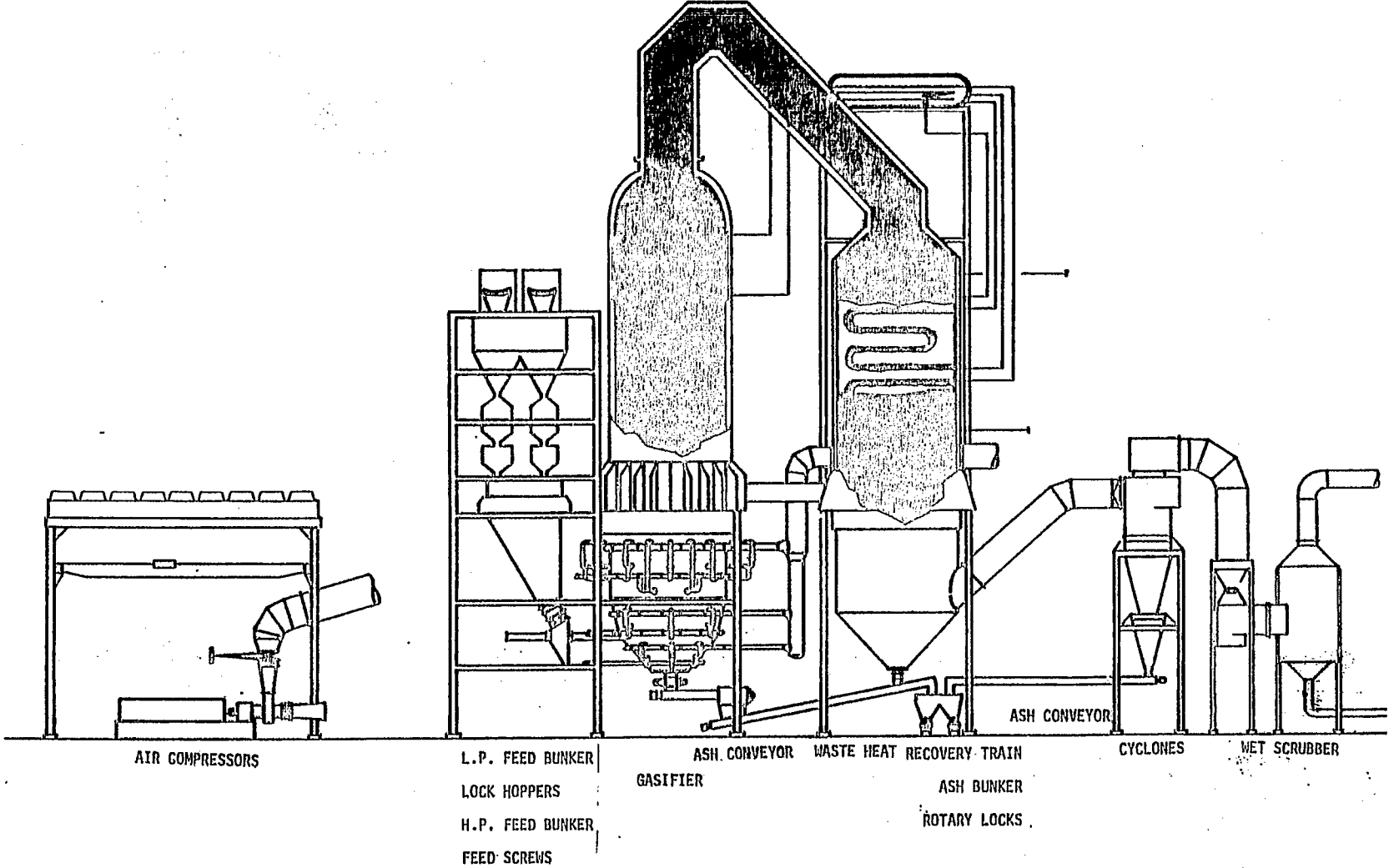
AIR COMPRESSORS

L.P. FEED BUNKER
LOCK HOPPERS
H.P. FEED BUNKER
FEED SCREWS

ASH CONVEYOR
GASIFIER

WASTE HEAT RECOVERY TRAIN
ASH BUNKER
ROTARY LOCKS

ASH CONVEYOR

CYCLONES

WET SCRUBBER

Figure C4.   Winkler Coal Gasifier Process Schematic

COAL GASIFICATION

WELLMAN-GALUSHA PROCESS

Low- and High-Btu Gas

BACKGROUND

Developer: Wellman Engineering Company

Status: Two units have been operated
                            commercially in the United
                            States on bituminous coal

CONCEPTUAL DESIGN   No Data Available.

Process Description

Coal gasifiers of the fixed-bed variety were once common in industrial complexes. One type that is now commercially available is Wellman-Galusha Generator shown schematically in Figure C5.

Crushed coal (3/16-5/16 in.) is dried and fed from the fuel bin by a lock-hopper system or through a rotary-drum feeder. A steam/oxygen mixture is introduced through a revolving grate at the bottom. Gasifiers are available with and without an agitator. The agitator producer has a slowly revolving horizontal arm which spirals vertically below the surface of the fuel bed. The agitator reduces channeling and maintains a uniform bed. The gasifier features internal jacketed side walls and a connecting overhead "steam dome" in which the steam needed for gasification is produced. The units built in the past were about 10 ft. in diameter.

The temperature of the gas leaving the gasifier is in the range of 1,000° to 1200°F depending on coal type. Pressure is about atmospheric. Ash is removed continuously through a slowly revolving eccentric grate at the reactor bottom.

Substitution of air for oxygen to the gasifier will produce a low-Btu raw gas. Raw gas leaving the gasifier is passed through a waste-heat-recovery system. Ash, which is carried over by gas, and tar are removed by scrubbing. The gas is then compressed. Pipeline quality gas can be produced by adding shift, purification, methanation, and dehydration.
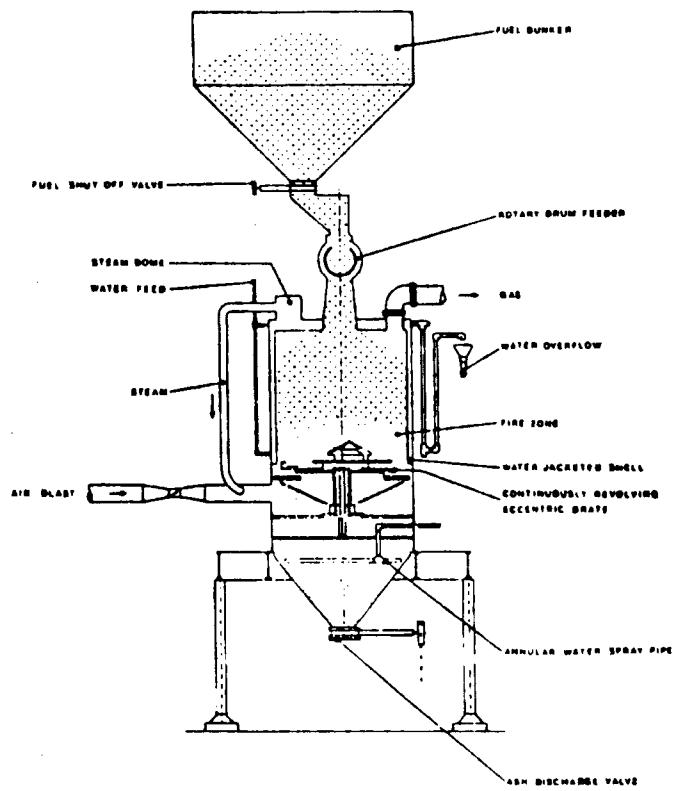
Figure C5. Wellman-Galusha Gasifier

COAL GASIFICATION

COMBUSTION ENGINEERING PROCESS

Low-Btu Gas

BACKGROUND

Sponsor:	ERDA Combustion Engineering Electric Power Research Institute
Developer:	Combustion Engineering
Contractor:	Combustion Engineering (Design, Construction and Operation of Process Demonstration Unit)
Contract Value:	ERDA - $15.0 million Others - $6.9 million
Status:	Detailed engineering and construction of the 5 tons of coal per hour process demonstration unit (PDU) is scheduled to be completed in spring 1977, and operations are expected to continue until mid-1978. PDU is located at Windsor, Connecticut.

CONCEPTUAL DESIGN   No Data Available

Process Description

The Combustion Engineering gasification process is based on an air-blown, atmospheric-pressure, entrained-bed gasifier. A schematic of the process is provided in Figure C6. Some pulverized coal and recycled char are fed to the combusiton section of the gasifier and burned to supply the heat necessary for the endothermal gasification reaction. In the combustion section, nearly all of the ash in the system is converted to molten slag, which is drawn off the bottom of the gasifier. The balance of the pulverized coal plus steam are fed to the reduction portion of the gasifier and are injected into the hot gases entering the reductor from the combustor. The gasification process takes place in the entrainment portion of the reactor where the coal is devolatized and reacts with the hot gases to produce the desired product gas. This 1,600°F product gas is cooled to 300°F. At this point, the gas contains solid particles and hydrogen sulfide that must be removed. Solids are removed and recycled by means of cyclone separators and venturi scrubbers. Hydrogen sulfide is removed and elemental sulfur is produced by the Stretford process. The clean low-Btu gas (127 Btu per standard cubic foot) can then be delivered to the burners of power boilers, gas turbines, or combinations of the two in a combined-cycle power generator.

Substitution of oxygen for air in the gasifier combustor will increase the heating value of product gas from 127 to 285 Btu per standard cubic feet of gas. The main virtue of the atmospheric gasification system is that development work is necessary on the operation and control of the gasifier only. All other components are commerically available items with predictable operating characteristics.
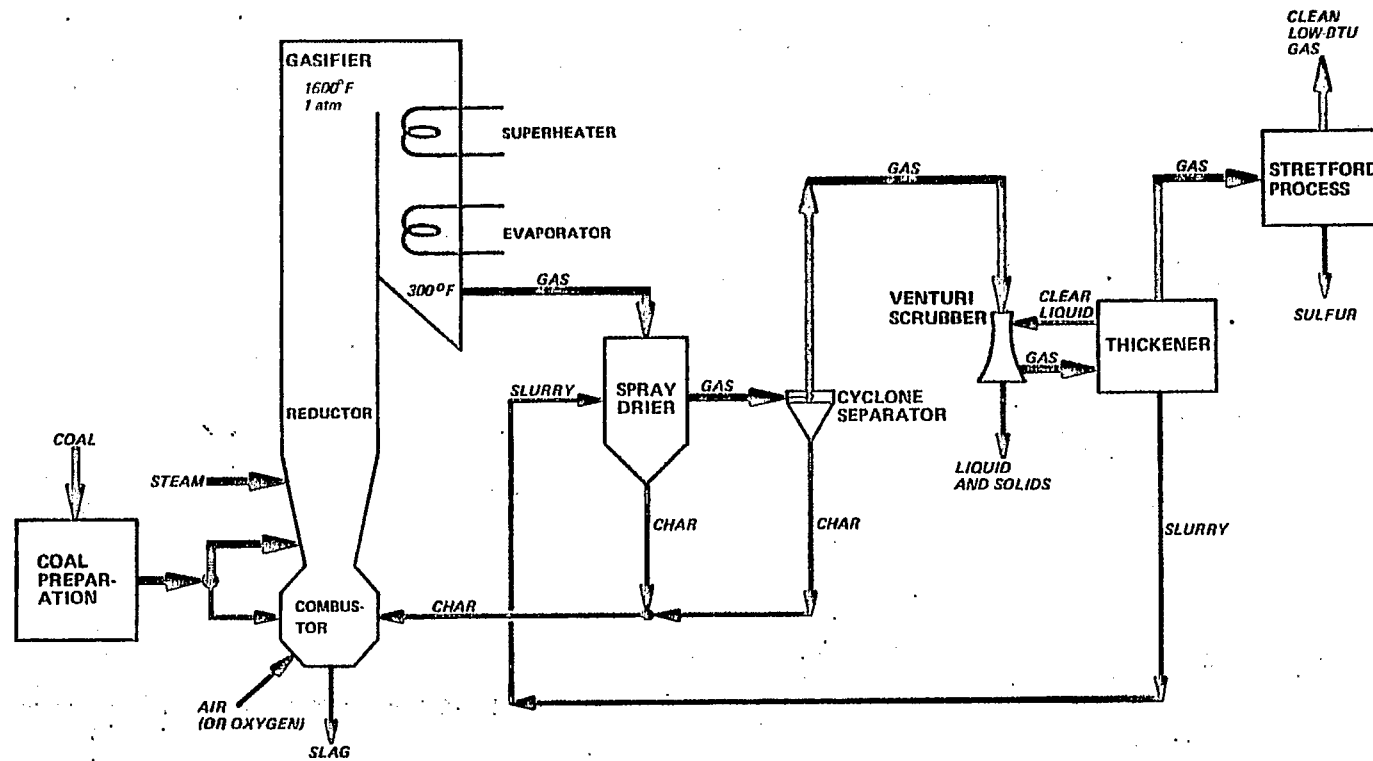
Figure C6. Low-Btu Gasification of Coal for Electricity Generation in the Combustion Engineering Process

COAL GASIFICATION

WESTINGHOUSE PROCESS

Low-Btu Gas

BACKGROUND

Sponsor:	ERDA Public Service Indiana Westinghouse Electric Corp. Amax Coal Company Bechtel, Inc. Peabody Coal Company/Kennecott Copper Corporation
Developer:	Westinghouse Electric Corp.
Contractor:	PDU Operated by Westinghouse Electric Corporation. Detailed Engineering, Design and Construction by Bechtel Corp.
Contract Value:	ERDA - $9.7 million Others - $4.2 million
Status:	Work is now under way with a 1,200 lb/hr process development unit. Design and construction of a 120 tons of coal per day pilot plant is scheduled for completion in 1977. The overall program is directed toward the operation of a combined-cycle power plant using a commercial-sized gasifier with a capacity of about 1,200 tons of coal per day. Plant is located at Waltz Mill, Pennsylvania. Public Service of Indiana has designated its Dresser Station, near Terre Haute, Indiana, as the site for the commercial plant.
Compatible Coal Types:	Not specified.

CONCEPTUAL DESIGN

No Data Available

Process Description

A schematic of the advanced coal gasification system for electric power generation is provided in Figure C7. The main reactor subsystems are the devolatizer/desulfurizer and the gasifier/agglomerator. Dry coal is introduced into the devolatizer through a central draft tube in which coal, hot gases, and recirculating char and dolomite flow upward at a velocity of 40 ft/sec. The hot solids recirculate downward in the annulus around the draft tube at weight rates of about 100 times the coal feed rate to prevent agglomeration of the fresh coal as it passes through its sticky phase. Dense dry char collects in the fluidized bed at the top of the draft tube and is withdrawn at this point. Dolomite or calcium oxide (sorbent) is added to the fluidized bed to absorb the sulfur present as hydrogen sulfide in the fuel gas. Spent dolomite is withdrawn from the bottom of the reactor and regenerated. Heat is supplied primarily by the high-temperature fuel gas produced in the gasifier-combustor. After separation of fines and ash, product gas is cooled and scrubbed with water for final purification.

Gasification of char produced in the devolatizer/desulfurizer is carried out in the gasifier/agglomerator. In the lower portion of the gasifier, char fines produced in the devolatizer are combusted with air to provide the basic heat source for the process. Product gases of CO_2 and steam are produced. In the upper portion of the gasifier, steam reacts with coarse char to form the CO and H_2 rich stream which goes to the devolatizer. The combustor, operating at about 2,100°F, also causes ash to reach its plastic stage, agglomerate, and fall out of the fluidized bed of char. It is removed at the bottom of the reactor.
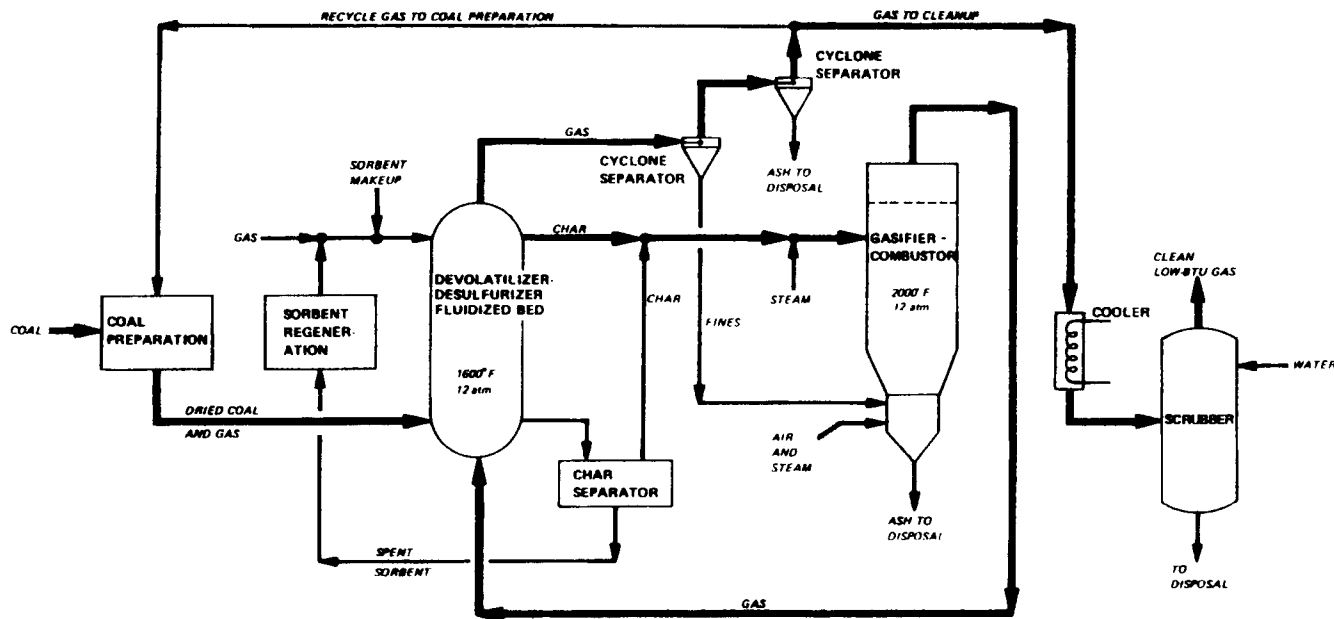
Figure C7. Advanced Coal Gasification System for Electric
Power Generation in the Westinghouse Process

APPENDIX D

HIGH-BTU GASIFICATION PROCESSES

Descriptions of the major high-Btu gasification process follow.

COAL GASIFICATION

LURGI PROCESS

High-Btu Gas

BACKGROUND

Developer: Lurgi Mineralotechnik g.m.b.h.

Announced Commercial and
   Demonstration Plants: Listing follows flow sheet
   (As of May 15, 1976)

CONCEPTUAL DESIGN

Plant producing 251 MSCFD
high-Btu gas

Coal Preparation

Coal Type: Navajo subbituminous

Coal Analyses:

Proximate, wt%		Ultimate (MAF), wt%	
Fixed carbon	35.0	Carbon	76.72
Volatile Matter	31.2	Hydrogen	5.71
Ash	17.3	Nitrogen	1.37
Moisture	16.5	Sulfur	0.95
		Oxygen	15.21

Heating Value, Btu/lb: 8872 (MAF)
                                   7340 (As Received)

Preparation: Coal is dried and ground
                                   to 1-3/4" x 3/16".
                                   Caking coals require
                                   pretreatment.

Feed System: Lock hopper

Gasification Reactor Description and Operating Conditions

Type: Counter-current moving bed

Temperature: Top: 1100-1400°F
                                           Bottom: 1700°F

Pressure: 420 psia

Input to Gasifier Reactor:

	lb/hr
Coal	1,722,200
Steam	1,762,200
Oxygen	468,500

Output from Gasifier Reactor:

Raw Dry Gas	lb/hr	Vol%
CO	535,500	19.5
H_2	76,500	5.0
CO_2	1,243,800	29.0
CH_4	174,000	11.2
H_2S	10,700	0.3
COS	-------	-----
N_2	8,800	0.3
Higher Hydrocarbons	28,900	0.9

By-Products	lb/hr
Ash	314,000
Tar & Oil	126,400
Phenols	10,100
NH_3	16,900
Hydrocarbon Liquids	18,400

Analysis of Net Dry Product Gas, Vol%

CH_4	95.9
H_2	0.8
N_2	1.2
CO_2	2.0
CO	0.1
H_2S+COS	

Heating Value: 972 Btu/SCF

Pressure: 915 psia

Analysis of Char, wt% Dry

   Not specified

 Heating Value:

Other Information

Net Process Water Consumption: 0.8 MGD

Type of Acid Gas Removal: Cold methanol (Rectisol)

Type of Sulfur Recovery: Stretford

Thermal Efficiency: 52.9-67.3%

Process Description

The Lurgi gasification process for high-Btu gas is shown in Figures D1 and D2. The Lurgi gasifier is classified as a high-pressure (300-500 psig), moving-bed, nonslagging steam-oxygen system producing synthesis gas from coal. The equipment consists of a double-walled pressure vessel whose walls form a water jacket to protect the outer pressure vessel wall from high reaction temperatures. Sized coal enters the top through a distributor and a mixture of steam and oxygen enters the bottom. Ash is discharged from the bottom of the reactor through a rotating grate into a lock hopper. Coal moving downward from the top of the reactor will be dried, devolatized, gasified, and oxidized in succession as the temperature increases.

Hot crude gas leaving the gasifier contains primarily carbon dioxide, carbon monoxide, hydrogen, and methane. To achieve the proper ratio of CO/H_2 for methanation, a portion of the crude gas is passed through a shift conversion unit. The converted gas and the bypass are then cooled to remove water and liquid by-products before gas purification. In gas purification, carbon dioxide and gaseous sulfur compounds are removed from the gas by the Rectisol process. The purified gas is then methanated to high-Btu product gas. The waste gas produced by Rectisol is treated by a Stretford unit to recover the by-product hydrogen sulfide as elemental sulfur.

The water and liquid by-products removed from the crude gas are further processed to recover tar, tar oil, crude phenol, ammonia, and water for use in the plant cooling system and other in-plant uses. Fuel requirements for the plant and process steam are provided by an air-blown coal-gasification unit which provides a clean, low-heating-value gas.
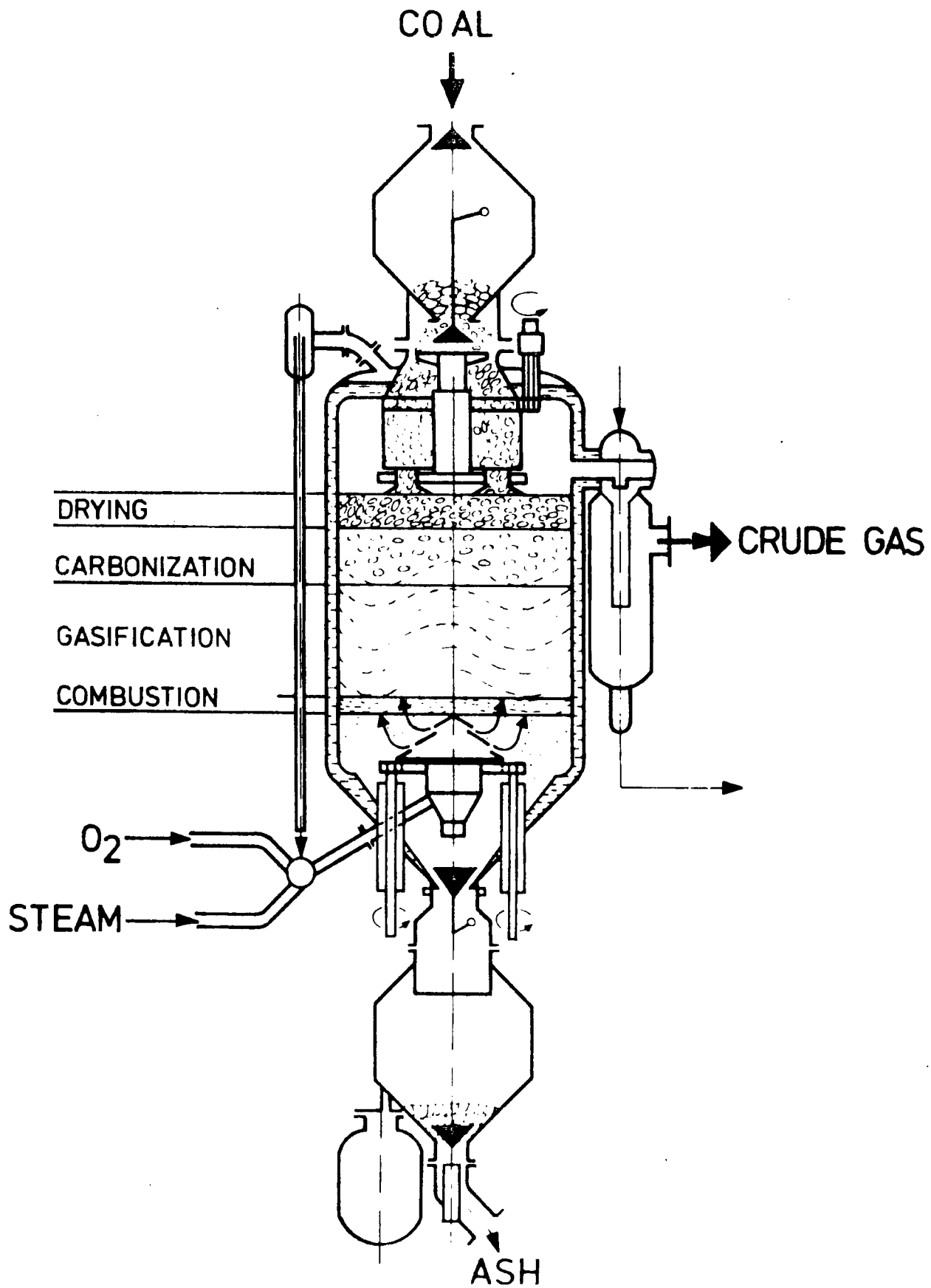
Figure D1.   Lurgi High-Btu Gasifier

Figure D2.   Lurgi High-Btu Gasification Process

COAL GASIFICATION

CARBON DIOXIDE ACCEPTOR PROCESS

High-Btu Gas

BACKGROUND

Sponsors: ERDA and AGA

Developer: Conoco Coal Development Company

Contractor: Conoco Coal Development Company

Contract Value: ERDA - $2.0 Million
$ M (Cost Share):   AGA - $1.0 Million

Status: A pilot plant is located in Rapid City,
                       South Dakota. The plant converts 40 tons
                       of coal daily into 500,000 SCFD of high-
                       Btu gas.

CONCEPTUAL DESIGN   (263 MSCFD high-Btu gas)

Coal Preparation & Storage Operation

Coal Type: Lignite

Coal Analysis:

Proximate, wt %		Ultimate (MAF), wt %	
Fixed Carbon	----	C	70.53
Volatiles	----	H	4.71
Ash	7.47	N	1.17
Moisture	33.67	S	1.00
		O	22.59

Heating Value, Btu/lb: 7375 (MAF)
                          6825 (As Received)

Pretreatment: Moisture content lowered to 5% in
                       fluidized preheater, coal ground to
                       less than 1/8"

Feed System: Lock Hopper

Gasifier Description & Operating Conditions

Type: Fluid bed
Temperature: 1500°F
Pressure: 150 psia
Input to Gasifier:

    Lignite: 1,413,400 lb/hr (0% moisture)
    Steam: 1,653,700 lb/hr
    Air: (For regeneration of acceptor)
                    3,373,400
    Dolomite:(Regenerated)
                    7,164,000 lb/hr

Main Output from Gasifier:

Raw dry gas from gasifier and quench:

CO	431,600 lb/hr
H_2	145,000 lb/hr
CO_2	308,500 lb/hr
CH_4	98,900 lb/hr
H_2S	1,142 lb/hr
COS	Not Reported
N_2	6,200 lb/hr
Higher Hydrocarbons	Not Reported

Other by-products from gasifier and quench:

Ash	See section below
Tar & Oil	-----------
Phenols	-----------
NH3	-----------
Hydrocarbon Liquids	-----------
Char	496,800 lb/hr

Char Analysis:

	wt %
C	63.41
H	0.54
O	2.26
S	0.97
N	0.25
Ash	32.57
Heating Value	9,450 Btu/lb

CO2 Acceptor Regeneration Section

Input to Regeneration Section

Char	496,810	lb/hr
Reacted acceptor	7,977,000	lb/hr
Air	44,500,000	SCFH
Dolomite makeup	254,454	lb/hr
CO_2	600,000	SCFH
Water	15,800	lb/hr

Output from Regeneration Section

Regenerated acceptor	7,164,000	lb/hr
Carbonated ash slurry (50% water)	466,000	lb/hr
Acid gas	450,000	SCFH
Flue gas	57,300,000	SCFH

Net Dry Product Gas Analyses:

Volume of Product Gas	263	MSCFD
Heating Value	972	Btu/SCF
Pressure of Product Gas	1000	psia

Gas Analysis (Volume%):

CH_4	93.0
H_2	4.8
N_2	0.8
CO_2	1.3
CO	0.1

Net Process Water Usage: 1.5 MGD

Type of Acid Gas Removal: ----------

Sulfur Recovery:

Type:	----------
Quantity Recovered:	9,920 lb/hr
Thermal Efficiency:	60.2%-76%

Process Description

In the carbon dioxide acceptor process (see Figure D3),
subbituminous coal is ground to 1/8 in., dried to 5%
moisture, and charged in a fluidized-bed preheater. The
preheated coal is then fed into the gasifier close to the
bottom of a fluidized bed of char. Rapid devolatization is
followed by gasification of the hydrocarbon. The necessary
heat for the endothermic gasification reactors is supplied
by the carbon dioxide acceptor reactor.

The manner in which an acceptor (limestone or dolomite)
is circulated between the gasifier and the regenerator to
supply this heat is the unique feature of the CO_2 acceptor
process. The acceptor, reduced to approximately 6x14
mesh, enters the gasifier above the fluidized char bed,
falls through the bed, and collects in the gasifier boot.
Hydrogasification-required steam enters through the boot
and the distributor ring, which is a sharp, stable interface
between the char and the char-acceptor mixture in the bed.
Dolomite, consumed at startup to avoid plugging, is replaced
by fresh acceptor once circulation rates are determined and
process operating temperature and pressure are reached.
Product gas passes through a steam-generating heat exchanger
and goes to the gas cleanup section.

The acceptor regenerator calcines the consumed acceptor.
Recarbonated acceptor from the gasifier flows through a
standleg and is conveyed pneumatically to the regenerator
bottom. Char, a product of gasification, is recycled to the
regenerator where it is burned in the presence of air.
The regenerator temperature is boosted to 1850°F. Due to
reversal of the carbon dioxide acceptor reaction, the acceptor
is calcined. The regenerated acceptor is returned to the
gasifier via a standleg. Flue gas from the regenerator
goes through a heat exchanger, generating steam for the
gasifier and the air compressor.

The flue gas from the regenerator and the product
gas are cleaned. The clean synthesis product gas is sent
to the methanation unit which consists of a shift converter,
a carbon dioxide absorber, hydrodesulfurizer, a zinc
oxide sulfur guard, and a packed-tube methanator. A
Dowtherm system is used for temperature control and heat
removal for the strongly exothermic methanation reaction.
The methanation process increases the heating value of the
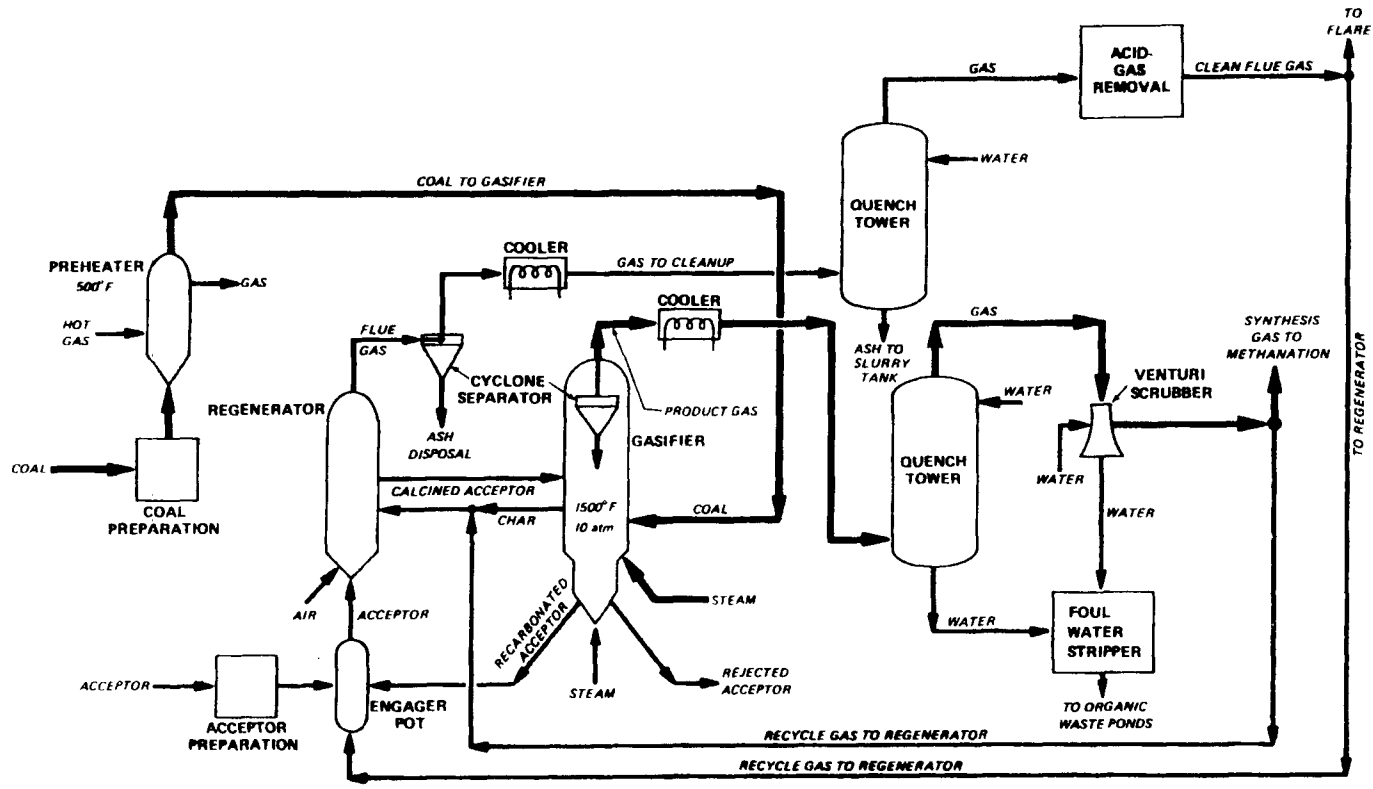gas to pipeline quality.

Figure D3.   CO$_2$ Acceptor Gasification Process

COAL GASIFICATION

HYGAS PROCESS

High-Btu Gas

BACKGROUND

Sponsor:	ERDA and the American Gas Association
Developer:	Institute of Gas Technology (IGT)
Contractor:	Institute of Gas Technology Pilot Plant Engineering and Construction by Procon Incorporated. Preliminary Engineering by Bechtel Corporation.
Contract Value:	ERDA - $29.2 million Others - $10.1 million
Status:	75 tons/day pilot is currently being operated by IGT. Steam-oxygen system complete, Fiscal '76. Preliminary demonstration plant design complete. Plans have been announced to build an $18 million pilot plant facility to demonstrate the steam-iron process for H_2 generation. Pilot plant located in Chicago, Illinois.
Compatible Coal Types:	Bituminous, Subbituminous, and Lignite.

CONCEPTUAL DESIGN

Plant producing 260 MSCFD high-Btu gas

Coal Preparation

Coal Type: Bituminous, Illinois No. 6

Coal Analyses:

Proximate, wt%		Ultimate (MAF), wt%	
Fixed Carbon	46.52	Carbon	78.45
Volatile Matter	30.36	Hydrogen	5.43
Ash	10.79	Nitrogen	1.53
Moisture	6.48	Sulfur	4.75
		Oxygen	9.85

Heating Value, Btu/lb: 12600 (MAF)
                                    11240 (As Received)

Preparation: Coal is dried to 1 to 2
                                    percent moisture and
                                    ground to less than
                                    8 mesh

Feed System: Coal-oil slurry

Gasification Reactor Description and Operating Conditions

Type: Fluidized bed, 4 sections

Temperature:

Section	°F
Top	600
2nd	1250
3rd	1750
Bottom	1900

Pressure: 1200 psia

Input to Gasifier Reactor:

	lb/hr
Coal	1,057,900 (0% moisture)
Steam	981,700
Oxygen	270,300

Output from Gasifier Reactor:

Raw Dry Gas	lb/hr	Vol%
CO	650,100	28.5
H_2	48,300	29.6
CO_2	763,800	21.3
CH_4	244,200	18.7
H_2S	43,300	1.6
COS	700	0.01
N_2	1,700	0.11
Higher Hydrocarbons	15,100	0.23

By-Products	lb/hr
Char	138,900
Tar & Oil	-------
Phenols	1,300
NH_3	11,300
Hydrocarbon Liquids	39,800

Analysis of Net Dry Product Gas, Vol%

CH_4	93.0
H_2	6.6
N_2	0.2
CO_2	0.1
CO	0.1

Heating Value: 965 Btu/SCF

Pressure: 958 psia

Analysis of Char, wt% Dry

Not specified

Heating Value: :   1,488 Btu/lb

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Other Information

Net process water consumption:

Hydrogen Generation Process	MGD
Steam/Iron	3.0
Steam/Oxygen	1.8

Type of acid gas removal: Cold methanol (Rectisol)

Type of sulfur recovery: Claus

Thermal efficiency: 60.3 - 70.5%

Process Description

A diagram of the HYGAS process is provided in Figure D4.
Raw coal is crushed, dried, and pretreated (in case of caking
coals) at 660°F to 750°F and atmospheric pressure. Prepared
coal is mixed in a slurry tank with light aromatic oil
recovered in the process. Noncaking coal is fed directly to
the slurry tank. The coal-oil slurry is pumped by a centri-
fugal pump to 100 atm and then sprayed into the light
oil vaporizer section of the gasifier, where most of the
light oil flashes off and is recovered downstream and
returned to the process. The coal passes to the next stage
operated at 1300 to 1500°F where approximately 20 percent
of coal is converted to methane by the hot gas from the
bottom stage of the hydrogasifier. Part of the devol-
atized char is hydrogasified with hydrogen and steam at
1700°F. An additional 25 percent of the initial coal is
converted to methane in this hydrogen-rich environment.
Char produced from the hydrogasifier is used for hydrogen
production in one of three alternate processes:
Electrothermal, Steam-Oxygen, or Steam-Iron. (Development
work on the Electrothermal Process has been terminated due to
the high cost of electricity.) The product gas (containing
methane and other raw gases, particulates, trace elements,
and water and oil vapors) from the reactor is quenched,
purified, and passed to the methanator. The ratio of hydrogen
to carbon monoxide in the purified gas entering the methanator
is adjusted to about three to one. The purified gas passes
through a nickel catalyst methanation reactor at controlled
temperature and is converted to pipeline-quality gas with an
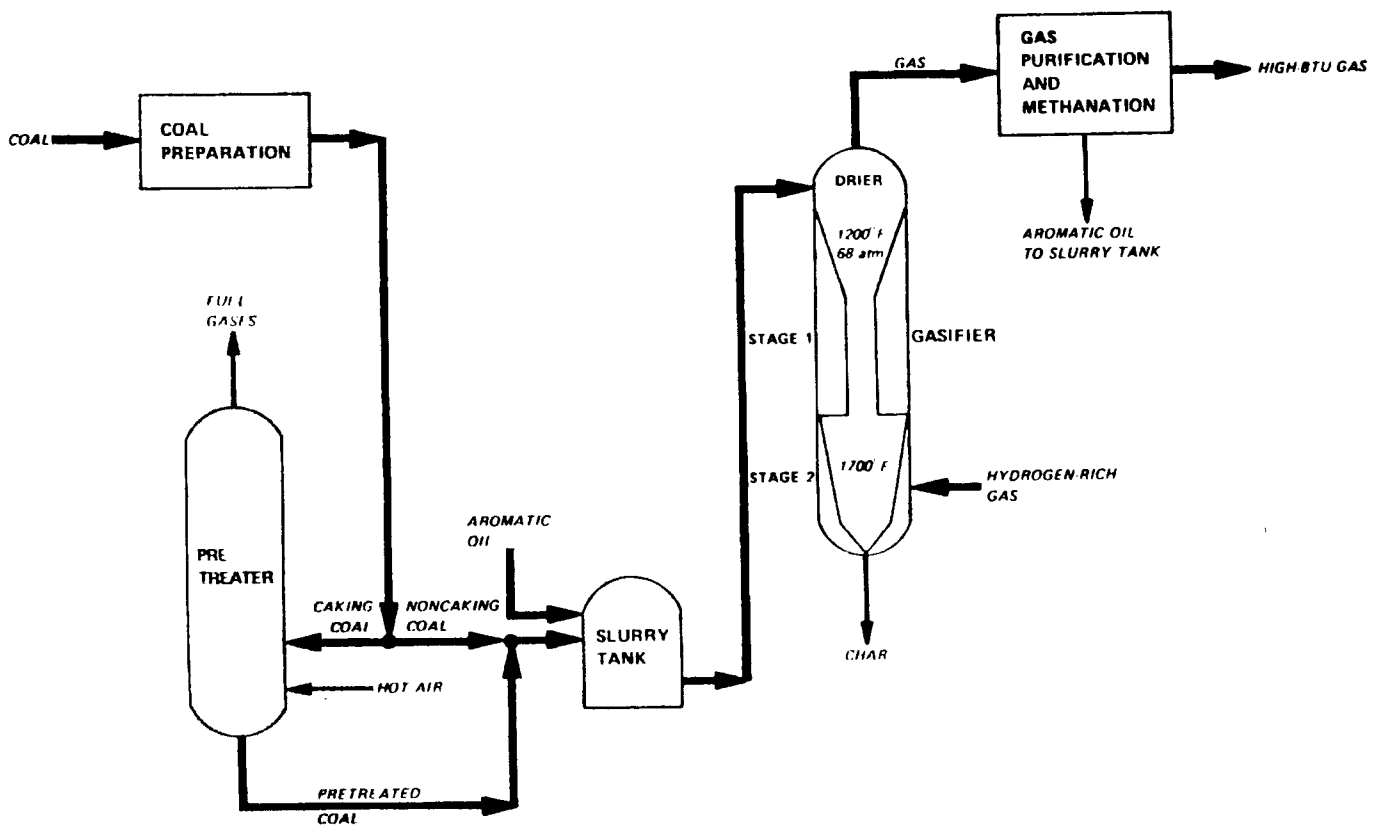average heating value of 965 Btu per cubic foot.

Figure D4.   HYGAS Process

COAL GASIFICATION

BIGAS PROCESS

High-Btu Gas

BACKGROUND

Sponsor: ERDA and American Gas
                            Association

Developer: Bituminous Coal Research, Inc.

Contractor: Project managed by Phillips
                            Petroleum Company. Respon-
                            sibility of constructing and
                            operating the pilot plant
                            awarded to Stearns-Roger,
                            Inc. Gasifier designed and
                            built by Babcock and Wilcox.

Contract Value: ERDA - $58.1 million
                            Others - $11.5 million

Status: 120 tons/day pilot plant was
                            scheduled for completion by
                            the second quarter of 1976.
                            Located in Homer City,
                            Pennsylvania.

Compatible Coal Types: Bituminous, Subbituminous,
                            and Lignite

CONCEPTUAL DESIGN   Plant producing 250 MSCFD
                            high-Btu gas

Coal Preparation

Coal Type: Bituminous, Western Kentucky No. 11

Coal Analyses:

Proximate, wt %		Ultimate (MAF), wt %	
Fixed Carbon	45.4	Carbon	80.20
Volatile Matter	39.5	Hydrogen	5.50
Ash	6.7	Nitrogen	1.62
Moisture	8.4	Sulfur	4.10
		Oxygen	8.58

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Heating Value, Btu/lb	12330 (MAF)
	11500 (As Received)
Preparation:	Coal is dried to 2 percent moisture and ground to 70 percent less than 200 mesh
Feed System:	Coal-water slurry

Gasification Reactor Description and Operating Conditions

Type:	Top Entrained
	Bottom Slagging
Temperature:	Top 1700°F
	Bottom 3000°F
Pressure:	1200 psia

Input to Gasifier Reactor:

	lb/hr
Coal	946,300 (1.3% moisture)
Steam	409,700
Oxygen	497,600

Output from Gasifier Reactor:

Raw Dry Gas	lb/hr	Vol %
CO	1,024,300	43.5
H_2	40,900	24.5
CO_2	512,300	14.0
CH_4	207,300	15.5
H_2S	40,600	1.4
COS	-------	----
N_2	15,300	0.6
Higher Hydrocarbons		

By-Products	lb/hr
Ash	68,400
NH_3	7,700
Tar and Oil	------
Phenols	------
Hydrocarbon Liquid	------

Analysis of Net Dry Product Gas, vol %

CH_4	91.8
H_2	5.1
N_2	1.9
CO_2	1.1
CO	0.1
H_2S+SO_2	----

Heating Value: 943 Btu/SCF

Pressure: 1075 psia

Analysis of Char, wt % Dry

Not Specified

Heating Value: --------

Other Information

Net process water consumption: 1.5 MGD

Type of acid gas removal: Hot carbonate (Benfield)

Type of sulfur recovery: Claus

Thermal efficiency: 61.8-66.8%

Process Description

The BIGAS process is a two-stage, high-pressure, oxygen-blown system using pulverized coal and steam in entrained flow. A diagram of the BIGAS process is provided in Figure D5. Basically, there are four major steps in the process: coal preparation, slurry preparation, gasification, and gas purification and methanation.

Coal preparation consists of pulverizing the coal so that approximately 70 percent will pass through 200 mesh. Both particle size and particle size distribution can vary, however. The coal, mixed with water, is fed to a centrifuge, where the solids are concentrated into a cake of 50 to 60 percent solids. The cake is then slurried in the blend tank to the consistency used in the process and the slurry is contacted with hot inert recycle gas for nearly instantaneous vaporization of the surface water. The coal is conveyed to a cyclone separator by the stream of water vapor and inert gas, then to the gasifier. The inert gas is recovered, reheated, and recycled. As the coal is conveyed from the cyclone to the gasifier, it is fluidized by gas recycled from the methanator.

The coal enters the gasifier through injector nozzles near the throat separating Stage 1 and Stage 2. Steam is introduced through a separate annulus in the injector. The two streams combine at the top and join the hot synthesis gas rising from Stage 1. A mixing temperature of about 2,200°F is attained rapidly and the coal is converted to methane, additional synthesis gas, and char. The raw gas and char rise through Stage 2, leave the gasifier at about 1,700°F, and are quenched to 800°F by atomized water prior to separation in a char cyclone. The raw gas (containing methane, carbon monoxide, carbon dioxide, hydrogen, water, and hydrogen sulfide) passes through a scrubber for additional cooling and cleaning. The clean gas, along with the desired amount of moisture, is sent to a carbon monoxide shift converter to establish the proper ratio of carbon monoxide and hydrogen required in the methanation process. Gas from the shift converter is purified to remove H_2S and CO_2 and then methanated to produce pipeline gas.
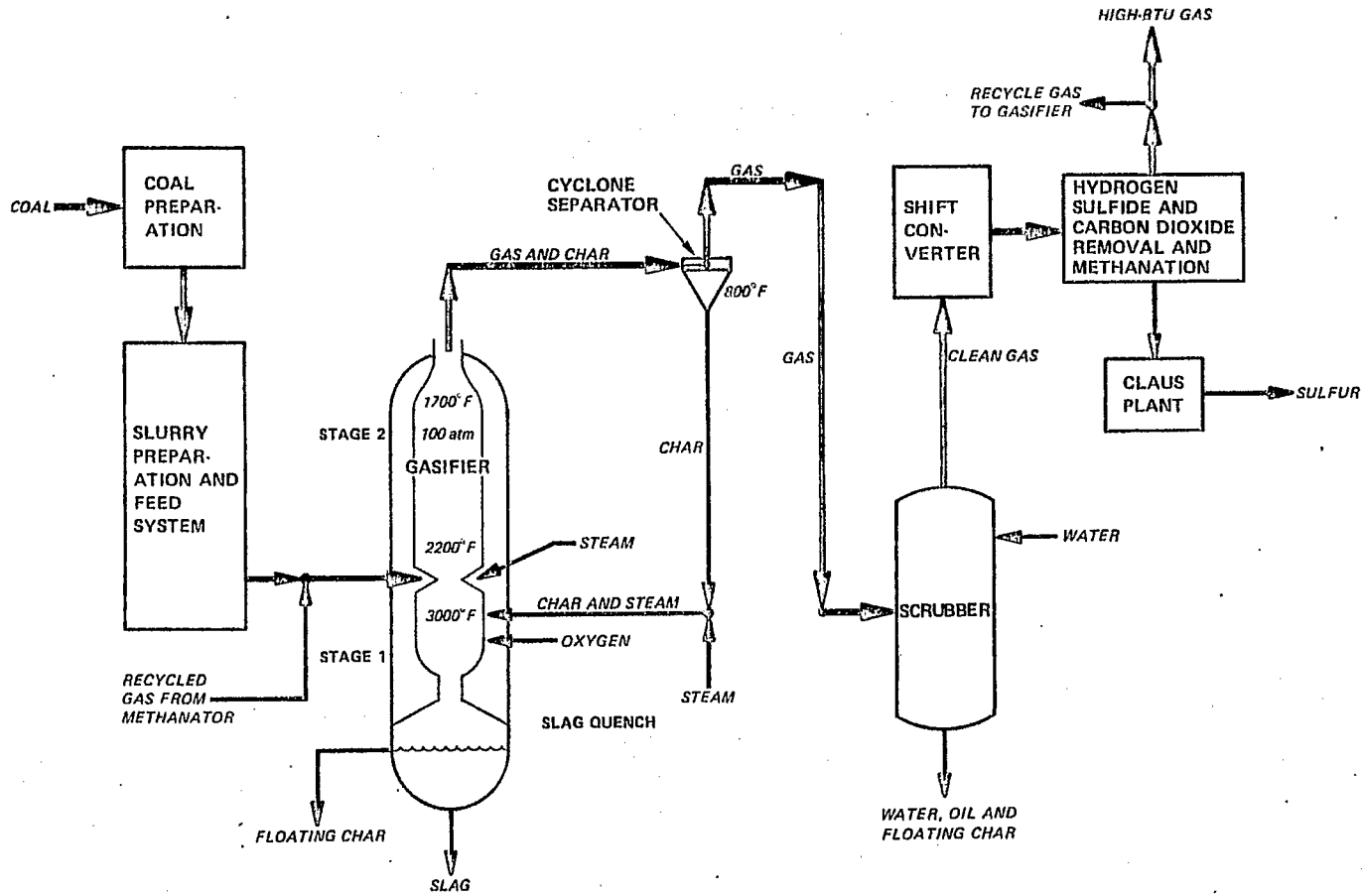
Figure D5. BIGAS Process

COAL GASIFICATION

SYNTHANE PROCESS

High-Btu Gas

BACKGROUND

Sponsor:	ERDA
Developer:	Pittsburgh Energy Research Center
Contractor:	Rust Engineering/Lummus Corp. Designed, Engineered, and Operated by C-E Lummus. Field Construction by Rust Engineering
Contract Value:	$9.6 million
Status:	75 tons/day pilot plant in operation. Located in Bruceton, Pennsylvania.
Compatible Coal Type:	Bituminous, Subbituminous, and Lignite

CONCEPTUAL DESIGN

Plant producing 250 MSCFD high-Btu gas

Coal Preparation

Coal Type: Bituminous, Pittsburgh Seam

Coal Analyses:

Proximate, wt %		Ultimate (MAF), wt %	
Fixed Carbon	32.3-38.7	Carbon	81.9
Volatile Matter	49.2-59.4	Hydrogen	5.8
Ash	7.4	Nitrogen	1.7
Moisture	2.5	Sulfur	1.8
		Oxygen	8.9

Heating Value, Btu/lb: 13700 (MAF)
                                      12690 (As Received)

Pretreatment: Coal is dried to 1.5 to
                                      2 percent moisture and
                                      ground to 70 percent less
                                      than 200 mesh

Feed System: Lock hopper

Gasification Reactor Description and Operating Conditions

Type: Fluidized bed

Temperature: Top   800°F
                                      Bottom   1700°F

Pressure: 100 psia

Input to Gasifier Reactor:

                          lb/hr

        Coal   1,187,500 (2.5% moisture)
        Steam   1,169,700
        Oxygen   304,000

Output from Gasifier Reactor

Raw Dry Gas	lb/hr	Vol %
CO	320,000	16.7
H_2	38,200	28.0
CO_2	871,000	29.0
CH_4	268,000	24.6
H_2S	12,200	0.5
COS	-------	----
N_2	16,000	0.8
Higher Hydrocarbons	15,000	0.3

By-Products	lb/hr
Char	362,200
Tar and Oil	43,200
Phenol	-------
NH_3	13,200
Hydrocarbon Liquids	7,400

Analysis of Net Dry Product Gas, vol %

CH_4	90.5
H_2	3.6
N_2	2.1
CO_2	3.7
CO	0.1
H_2S+SO_2	-----

Heating Value: 927 Btu/SCF

Pressure: 100 psia

Analysis of Char, wt % Dry

Carbon	71.4
Hydrogen	0.9
Nitrogen	0.5
Sulfur	1.5
Oxygen	1.8
Ash	23.9

Heating Value: 11,000 Btu/lb

Other Information

Net process water consumption: 1.0 MGD

Type of acid gas removal: Hot carbonate (Benfield)

Type of sulfur recovery: Stretford

Thermal efficiency: 59.3-66.0%

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Process Description

A schematic of the Synthane process is provided in Figure D6. Crushed, dried, and pressurized coal is fed to the fluidized-bed pretreater (in case of caking coals) through a lock-hopper system. It is pretreated with steam and oxygen at 800°F where it is partially devolatized and its caking tendency destroyed.

The pretreated coal overflows from the pretreater into the two-zone gasifier, which consists of a dense fluid bed at an expanded top section and a dilute fluid bed at a contracted bottom section. By contacting the coal with hot gas coming from the dilute fluid bed, devolatization and hydrogasification take place at 1100 to 1470°F and 1000 psia. The devolatized coal from the dense fluid bed is gasified with steam and oxygen in the dilute fluid bed at 1750 to 1800°F to produce synthesis gas for the dense fluid bed. Steam and oxygen enter the gasifier just below the fluidizing gas distributor. Unreacted char flows downward into a bed fluidized with steam and water sprays, and is removed by pressurized lock hoppers. This char can be used to produce process steam.

The product gas, containing methane, hydrogen, carbon monoxide, carbon dioxide, ethane, and impurities, is passed through an oil venturi scrubber and a water scrubber to remove carry-over ash, char, and tars. The cleaned gas goes to a shift converter, where the ratio of H_2 to CO is adjusted to a value of 3:1. Gas from the shift converter is purified to remove CO_2 and H_2S and then methanated and dehydrated to produce pipeline gas. Two alternative methanation systems are being investigated: the hot gas recycle system and the tube wall reactor system.
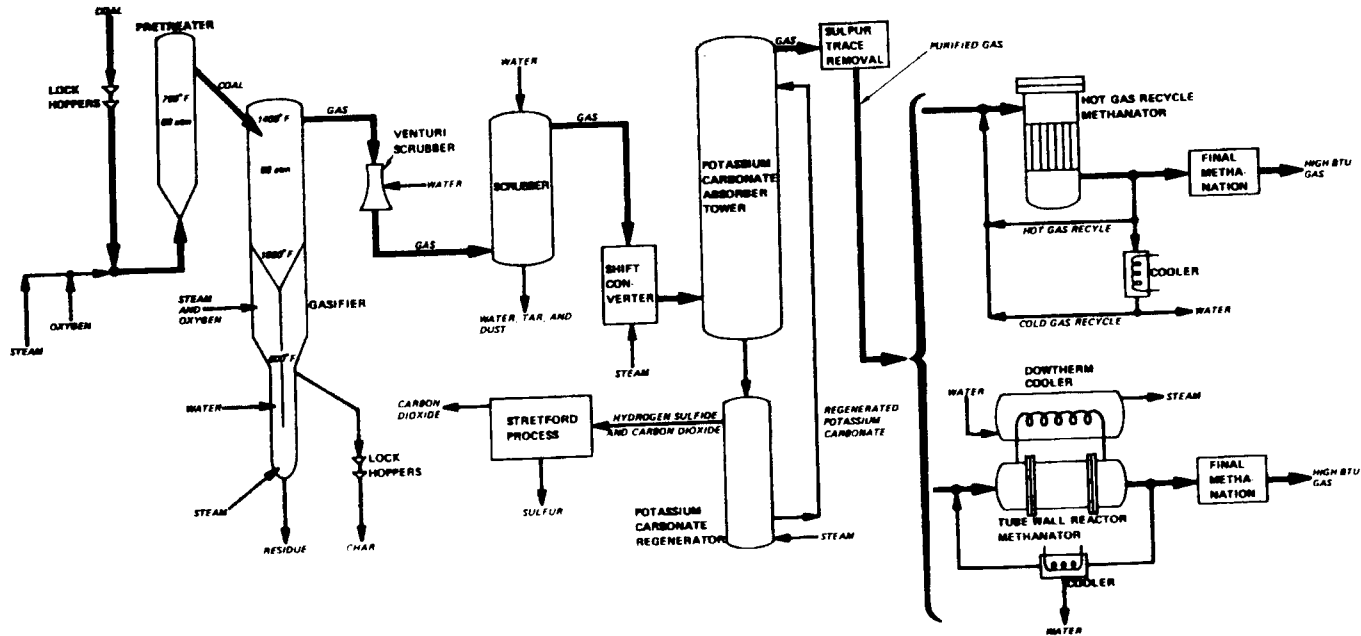
Figure D6.   SYNTHANE Process

COAL GASIFICATION

HYDRANE PROCESS

High-Btu Gas

BACKGROUND

    Sponsor: ERDA

    Developer: Pittsburgh Energy Research
                        Center

    Status: 26 tons/day process
                        development unit is being
                        designed and construction is
                        planned at Morgantown, West
                        Virginia

CONCEPTUAL DESIGN   No Data Available

Process Description

The Hydrane flow sheet is shown in Figure D7. Crushed raw coal is fed to a two-zone hydrogenation reactor operated at 1000 psig and 1650°F. In the top zone, the coal falls freely as a dilute cloud of particles through a hydrogen-rich gas containing some methane from the lower zone. About 20 percent of the carbon in the raw coal is converted to methane, causing the coal particles to lose their volatile matter and agglomerating characteristics. The coal is now essentially a char. This char falls into the lower zone where hydrogen feed gas maintains the particles in a fluidized state and also reacts with about 34 percent more of the carbon to make methane. The product gas exits from the center of the reactor and is cleaned of entrained solids and some unwanted gases. After cleanup, methanation of the small amount (2 to 5 percent) of residual carbon monoxide gives a pipeline quality, high-Btu, substitute natural gas. Char from the lower zone of the hydrogasifier is reacted with steam and oxygen to make the needed hydrogen.
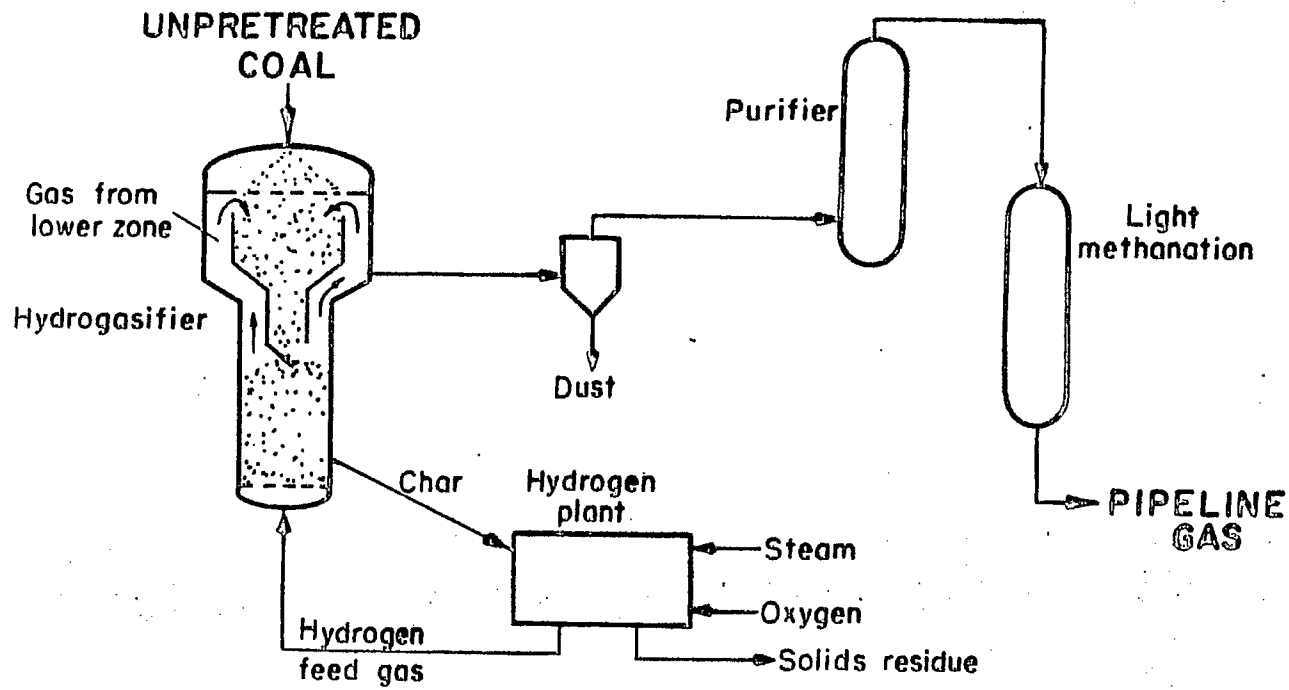
Figure D7.   HYDRANE Process

COAL GASIFICATION

AGGLOMERATING BURNER PROCESS

High-Btu Gas

BACKGROUND

Sponsor:	ERDA and the American Gas Association
Developer:	Battelle Memorial Institute
Contractor:	Pilot Plant Installation and Operation by Battelle. Engineering, Design, and Construction by Chemical Construction Corporation (Chemico)
Contract Value:	ERDA - $7.2 million Others - $1.6 million
Status:	25 tons/day pilot plant located at West Jefferson, Ohio. Gas purification, shift conversion, and methanation of the product gas are not part of the present program.

CONCEPTUAL DESIGN   No Data Available

Process Description

The flowsheet for the Agglomerating Burner process is shown in Figure D8. Coal is separated into two sizes (1-100) mesh for use in burner and -8+100 mesh for use in gasifier) and is dried. Caking coal is fed to a fluidized-bed pretreater where it is mixed with gas and air at atmospheric pressure at 750°F. Treated coal is cooled, fed to the steam fluidized-bed gasifier, then burned with air in a fluidized-bed burner, in a manner allowing agglomeration of the ash at a temperature approaching the ash fusion point (2100°F). The hot flue gases produced in the burner are free of fly ash and can be expanded in a gas turbine for energy recovery.

Hot ash agglomerates are transferred continuously from the burner to the gasifier by means of a steam lift. Superheated steam enters the gasifier below the distributor plate. Coal is fed through the lock hoppers by inert gas and is contacted with hot ash agglomerates (200°F) from the burner. The sensible heat is utilized from the gasification reaction. Raw gas from the gasifier is sent to a cleanup section. The unreacted char is transferred together with cool-ash agglomerates (1500°F) to the burner where the char is burned with air and ash agglomerates are heated to 2000°F. Ash equivalent to the ash content of the coal fed to the burner is removed from the system continuously to maintain a constant quantity of ash agglomerates in the cycle.

Figure D8. Agglomerating Burner Process

COAL GASIFICATION

KELLOGG MOLTEN SALT PROCESS
High-Btu Gas

BACKGROUND

Sponsor:	ERDA (1964-1967)
Developer:	M. W. Kellogg Company
Contractor:	M. W. Kellogg Company
Status:	OCR (now ERDA) funded a bench-scale program from 1964-1967. Major difficulties were experienced with materials of construction. OCR ceased sponsorship for this reason, budgetary restrictions, and assignment of higher priorities to other coal gasification processes. M. W. Kellogg has carried additional development since 1967, but no support has yet been obtained for construction of a large-scale pilot plant.

CONCEPTUAL DESIGN   No Data Available

Process Description

The block diagram of the single-vessel coal gasification
process is shown in Figure D9. Coal is crushed to pass through
12 mesh and pressurized in lock hoppers. It is then fed to
the gasifier by a stream of preheated oxygen and steam
along with recycle sodium carbonate recovered from the ash
rejection system. The coal-steam reaction conditions are
1700°F and 1200 psi. The coal-steam reaction is catalyzed
by the molten salt contained in the reactor so that gas
free of tar, with an appreciable methane content is produced.
The heat required for the coal-steam reaction is provided
by oxidation of a portion of the coal with oxygen in the
reactor. A bleed stream of molten salt containing ash
in suspension is withdrawn from the bottom of the gasifier and
is contacted with water to dissolve the sodium carbonate.
Ash is separated by filtration and the carbonate solution is
treated to precipitate bicarbonate. The bicarbonate is
filtered out and heated to restore the carbonate salt which
is then recycled to the gasifier.

Raw gas leaving the gasifier passes through a heat recovery
section and any entrained salt is removed. It further
passes through the shift conversion unit, where the H_2 to
CO ratio is properly adjusted. Effluent gas from shift
conversion is purified, methanated, and dehydrated to
produce pipeline quality gas.
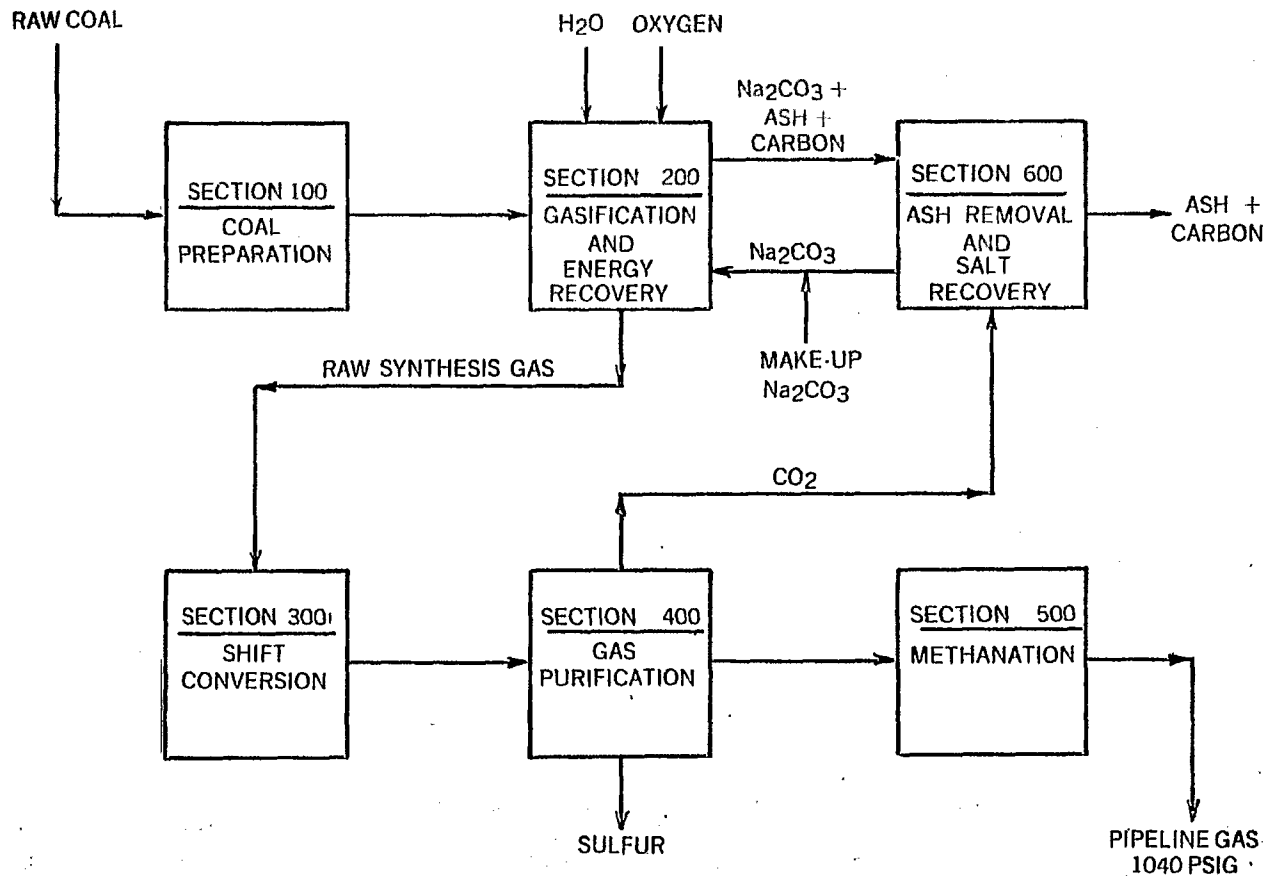
Figure D9. M.W. Kellogg's Molten Salt Process

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APPENDIX E

PYROLYSIS AND HYDROCARBONIZATION LIQUEFACTION PROCESSES

Descriptions of the major pyrolysis and hydrocarbonization processes follow.

COAL LIQUEFACTION

CHAR OIL ENERGY DEVELOPMENT (COED) PROCESS

BACKGROUND

Sponsor:	ERDA
Developer:	FMC Corporation
Contractor:	FMC Corporation
Contract Value:	$21 Million
Status:	36 tons/day pilot plant operation completed. Located in Princeton, New Jersey.
Compatible Coal Types:	Bituminous, Subbituminous, and Lignite

----

CONCEPTUAL DESIGN

Plant producing 328,800 lb/hr of Syncrude

Coal Preparation Operation

Coal Type: Bituminous, Illinois #6

Coal Analyses:

Proximate, %		Ultimate (MAF), %	
Fixed Carbon	44.0	Carbon	75.5
Volatiles	32.0	Hydrogen	6.0
Ash	10.0	Nitrogen	1.2
Moisture	14.0	Sulfur	4.6
		Oxygen	13.2

Heating Value, Btu/lb: 11300 (MAF)
10170 (As Received)
12420 (5.9% Moisture)

Preparation: Coal is dried to 5.9 percent moisture and ground to less than 16 mesh (minimum fines)

Feed System: Mechanical feeders to a mixing tee from which it is blown into dryer and first stage pyrolysis

Liquefaction Description and Operating Conditions

Type of Process: Fluidized-bed pyrolysis

Number of Reactors: Two sets of four reactors

Dimensions: 60'-70' in diameter

Reactor Temperature: Stage 1   550-600°F
                          Stage 2   850°F
                          Stage 3   1050°F
                          Stage 4   1550°F

Reactor Pressure: 8 psig

Cooling Mechanism: Cooling tower, 3 MGD

Input to Liquefaction Reactor:

    Coal   2,126,000 lb/hr (5.9% moisture)
    Steam   507,200 lb/hr
    Natural Gas   48,600 lb/hr*
    Combustion Air   732,000 lb/hr
    Oxygen   313,000 lb/hr
    Transport gas   94,100 lb/hr

Output from Liquefaction Reactor:

    Raw Product: 2,174,500 lb/hr
    Char   1,042,600 lb/hr
    Gas   732,000 lb/hr
    Water   187,000 lb/hr

  *Does not include 288,500 lb/hr gas recycled through
   char cooler

Hydrotreating Process:

Type of process: Three sections, downflow

Input to Hydrogen Production:

    Product Oil: 371,800 lb/hr
    Hydrogen Makeup: 56,800 lb/hr
    Stripping Gas: 205,600 lb/hr
    Fuel Gas: 167,000,000 Btu/Hr

Output from Hydrogen Production:

    Liquid Products: 328,800 lb/hr
    Sour Gas: 58,000 lb/hr
    Stripping Gas: 214,000 lb/hr
    Sour Water: 33,200 lb/hr
    Flue Gas   Not Specified

Hydrogen Production

Type of Process: Steam reforming of natural gas

Input to Hydrogen Production

Mixture of clean product gas and hydrotreater off-gas	108,000 lb/hr
Net Water Consumption	86,000 lb/hr
Fuel Gas	46,000 lb/hr
Air	------------

Output from Hydrogen Production:

Hydrogen	56,800 lb/hr
Steam	------------
Flue Gas	------------
Water	------------

Overall Output from COED Process

Liquid Product	328,800 lb/hr
Char	1,042,600 lb/hr
Gas	732,000 lb/hr
Water	187,000 lb/hr
Sulfur	42,500 lb/hr

Analysis of Liquid Product, (wt %)

Carbon	87.1%
Hydrogen	10.9%
Nitrogen	0.3%
Oxygen	1.6%
Sulfur	0.7%
Ash	0.1%
Moisture	0.1%

Heating Value (Approximate):   19,000 Btu/lb

Analysis of Char, (wt % Dry)

Carbon	73.8
Hydrogen	0.8
Nitrogen	1.0
Sulfur	3.2
Oxygen	0.0
Ash	21.2

Heating Value: 11,700 Btu/lb

Other Information:

Net Process Water Consumption: Not specified

Type of Acid Gas Removal: Primary - (H_2S+CO_2)
                                         hot carbonate
                                        Secondary - (CO_2 only)
                                         not specified

Type of Sulfur Recovery: Claus

Thermal Efficiency: 57.6-72.2%

Process Description

The COED (Char Oil Energy Development) process reacts coal
in multistage fluidized beds producing gas, oil, and char (see
Figure E1). Initially the coal is crushed and dried. Pyrolysis
then occurs in a four-stage reactor. Each successive stage
operates at a higher temperature. Each temperature is
slightly lower than the temperature at which the coal
type agglomerates. The fuel to heat the reactors
originates in the fourth stage of the reactor where char
is burned with oxygen in the presence of steam. The
heated gases leave the fourth stage and flow countercurrently
to the char.

After acting as the fluidizing medium for the second and
third pyrolysis stages, the hot gases are sent to the
product recovery system. Gas and oil are recovered from
vapors leaving the second stage. A cyclone is utilized
to remove fines from the vapors. The vapors are then
quenched with water in a venturi scrubber, condensing the
oil. The gases and oils then are separated in a decanter.

After desulfurization, part of the product gas is converted
to hydrogen and recycled to the process. The remainder
is either sold as fuel gas or converted to pipeline gas or
hydrogen.

The decanted oil is dehydrated and filtered in a rotary
pressure precoat filter. The oil is pressurized and
hydrotreated in a fixed-bed catalytic reactor. The
hydrotreater removes nitrogen, sulfur, and oxygen by
reacting with hydrogen to produce ammonia, hydrogen
sulfide, and water.

Sulfur is removed from the char in a shaft kiln. Hydrogen
added to the kiln reacts with the char to produce hydrogen
sulfide. The hydrogen sulfide is then adsorbed by an
acceptor such as calcined limestone or dolomite. The
acceptor, which can be regenerated, is separated from the
char in a continuous fluidized separator. The product
char can be reacted in a gasifier with steam and oxygen
to make low-Btu gas.
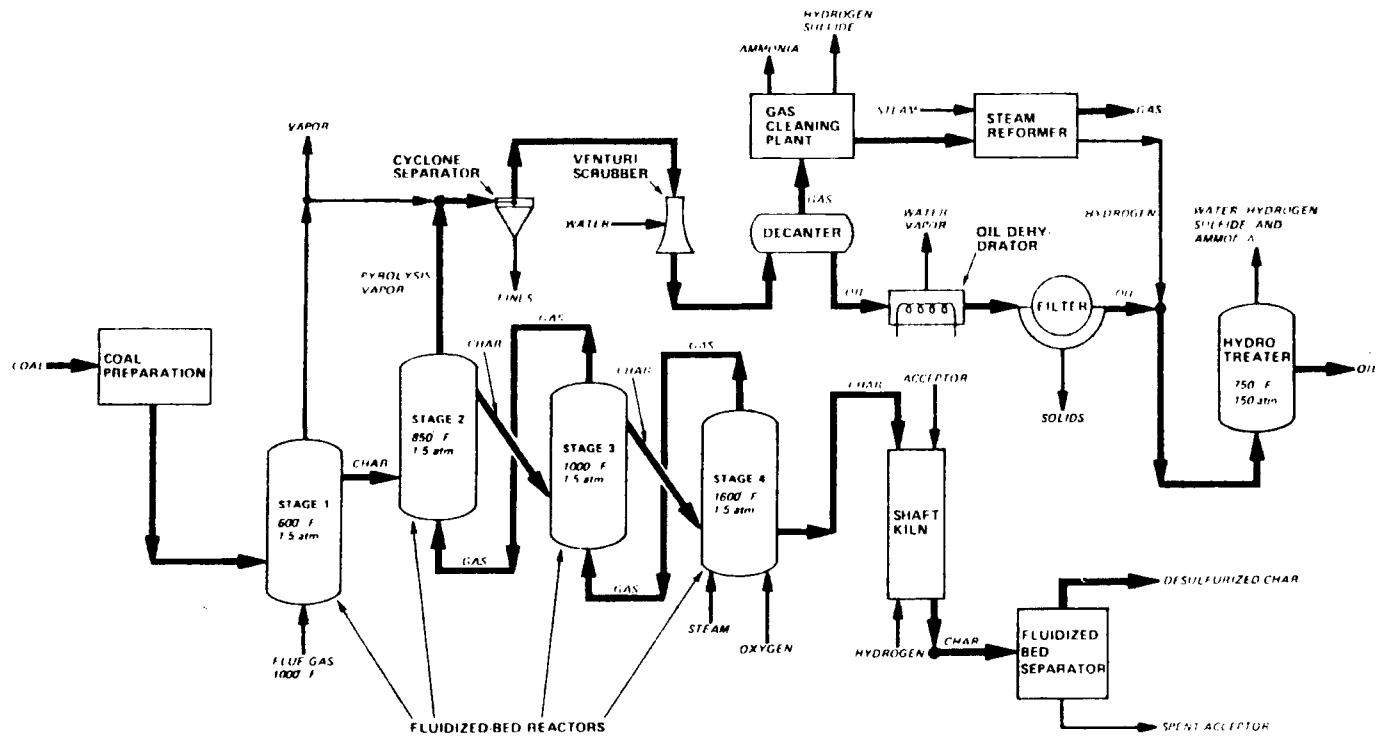
Figure E1.   COED Process Flow Diagram

COAL LIQUEFACTION

COALCON PROCESS

GENERAL

Sponsor: ERDA

Developer: Union Carbide

Contractor: Consortium of Companies

Principal Members	Company
Metals--------------------------	Reynolds Metals Co.
Chemicals--------------------	Du Pont Union Carbide Corp.

Architectural and
  Engineering Services------
	Chemical Construction
	  Corporation

Petroleum------------------------	Ashland Oil Co. Mobil Oil Co. Sun Oil Co. Atlantic Richfield Co.
Coal-------------------------	Youghiogheny & Ohio Coal Company
Electric--------------------	Electric Power Research Inst.
Gas--------------------------	Consolidated Gas Co.
Heavy Industry-------------	Martin Marietta

Contract Value: ERDA - $130 million
                       Others - $107 million

Status: 2600 tons/day demonstration
                       plant is to be located in New
                       Athens, Illinois. Contract
                       awarded to COALCON for the
                       phased design, construction,
                       and operation. Scheduled
                       operational date is Fiscal
                       Year 1980.

CONCEPTUAL DESIGN

Coal Preparation Operation

Coal Type: Bituminous, Lignite, Subbitumious

Coal Analyses (Pittsburg
  No. 8 Coal):

Proximate, %		Ultimate (MAF), %	
Fixed Carbon	54.7	Carbon	82.4
Volatiles	45.3	Hydrogen	5.5
Ash	9.1	Nitrogen	1.2
Moisture	3.7	Oxygen	113.2
		Sulfur	3.6

Heating Value, Btu/lb: 14,900 (MAF)
                                13,200 (As Received)
                                13,600 (Dry)

Preparation: 80% 100 mesh, 1 percent moisture

Feed System: dry, lock hopper

Liquefaction Description and Operating Conditions:

   Type of process: Fluidized-bed hydrogenation (hydro-
                       carbonization)

No other information is currently available on this process

Process Description

The COALCON process shown in Figure E2 is based on a dry, fluid-bed hydrogenation technique known as hydrocarbonization. The feed coal is crushed, sized to 80% through 100 mesh, and dried to about 1% moisture. Prepared coal is then fed to the hydrocarbonization reactor through a lock hopper system where coal is heated to 1000°F in the presence of hydrogen at approximately 500 psi. Proper distribution of hydrogen to the reactor gives better fluidization and hence higher coal reactivity.

The hydrocarbon vapor product leaves the reactor through a cyclone separator. The vapor is then cooled and scrubbed of final dust; the heavier hydrocarbons condense to form the liquid hydrocarbon products. The condensed product is further fractionated to separate lighter and heavier hydrocarbons. The uncondensed gaseous products are separated and treated to produce a high-Btu pipeline quality gas. The essential steps include acid gas removal, hydrogen purification, and methanation.

The char from the hydrocarbonization reactor is removed through a lock hopper system, cooled, and ground to the required size for use in gasifiers. Hydrogen produced in the gasifier is used in the process.
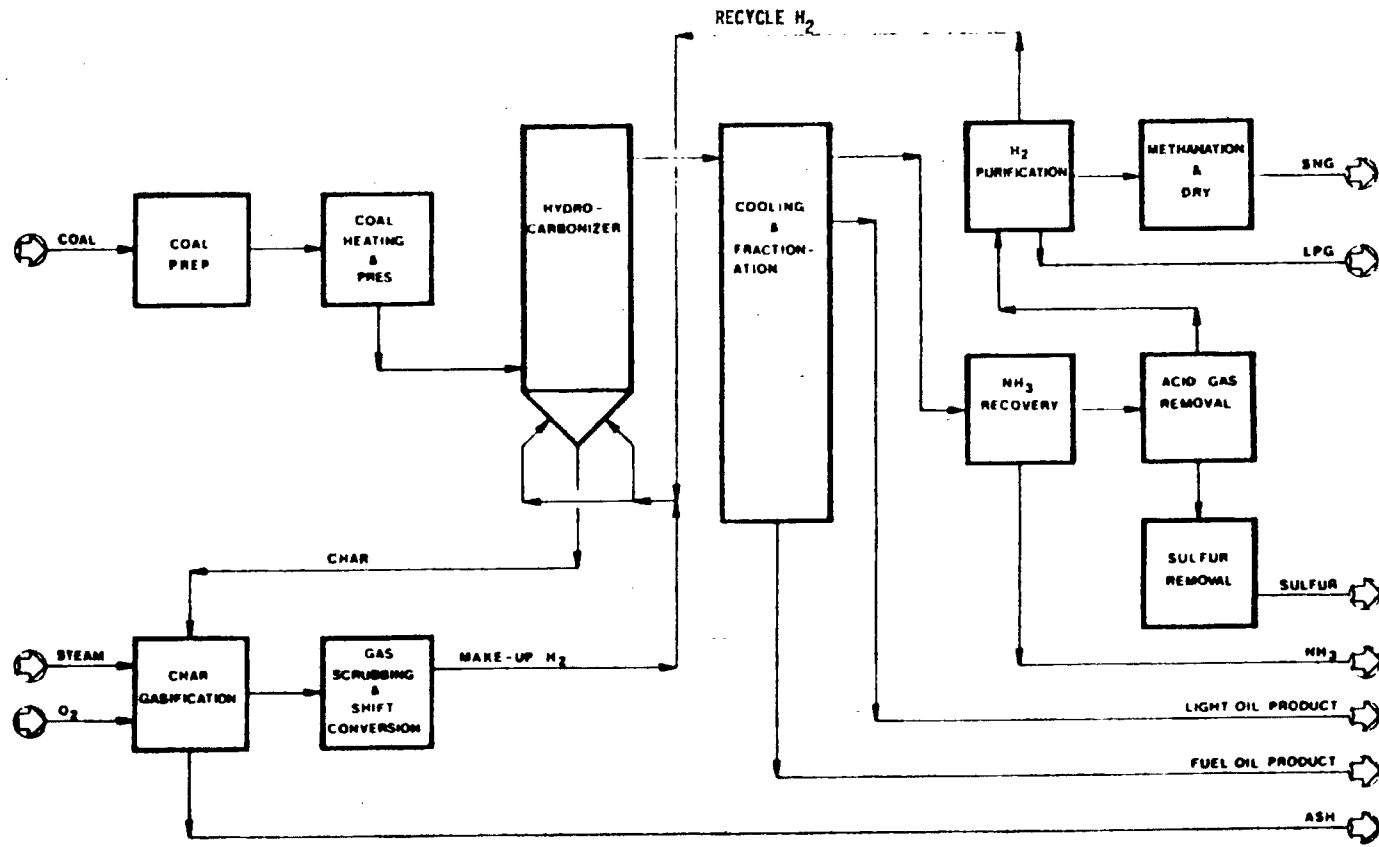
Figure E2. Coalcon Hydrocarbonization Process

COAL LIQUEFACTION

FISCHER-TROPSCH PROCESS

BACKGROUND

Developer: M. W. Kellogg Co. and Arge-
Arbeit Germeinschaft Lurgi
and Ruhrchemie

Status: The Sasol plant (6,600 tons of
coal/day to the gasifier) has
been in operation in South
Africa since 1957.

Compatible Coal Type: Depends upon gasifier type

CONCEPTUAL DESIGN   No data available

Process Description

The schematic for a Fischer-Tropsch based process is shown in Figure E3. This process basically converts carbon monoxide and hydrogen to liquid hydrocarbons. The two chemical equations which generalize the formation of hydrocarbons are:

$$nCO + 2nH_2 = (CH_2)_n + nH_2O$$

$$2nCO + nH_2 = (CH_2)_n + nCO_2$$
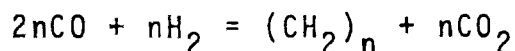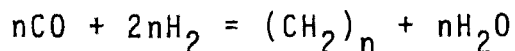
Noncaking coal is crushed to 3/8 to 1-1/2 in., dried and reacted with oxygen and steam in a Lurgi gasifier at 350-450 psi, generating a gas composed mostly of carbon monoxide and hydrogen. Gas is quenched to remove tar and oil. Then, CO_2 and H_2S are removed to produce synthesis gas.

A part of the synthesis gas is passed through a fixed catalyst bed contained in vertical tubes (Arge Synthesis). Released heat is absorbed by boiling water outside the tubes. Feed gas has an H_2/CO ratio of about 2. Operating conditions are 430°-490° and 360 psig. Recycle gas to fresh-feed ratio is about 2.4:1. The products of the fixed bed synthesis are straight-chain, high-boiling hydrocarbons, with some medium-boiling oils, diesel oil, LP-gas, and oxygenated compounds.

The portion of the synthesis gas which did not go to the Arge synthesis goes to a fluid-bed reactor (Kellogg synthesis). A portion of the tail gas from the Kellogg fluid bed is reformed with steam to increase the H_2/CO ratio to about 3, and is mixed with the fresh synthesis gas. In the fluid bed the catalyst is circulated along with the synthesis gas. Gas and catalyst leaving the reactor are separated in cyclones and the catalyst is recycled. Operating conditions are 600°-625°F and 330 psig. Recycle gas to fresh feed ratio is 2:1. Products from the fluid-bed synthesis are mainly low-boiling hydrocarbons (C_1-C_4) and gasoline, with little medium and high-boiling material. Substantial amounts of oxygenated products and aromatics are made. A portion of the fixed-bed and fluid-bed tail gas is removed and used for utility gas.

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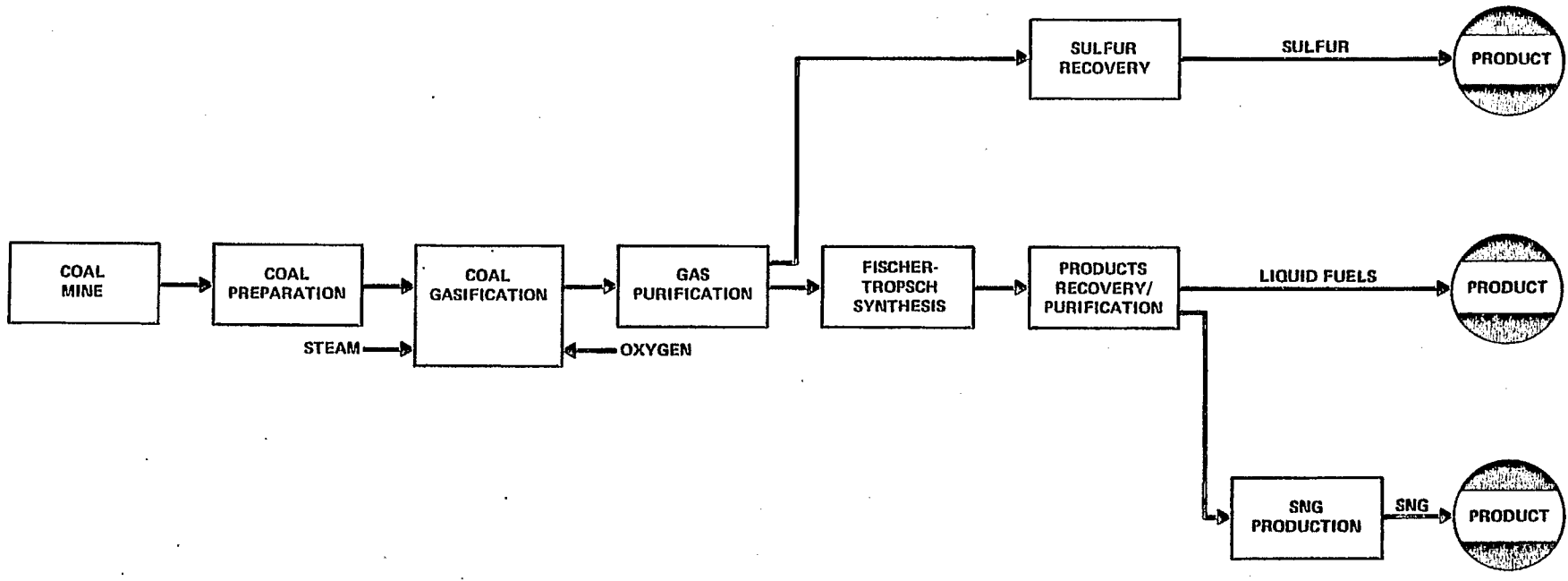
Figure E3.   Fischer-Tropsch Process

APPENDIX F

HYDROGENATION LIQUEFACTION PROCESSES

        Descriptions of the major hydrogenation processes
follow.

Preparation:	Coal is dried to 2.7% moisture and ground to 1/8"
Feed System:	Conveyor to solvent slurry tank

Liquefaction Reactor Description and Operating Conditions

Type:	Non-catalytic hydrogenation
Number of Reactors:	------------
Pressure:	1,000 psig
Temperature:	840°F

Cooling Mechanism: Not specified, cooling towers used

Input to Liquefaction Reactor:

Coal	833,300 lb/hr (2.7% moisture)
Steam (Water)	110,500 lb/hr
Recycle Slurry	1,666,700 lb/hr
Synthesis Gas	740,300 lb/hr
Combustion Air:	811,900 lb/hr

Ouput from Liquefaction Reactor:

Raw Product (includes Char)	3,689,700 lb/hr
Gas	873,200 lb/hr

Hydrotreating:

Input to Hydrotreating:

Product Oil	405,400 lb/hr
Hydrogen Makeup	8,200 lb/hr
Fuel Gas	9,500 lb/hr
Combustion Air	125,700 lb/hr
Water or Steam	29,600 lb/hr

Output from Hydrotreating:

Liquid Products (not including 10,100 lb/hr to plant fuel)	385,750 lb/hr
Sour Gas	15,900 lb/hr
Sour Water	41,400 lb/hr
Flue Gas	135,156 lb/hr

COAL LIQUEFACTION

SOLVENT REFINED COAL (SRC) PROCESS

BACKGROUND

Sponsor:	1. ERDA 2. EPRI, Southern Services, Inc. ERDA
Developer:	Pittsburgh and Midway Coal Mining Company (PAMCO)
Contractor:	1. PAMCO 2. Catalytic, Inc.
Contract Value:	1. $42 million 2. Not specified
Status:	2 Pilot Plants in Operation 1. Tacoma, Washington - 50 tons/day 2. Wilsonville, Alabama - 6 tons/day
Compatible Coal Type:	Bituminous, Brown Coal

CONCEPTUAL DESIGN

Plant produces approximately 16,667 barrels/day of 0.5% sulfur oil and 8,333 barrels/day of 0.2% sulfur oil.

Coal Preparation Operation

Coal Type: Bituminous, Illinois #6

Coal Analyses:

Proximate Analysis %		Ultimate Analysis (MAF) %	
Fixed Carbon	35.58	Carbon	78.46
Volatiles	47.82	Hydrogen	5.20
Ash	6.59	Nitrogen	1.19
Moisture	10.00	Sulfur	3.75
		Oxygen	11.40

Heating Value, Btu/lb:	11320 (MAF) 10570 (As Received) 12280 (2.7% Moisture)

Hydrogen Production

Type of Process: CO Shift

Input to Hydrogen Production:

Char, Ash, and Heavy Liquid	255,100 lb/hr
Gasifier Steam	77,500 lb/hr
Oxygen	163,700 lb/hr
Other Steam and Water	563,600 lb/hr
Fuel Gas	7,100 lb/hr
Air	93,800 lb/hr

Output from Hydrogen Production:

Hydrogen	8,200 lb/hr
Synthesis Gas	303,200 lb/hr
Ash (contains 59,400 lb/hr of slag)	108,300 lb/hr
Acid Gas	111,600 lb/hr
Steam	331,500 lb/hr
Flue Gas/CO_2	168,300 lb/hr
Water	129,700 lb/hr

Overall Products from SRC Process

Heavy Liquid

Amount	242,900 lb/hr
Sulfur Content	0.59%
Gravity	-9.7°API
Heating Value	16,660 Btu/lb

Hydrotreated Liquid

Amount	120,200 lb/hr
Sulfur Content	0.2%
Boiling Range	400-870°F
Gravity	13.9°API
Heating Value	18,330 Btu/lb

Light Oils

Amount	22,700 lb/hr
Sulfur	1 ppm
Boiling Range	C4-400°F
Gravity	52°API
Nitrogen	26,400 lb/hr

Sulfur	26,400 lb/hr

Other Information

Net Process Water Consumption: ----------

Type of Acid Gas Removed: Primary - mono-ethanol
                                                   amine/caustic
                                         Secondary - hot carbonate

Type of Sulfur Recovery: Claus

Thermal Efficiency: 60.3-70%

Process Description

The Solvent Refined Coal (SRC) process (see Figure F1) converts high-sulfur, high-ash coal to ashless, low-sulfur liquid fuel. Pulverized coal is mixed with a coal-based solvent in a slurry tank. Hydrogen, produced elsewhere in the process, is combined with the slurry. The mixture is then pumped through a preheater and into a dissolver where about 90 percent of the dry, ash-free coal is dissolved. Simultaneously the coal is depolymerized and hydrogenated. The solvent is hydrocracked, forming lower molecular weight hydrocarbons such as light oil and methane. The sulfur is removed as hydrogen sulfide.

After leaving the dissolver, the gases are separated from the slurry of undissolved solids and coal oil solution. Raw gas goes to a hydrogen recovery and gas desulfurization unit. The recovered hydrogen is recycled with the fresh coal feed slurry. Hydrocarbon gases are released and the hydrogen sulfide is converted to elemental sulfur.

Solids filtered from the slurry (containing unreacted carbon) are sent to a gasifier-converter where they are combined with additional coal, oxygen, and steam, and thereby converted to hydrogen for use in the process. The refined-coal is separated from the solvent in the solvent recovery unit. This refined coal has a solidification point of 350°F-400°F.
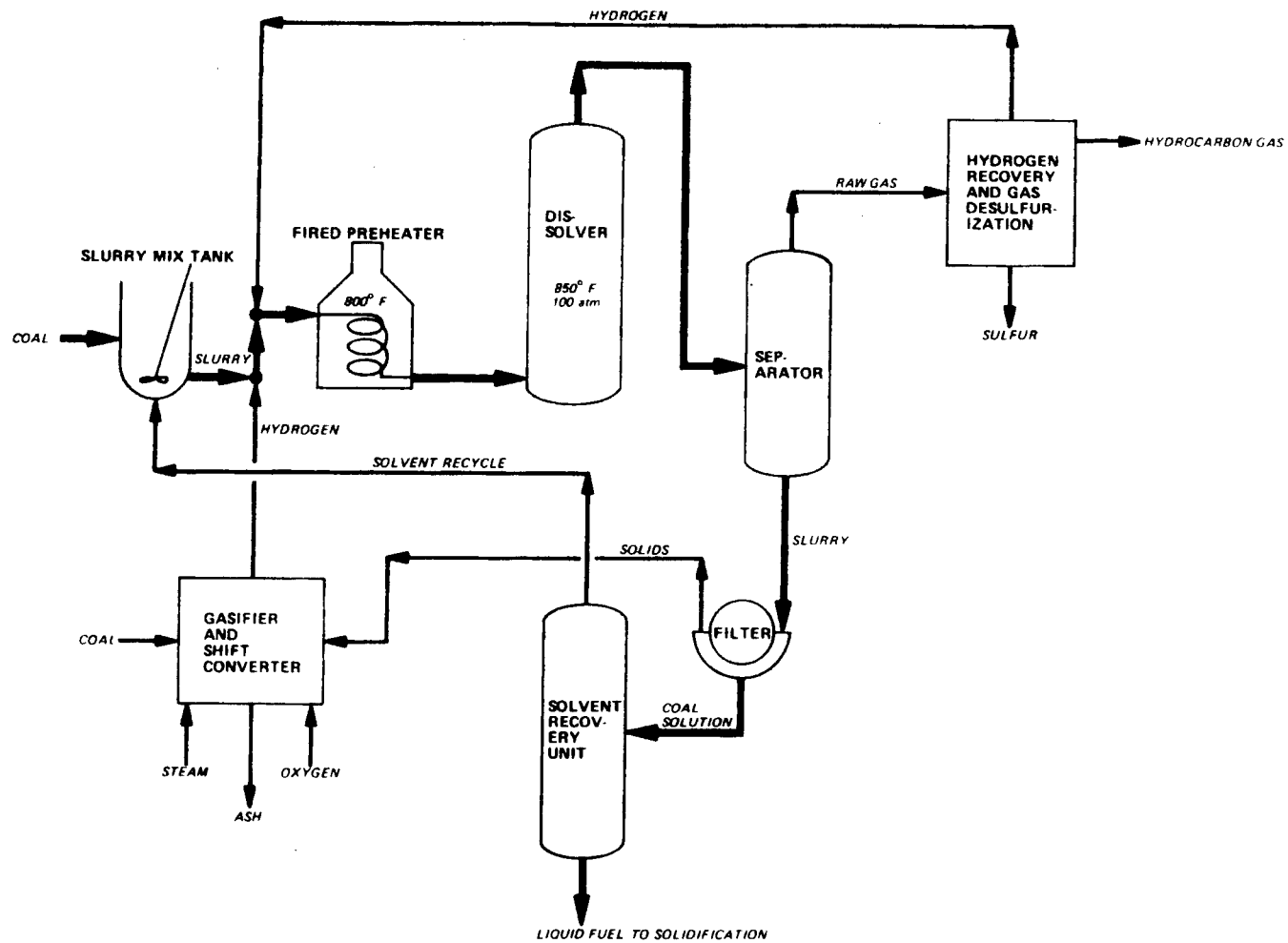
Figure F1.   SRC Process Flow Diagram

COAL LIQUEFACTION

H-COAL PROCESS

BACKGROUND

Sponsors:	ERDA, State of Kentucky, Electric Power Research Institute, and Several Oil Companies
Developer:	Hydrocarbon Research, Inc.
Contractor:	Hydrocarbon Research, Inc.
Contract Value:	ERDA-$8.1 million Others-$2.7 million
Status:	A 3 ton/day bench plant is in operation at Trenton, New Jersey and a 600 ton/day plant is being designed for construction at Catlettsburg, Kentucky
Compatible Coal Types:	Lignite, Subbitumious, Bituminous

CONCEPTUAL DESIGN

Plant produces 91,240 barrels of crude oil per day

Coal Preparation Operation

Coal Type: Bituminous, Illinois, #6

Coal Analyses:

Proximate, %		Ultimate (MAF), wt %	
Fixed Carbon	37.8	Carbon	78.5
Volatiles	43.3	Hydrogen	6.0
Ash	8.9	Nitrogen	1.1
Moisture	10.0	Sulfur	5.5
		Oxygen	8.9

Heating Value, Btu/lb: 11560 (MAF)
10530 (As Received)

Preparation: Coal is dried until essentially all moisture is removed and then crushed to less than 40 mesh

Feed System: Coal is mixed with recycle oil to form a slurry

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Liquefaction Reactor Descriptions and Operating Conditions

Type: Catalytic hydrogenation, ebullating
                               bed

Number of Reactors: ------------

Dimensions: ------------

Reactor Temperature: 850°F

Reactor Pressure: 2000 psig

Cooling Mechanism: Non-contact cooling water with
                               cooling tower

Input to Liquefaction Reactor:

       Coal   2,083,300 lb/hr (dry)
       Recycle Slurry 4,166,700 lb/hr
       Gas   65,800 lb/hr

Output from Liquefaction Reactor:

       Raw Product   ------------
       Gas   ------------

Hydrotreating Process: The H-Coal process does not
                               require hydrotreating

Hydrogen Production

Type of Process: Steam-carbon reaction (gasification)

Input to Hydrogen Production:

       Heavy Bottoms and Coal   653,300 lb/hr
       Gasifier Steam (from waste heat
                       boiler)   177,800 lb/hr
       Oxygen   414,000 lb/hr
       Other Steam and Water   1,528,300 lb/hr

Output from Hydrogen Production:

       Hydrogen   92,000 lb/hr
       Ash   222,300 lb/hr
       Steam   1,104,800 lb/hr
       Flue Gas/CO_2 (includes 19,800
                                            lb/hr of H_2O vapor)
       Water   554,800 lb/hr
       Acid Gas   291,500 lb/hr

Overall Products from H-Coal Process

Synthetic Crude	1,201,300 lb/hr
By-Product Fuel Gas	100,800 lb/hr
High-Btu Char	0
Sulfur	107,900 lb/hr
Ammonia	17,100 lb/hr

Analysis of Synthetic Crude:

Gravity	25.2 °API
Hydrogen,	9.48%
Sulfur	0.19%
Nitrogen	0.68%
Heating Value	18,290 Btu/lb

Analysis of By-Product Fuel Gas:

Hydrogen Content (volume %)	56
Heating Value	24,000 Btu/lb
	(900 Btu/scf)

Other Information

Type of Acid Gas Removal:	Primary - alkanolamine
	Secondary - hot carbonate
Type of Sulfur Recovery:	Claus
Thermal Efficiency:	67.7-77.0%

Process Description

The H-coal process (see Figure F2) is a catalytic hydro-genation process that produces low-sulfur boiler fuels and syncrude from high-sulfur coal.

The coal is dried and crushed, mixed with recycle oil, and pumped to a pressure of 2,000 psig. Compressed hydrogen is added to the slurry. The mixture is preheated and charged continuously into an ebullating-bed catalytic reactor. The upward passage of the internally recycled reaction mix keeps the catalyst in a fluidized state. The temperature of the reactor is regulated by adjustment of the quantities of reactants entering the preheater.

The heavier components of the vapor leaving the top of the reactor are collected by cooling the gas. The hydrogen-rich gas that remains following adsorption of ammonia is pressurized and mixed with the input coal slurry. The liquid-solid product (unconverted coal, oil, and ash) is fed to a flash separator. An atmospheric distillation unit treats the material that boils off. The remaining bottoms product (heavy oil and solids) is further separated with a hydroclone (liquid-solid separator) and a vacuum still.

The gas and liquid products (hydrocarbon gas, hydrogen sulfide, ammonia, light distillate, heavy distillate, and residual fuel) may be further refined as desired.

The type of fuel produced in the H-coal process can be regulated by altering the operating conditions. For syncrude oil production, additional hydrogen is used, reducing the yield of residual oil. The solid-liquid separation can be accomplished by vacuum distillation, thus eliminating the liquid-solids separation phase unit. A clean fuel gas and low-sulfur residual fuel can be obtained by lowering the temperature and pressure in the catalytic reactor and limiting hydrogen consumption.
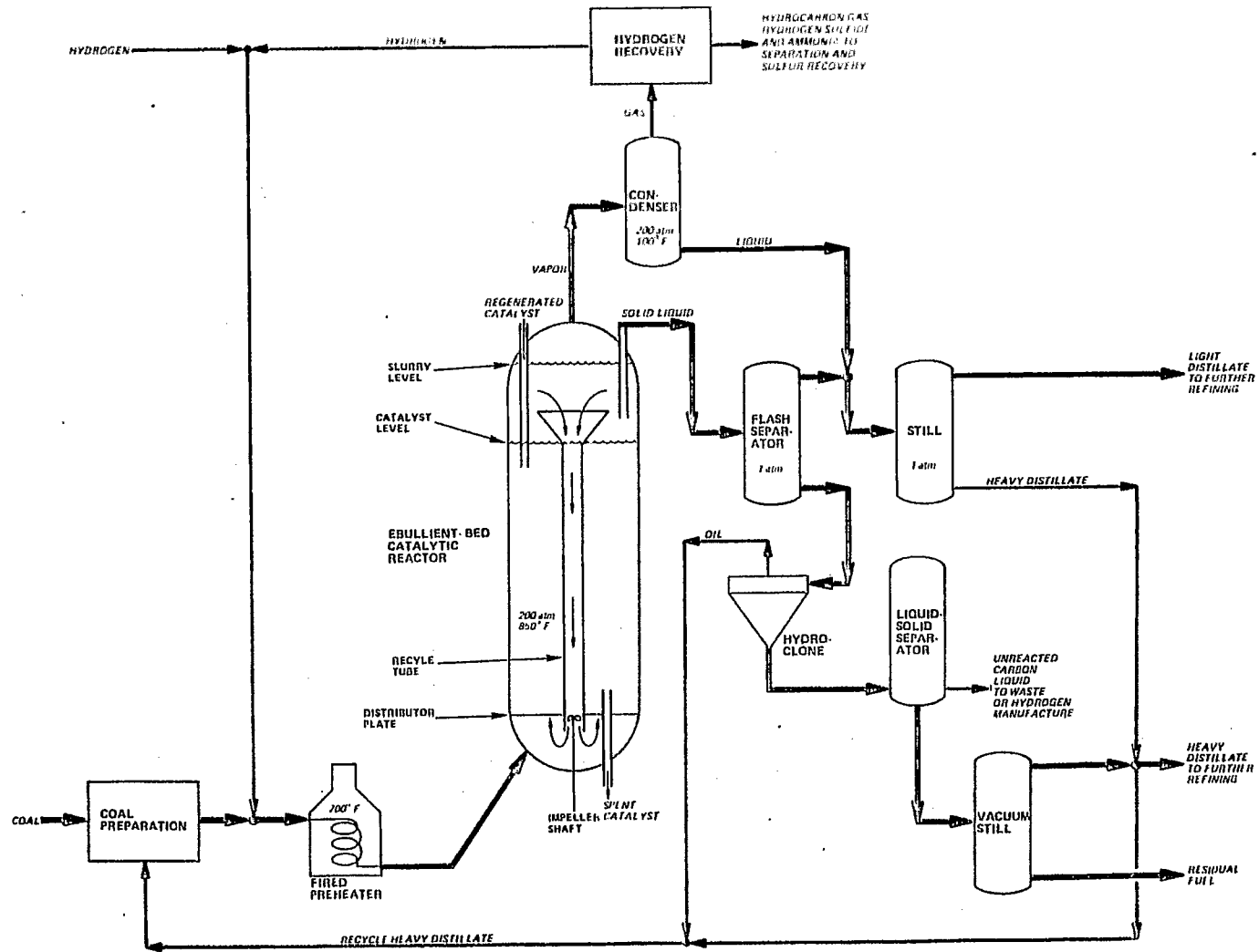
Figure F2. H - Coal Process Flow Diagram

COAL LIQUEFACTION

EXXON DONOR SOLVENT PROCESS

BACKGROUND

Sponsor:	ERDA
Developer:	Exxon Research & Engineering Company
Contractor:	Exxon
Contract Value:	Not Specified
Status:	One ton/day pilot plant in operation in Baytown, Texas.
	Planning for a 250 ton/day, 50,000 bbl/day pilot plant has begun.
Compatible Coal Type:	Lignite, Subbituminous, Bituminous

CONCEPTUAL DESIGN: 50,000 bbls/day of low-sulfur fuel oil

Coal Preparation and Storage:

Coal Type: Illinois #6, Bituminous

Coal Analyses (as received):

Proximate, wt %		Ultimate, wt %	
Moisture	16.0	Carbon	58.17
Ash	8.0	Hydrogen	4.22
Volatile Matter	35.0	Nitrogen	1.54
Fixed Carbon	41.0	Chlorine	0.18
Sulfur	3.50	Sulfur	3.50
Alkalies, Na2O	0.15	Oxygen	7.89
		Ash	8.00
		Moisture	16.50

Heating Value, Btu/lb: 10700 (MAF)
                          9840 (As Received)

Pretreatment: Coal is dried and ground to 8 mesh

Feed System: Tubular pneumatic conveyor

Liquefaction Reactor Description and Operating Conditions

Type of Process:	Stirred tank, tubular plug flow, tubular with external and internal recirculation, ebullating catalytic bed.
Temperature:	370-480°C
Pressure:	300 psig to 2500 psig
Input:	1,340,000 - 1,540,000 lb/hr
Hydrotreating Process:	No information available
Hydrogen Production:	No information available
Overall Output:	Total of 50,000 barrels/day of Naphtha and Fuel Oil

Analysis, wt %

	Heavy Naphtha		200°C + Fuel Oil	
	Raw Liquid	Hydrotreated Liquid	Raw Liquid	Hydrotreated Liquid
Carbon	85.60	86.80	89.40	90.80
Hydrogen	10.90	12.90	7.70	8.60
Oxygen	2.82	0.23	1.83	0.32
Nitrogen	0.21	0.06	0.66	0.24
Sulfur	0.47	0.005	0.41	0.04
Heating Value, Btu/lb	18,307	19,295	17,103	18,091

Other Information

Type of Acid Gas Removal:	Monoethenolamine (MEA)
Turndown Flexibility:	50%

Process Description

The Exxon Donor Solvent Process (see Figure F3) converts high-sulfur, high-ash coal into naphtha and low-sulfur, low-ash fuel oil. The coal feed is dried, ground, and screened. The coal and recycled solvent are mixed in a slurry preparation vessel. The slurry is then fed through a preheater into a liquefaction reactor. The hydrogen treating gas is preheated either separately or in a mixture with the slurry. The products are gas, raw coal liquids, and a heavy bottoms stream composed of unreacted coal and mineral matter. Distillation separates the liquids, and the spent solvent is catalytically hydrogenated for recycle. Heavy bottoms from the distillation are processed to yield other liquids and hydrogen or fuel gas. Gases generated during liquefaction are used as fuel and for hydrogen manufacture.
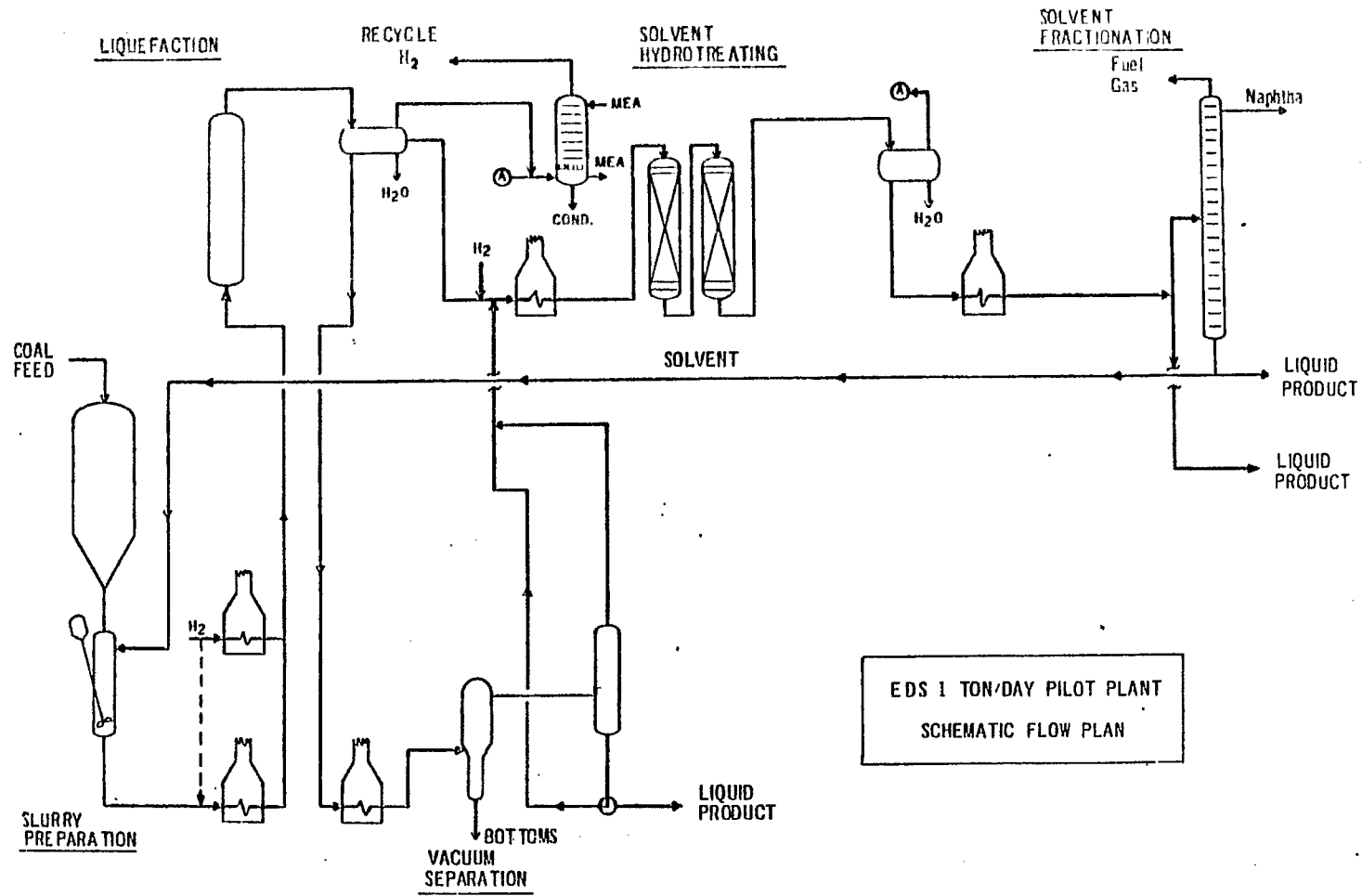
Figure F3. EDS Process Flow Diagram

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COAL LIQUEFACTION

SYNTHOIL PROCESS

BACKGROUND

Sponsor:	ERDA
Developer:	Pittsburgh Energy Research. Center of ERDA
Contractor:	Foster Wheeler Energy Corp.
Contract Value:	ERDA - $6.9 Million Foster Wheeler-$1.1 Million
Status:	A 10 ton/day pilot plant is in operation at Pittsburgh Energy Research Center, Bruceton, Pennsylvania. A 7,000 ton/day plant is under preliminary design
Compatible Coal Type:	Lignite, Subbituminous, Bituminous

CONCEPTUAL DESIGN

Plant converts Wydoak coal to 50,000 barrels/day of oil

Coal Preparation Operation

Coal Type: Subbituminous, Wyodak

Coal Analysis:

<u>Ultimate, WT, %</u>

Moisture	29.0
Ash	6.6
Carbon	47.0
Hydrogen	3.5
Nitrogen	0.5
Sulfur	0.7
Oxygen	12.7

Heating Value, Btu/lb: 8050 (MAF)
                                7420 (As Received)

Preparation: Coal is dried to 0.5 percent
                            water and ground to 65 percent
                            less than 200 mesh

Feed System: Screw fed

Liquefaction Reactor Description and Operating Conditions

Type: Catalytic Hydrogenation, Turbulent Bed

Number: 7

Dimensions: 2900 cu ft, 6.67' ID x 83"

Temperature: 860°F

Pressure: 4200 psig

Cooling Mechanism: Countercurrent heat exchange

Input to Liquefaction Reactor (including hydrogen
    production)

                            lb/hr

        Coal   1,704,800
        Steam   147,000
        Oil   1,594,200
        Residue   16,000
        Oxygen   302,960
        Char   178,000

Output from Liquefaction Reactor
    No information available

Hydrogen Production

Type of Process: Fluidized gasification

Input to Hydrogen Production:

        Char (recycled)   89.0 tons/hr
        Coal   184.2 tons/hr
        Oxygen   151.48 tons/hr
        Steam (450 psig
            and 900°F)   148,000 pounds/hr

Output from Hydrogen Production:

<u>Million SCFH</u>

H_2	12.51
CO	0.22
CO_2	0.01

<u>Overall Products from Synthoil Process</u>

Ammonium sulfate	15,240 lbs/day
Sulfuric acid	11,333 lbs/day
Heavy Fuel Oil	50,000 barrels/day
Fuel Gas	840,800 SCFH
Ash	10,583 lbs/hr

Analysis of heavy fuel oil

Sulfur content	0.7%
Heating value	18,300 Btu/lb

<u>Other Information</u>

Raw water usage:	20.4 MGD
Type of acid gas removal:	Primary secondary hot carbonate
Thermal Efficiency:	---------------

Process Description

In the Synthoil process (see Figure F4), a catalytic hydro-
genation process, high-sulfur coal is converted to low-ash, low-
sulfur fuel oil. The coal is crushed, ground, and dried. Re-
cycled product oil is then combined with the coal, forming a
slurry. The slurry is mixed with recycle hydrogen,
preheated, and transported to the fixed-bed catalytic
reactor. The hydrogen propels the slurry through the
reactor so violently that plugging by the coal mineral
matter is prevented. The turbulence of the slurry promotes
mass and heat transfer, encouraging hydrodesulfurization and
liquefaction. The catalyst consists of cobalt molybdate
on silica-promoted alumina. The resulting mixture is
cooled and the liquid and unreacted solids are separated
from the gases.

The liquids and residue are then centrifuged. A portion of
the liquid is recycled and combined with the feed coal.
The remainder, the product oil, is low in sulfur. The
char is pyrolyzed, yielding additional product oil and ash.
The ash, containing some carbonaceous material, is sent to
the gasifier and the resulting gas is sent to the shift
converter.

The gases leaving the separator are purified and combined
with the ash, water, and oxygen, yielding a hydrogen product.
In the gas purification system, ammonia, water, hydrocarbon
gases, and hydrogen sulfide are removed. The sulfide is
then converted to elemental sulfur.
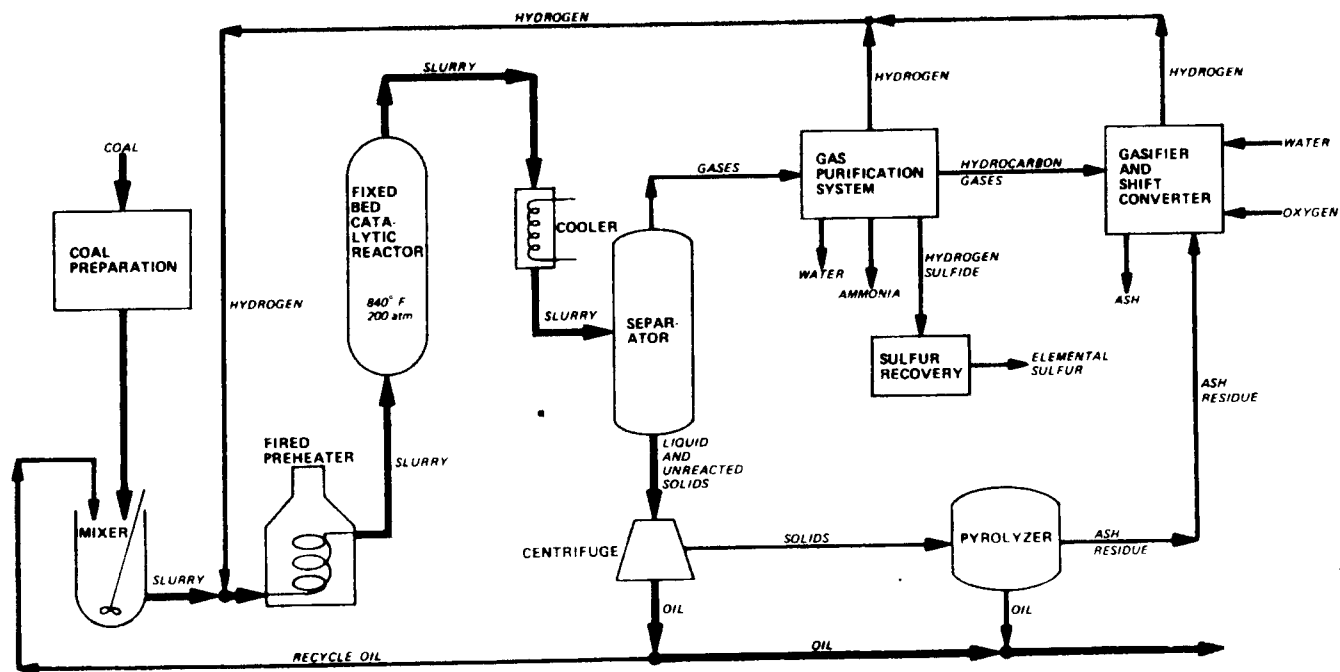
Figure F4.   SYNTHOIL Process Flow Diagram

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COAL LIQUEFACTION

COSTEAM PROCESS

BACKGROUND

    Sponsor: ERDA

    Developer: Pittsburgh Energy Research Center

    Status: 10 tons/day, lignite-fed pilot
plant demonstration unit under
design. Unit to be located·
at Grand Forks, North Dakota.

    Compatible Coal Type: Lignite

CONCEPTUAL DESIGN   No Data Available

Process Description

The schematic of the COSTEAM process is shown in Figure F5. It differs from other coal to oil processes which use hydrogen directly under conditions of high temperature and pressure in the presence of a catalyst. The COSTEAM process uses synthesis gas (or carbon monoxide) and steam, and does not require a catalyst.

A slurry consisting of 30-50 weight-percent of air-dried, pulverized coal in lignite-derived oil is pumped with synthesis gas or carbon monoxide into a stirred reactor at 4,000 psig and 800°F. Water required for the reaction is obtained from the coal. The effluent stream goes through a gas-liquid separation where the raw oil is separated from the product gas. Then a centrifuge or filter is used to remove any unreacted coal and ash from the oil. The resulting low-sulfur, low-ash oil can be used for steam generation in conventional power plants.

LIGNITE

Recycle oil

Feed tank

Reactor

Centrifuge

Slurry pump

Compressor

Product gas

Unreacted solids

Synthesis gas

Product receiver

FUEL OIL
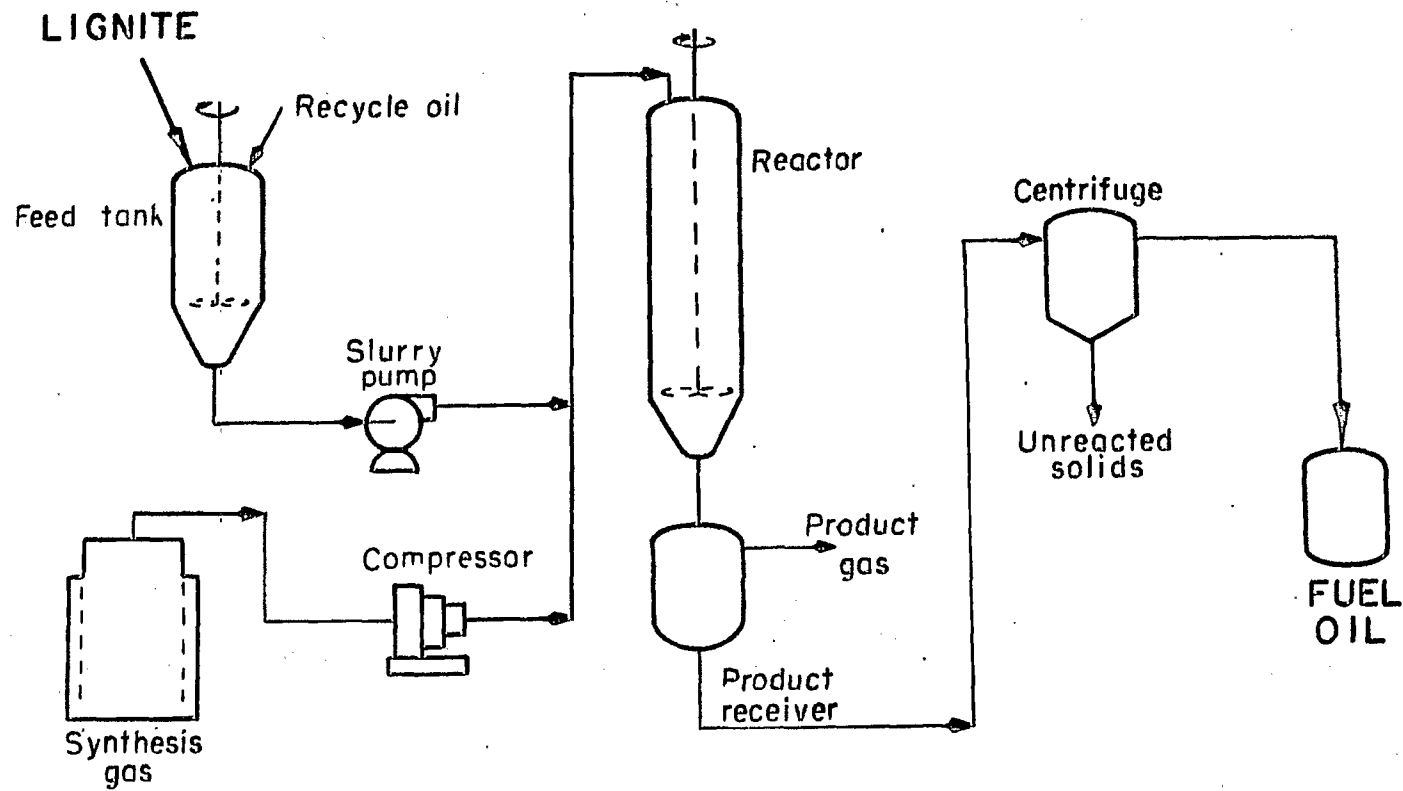
Figure F5.   Costeam Process

APPENDIX G

EXAMPLES OF BOILER CONVERSION

Following are two examples of conversion of boilers originally designed to fire oil or gas to conventional coal-fired units. This discussion was excerpted from *Power Magazine* July 1976. A list of required equipment modifications and additions is included. A rough estimate of costs for modifications would be $3/lb of steam generated for oil- and gas-fired boilers when utilizing new, factory-assembled equipment or $6/lb for erection of modifications in the field.[6]

The first example compares a bottom-supported oil/gas-fired unit rated 300,000 lb/hr to the same unit modified for spreader-stoker firing. The capacity on coal, as limited by furnace size and grate area, would be about 200,000 lb/hr, but the need to limit velocities through the baffled boiler bank to reduce erosion to acceptable values lowers the nominal rated capacity to between 150,000 and 175,000 lb/hr, depending on the coal selected and the ash constituents produced during combustion.

A conversion of this type requires these steps:

- Modify the furnace bottom pressure parts to accommodate a spreader-stoker and an overfire air system.

- Provide space for the dropped furnace bottom, an ash hopper, and an ash removal system.

- Add superheater surface to maintain design steam temperature.

- Install additional sootblowers and associated piping, etc., to keep convection surfaces clean.

- Add hoppers for gas-pass fly ash collection and reinjection to minimize carbon loss.

- Modify the air heater to limit air temperature to the grate, and install an economizer to regain the heat-recovery capability lost in modifying the air heater.

- Install a dust collector ahead of the regenerative air heater to prevent air heater plugging. Where tubular air heaters are installed, a dust collector is not required.

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[6]Perry, R. H., *Chemical Engineers Handbook*, Fifth Edition, (McGraw Hill, 1973).

- Install new foundations, support steel, ductwork, etc., as required.

- Modify combustion and safety controls.

- Add an induced-draft fan for balanced-draft operation.

- Modify the furnace buckstays and add ductwork stiffeners required for balanced-draft operation.

Such a conversion impacts heavily on plant operations. Field modifications, for example, take about 12 months (based on a 40-hr week), while the entire job, including engineering and equipment lead times, can run 18-24 months. During the conversion, the boiler will be out of service for perhaps 9 months. A comparable schedule for a new unit would require 13 months from order to shipment, about 12 months for installation, and 2-3 months for pre-operational cleaning, shakedown, and staff training.

A top-supported distillate-oil and gas-fired unit rated 400,000 lb/hr, converted to pulverized-coal firing, is also discussed. The capacity obtained with pulverized coal is a nominal 265,000 lb/hr. The new rating is limited by furnace heat-release rates and by the coal selected. If a spreader stoker had been selected for this unit, the maximum obtainable capacity would be only 200,000 lb/hr, because of physical constraints on grate size.

To convert this boiler to pulverized-coal firing it is necessary to:

- Modify the furnace-bottom pressure parts to accommodate a hopper for furnace-ash collection and removal. This includes revamping downcomers to serve the ring header replacing the original single header.

- Provide space for the dropped furnace bottom, an ash hopper, and an ash removal system.

- Modify the windboxes, coal nozzles, and ignition equipment.

- Add pulverizers and coal piping.

- Install sootblowers in the furnace walls, superheater, and boiler bank.

- Modify the superheater to obtain the desired spacings.

- Modify the air heater, as required, to prevent plugging by coal ash. Add a primary-flow air heater if the existing unit cannot develop the pulverizer air inlet temperature required because of high-moisture coal.

- Install new foundations, support steel ductwork, etc., as required.

- Modify the combustion and safety controls.

- Add an induced-draft fan to boost unit reliability.

- Modify the furnace buckstays and add ductwork stiffeners required for balanced-draft operation.

These modifications probably will take upwards of 24-30 months to complete, including engineering time. The limiting item here is the pulverizer equipment, which may require 24 months for delivery. By comparison, it takes about 30 months to bring a new top-supported unit into service.

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  Ft Carson, CO 80913
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AMC
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USACC
  Ft Huachuca, AZ 85613
  HQ, 1st Inf Div & Ft Riley, KS 66442
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3800 ABW/DEE
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Maxwell AFB, AL 36112

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