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PROJECT POGO
TOTAL COAL UTILIZATION
COG REFINERY DESIGN CRITERIA

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Prepared by:
THE RALPH M. PARSONS COMPANY
Pasadena, California 91124

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SECTION I

INTRODUCTION

The objective of this work is to develop design criteria for a conceptual design/economic evaluation for a multiproduct complex to convert coal to electric power, oil, gas, and other products. ERDA has designated this multiproduct complex, POGO, an acronym for power-oil-gas-other. POGO is an outgrowth of earlier work on a design concept referred to as coal-oil-gas (COG). Therefore, the POGO concept uses multiple processes in a preferred combination to produce a broad spectrum of environmentally acceptable fuels, plus other products, that will be economically competitive with alternative sources of these products.

The objective was achieved by analyzing the capabilities of the major generic types of liquefaction processes and then by comparing the projected technical and economic performances. The next step was to compare the predicted performance of a number of potentially viable candidate combinations of processes and to recommend the preferred process combination, plus preliminary design criteria. The intent is that the resulting complex would use the best available coal conversion processes in combinations such that the byproducts or wastes of one process would form inexpensive raw materials for another process. In this manner, what might have been expenses could be turned into savings, and the final product cost could be lower than that possible with a single process plant.

The program was designed to review and analyze at least one candidate process in each of the following generic liquefaction categories:

Category	Process Reviewed
Hydroliquefaction	
Noncatalytic	SRC I
Pseudocatalytic	SRC II, Oil/Gas
Catalytic	H-Coal, Synthoil
Donor Solvent	CSF
Pyrolysis	
Direct	COED
Hydropyrolysis	Coalcon
Indirect	Fischer-Tropsch

The program also considered combinations of these processes and alternatives of supporting processes for feed preparation, plus downstream purification, recovery, and refining.

A few restrictions on process candidates and combinations were accepted within the limits of the time and resources available for the analysis. The results of two conceptual designs/economic evaluations completed earlier were used as input to this analysis/review effort; this included an SRC II-based clean boiler fuel plant design published in 1973 (Ref. 1) and a COED-based pyrolysis design published in 1974 (Ref. 2).

This program also used results available from in-progress designs for a Fischer-Tropsch plant (Ref. 3) and an Oil/Gas SRC II-based plant (Ref. 4). Input for the H-Coal and Synthoil reviews included published information, material provided by ERDA, and personal communications. The Coalcon review was based on material provided by ERDA.

Section 2 of this report summarizes the logic sequence used to select a preferred configuration for the more detailed conceptual design work. This preferred process combination is defined. In the course of presenting the logic sequence, interpretations of the characteristics of the separate process candidates are described.

SECTION 2

SUMMARY

Design criteria have been developed for a conceptual coal conversion complex to produce environmentally clean liquid and gaseous fuels, plus electrical power. A summary is presented of this design criteria development program.

The objectives for the program are best described by reference to the work statement for the POGO conceptual design/economic analysis assignment that specified three phases for the work:

(1) The contractor shall perform and submit preliminary analyses of existing processes and make recommendations from which the Government shall select the better combinations.

(2) Complete conceptual design of the processes selected under phase 1.

(3) Optimize concept design.

The program plan included design development for processing three coals in three different geographical areas of the United States. The intent is to study preferred process configurations and to optimize the results.

This report summarizes the results of the work that fulfilled the obligations under phase 1, described above. The design criteria presented here are now being used for development of the phase 2 conceptual design.

The development of the design criteria required analyses of candidates from all major generic types of coal conversion technologies, plus a number of potentially viable combinations of processes. The following factors should be noted when using the results reported:

- The resources available for the analyses were limited, both in personnel manhours and in cost, with regard to the broad scope of the objectives.
- All technologies that were reviewed are still under development.
- The information available represents the status at a point in time that is based on information available to an investigative team.
- The data and information came from many sources, and comparisons must rationalize the nature and quality of the input; i.e., some of the predicted economics are based on completed comprehensive conceptual design/economic evaluations by independent designers, while others are based on information supplied by process developers.

The results presented here, placed in their proper perspective based on the method of development, provide a broad display of major characteristics of coal liquefaction processes now under development and their potential, "relative" economics. Significance should be attached to the reference to relative values rather than absolute values, which must come from more detailed assessment efforts. The results provided the basis for a systematic and complete program designed to select a preferred process configuration for a subsequent, detailed conceptual design assignment. Key elements of the program are summarized in the following paragraphs.

The design criteria program consisted of the following logic pattern:

- Preliminary screening of existing processes in which approximately 85 combinations and permutations of individual coal conversion processes, plus supporting facilities, were considered using semiquantitative screening procedures.

- A preliminary review/analysis of nine coal conversion complexes included at least one candidate process from each of the major generic coal liquefaction categories.

  - Process descriptions, block flow diagrams, heat and material balances, and preliminary economics were developed for each candidate process.

  - Process and economic analysis results developed for prior conceptual designs, plus two in-progress designs, were used as input to this phase of the program.

  - Results: The solvent refined coal (SRC) type of hydroliquefaction processes showed promise as a low-cost, clean fuels producer. The consolidation synthetic fuel (CSF) type of donor-solvent process appeared to be of a slightly higher cost. Low-pressure pyrolysis appeared to be a high fuel cost route; other candidate processes arrayed themselves in intermediate-projected product-fuel cost positions.

- A short list of four high potential process/process combination candidates was developed after analysis of the results of the preliminary review/analysis program, plus further analytical work. The list consisted of:

Case	Process Configuration
I	CSF with low-temperature carbonization
II	Flash pyrolysis, CSF, and Fischer-Tropsch
III	Flash pyrolysis and Fischer-Tropsch
IV	Flash pyrolysis and SRC

The flash pyrolysis was included to "skim" easily recoverable high Btu gas and tar from the feed coal by a pressurized flash pyrolysis step and to produce a char that, in turn, is gasified to produce the necessary syngas and/or hydrogen for use in liquefaction. The flash pyrolysis also permitted the development of a method to exclude the troublesome filtration step from SRC processing. The elimination of this step is important because filtration of the fine (1 to 10 micron particle size), unreacted coal-plus-ash solids is expensive and a difficult, commercial operation. This point is discussed in OCR R&D Report No. 82, Interim Report No. 1 (Ref. 1).

Preliminary design configurations and economics were developed for each of the four cases listed above, plus a suggested second-generation U.S. Fischer-Tropsch plant and Oil/Gas (an SRC II-based process) designs that were in progress at Parsons. The technical and economic results were analyzed.

- A preferred process configuration was selected that had been based on the results of the programs' steps described above. Case IV was selected as the recommended configuration; Figure 4-4 of Section 4 shows the block flow diagram for this case.

- A design criteria document was developed for Case IV and is presented in this report. It is intended to:

  - Describe key elements of the design that will permit users to anticipate size, product state, and general characteristics of the resulting facility.

  - Permit designers to proceed with their objectives and work.

The completion of the selection process has provided the basis for proceeding with the development of the conceptual design/economic evaluation of the POGO complex. Preliminary economic analyses were based on information that was available to the investigators in mid-1976. Limited schedule and budget were available to meet the broad scope of the objectives, which included the analysis of all potentially viable coal conversion candidate process combinations, plus advanced electrical power generation facilities. Within these constraints, a systematic program of analysis, a significant amount of technical and economic analysis supporting the assembled information, and a decision regarding the preferred design criteria have been completed.

Information presented in this report should be used with full recognition of the manner and purpose of its development. Comparisons were based on a number of technologies that were only under development and on information available to a particular investigative team.

Parsons recommends that assessment of candidate processes be continued and expanded as more information becomes available. Future emphasis should be placed on product characteristics/marketability, process/thermal efficiency comparison between alternatives, and materials of construction/equipment performance; however, other factors must also be considered. It is suggested that the type of preliminary assessment presented here be extended and that increasingly sophisticated analysis procedures be applied as the quantity and quality of informational input from the development programs increase.

COLLECTED WORK NO. 22

PROJECT POGO - A COAL REFINERY

J. B. O'HARA
Manager, Energy Department
H. W. KLUMPE
Technical Advisor, Power Division
A. BELA
Principal Project Engineer
N. E. JENTZ
Chief Process Engineer

THE RALPH M. PARSONS COMPANY

Pasadena, California 91124

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J. B. O'Hara, H. W. Klumpe, A. Bela, and N. E. Jentz

The Ralph M. Parsons Company
Pasadena, California 91124

INTRODUCTION

The development of the capability to produce ecologically acceptable liquid, gas, and solid fuels from indigenous coals at a cost which is competitive with alternative energy sources remains a national objective. A number of processes have been proposed for production of synfuels and electricity from coal. The Ralph M. Parsons Company, under contract to the Office of Coal Research (OCR) and then the Energy Research and Development Administration - Fossil Energy (ERDA), has completed and published five (5) conceptual designs/economic evaluations for coal conversion complexes.[1,2,3,4,5] These have included all major generic classifications of coal liquefaction, i.e., hydroliquefaction, donor solvent, pyrolysis, and indirect liquefaction. Parsons work was done in support of OCR/ERDA's coal conversion technology development program. Procedures for production of petrochemical feedstocks and chemicals from coal have also been described;[6] this type facility also uses a number of steps common to synfuels-from-coal complexes.

This paper describes key elements of a conceptual design which combines three coal conversion operations -- hydroliquefaction, pyrolysis and gasification -- with advanced electric power generation in a coal refinery which produces a broad slate of synfuels plus power. The complex is referred to as Project POGO, which is an acronym for Power-Oil-Gas-Other -- it is an outgrowth of the work done earlier to develop the COG (Coal-Oil-Gas) Refinery Concept. Its configuration is the result of an analysis of preferred combinations of coal conversion technologies.[7]

The detailed report describing the facilities and projected economics for PROJECT POGO is scheduled for publication in 1978.

OBJECTIVES

The objectives of this presentation are:

- To describe the POGO Coal Refinery Complex
- To describe the process preference studies used to select the preferred electrical power generation facilities
- To describe the power plant section of the complex and how it interacts with the process plant.

FACILITY DESCRIPTION

Designs were developed for three sections of the country. These consisted of the Appalachian Region of the Eastern Coal Province, the Eastern Region of the Interior Coal Province, and the Powder River Area of the Rocky Mountain Coal Province. The description presented here is for the Eastern Region, Interior Coal Province Case.

The complex is described in the Figure 1 simplified block flow diagram. Here we see that the material inputs are coal resources in the ground, air, water, machinery/equipment, and operating supplies -- the complex contains a captive coal mine and produces all of its utilities. Products are:

- SNG
- LPG's
- Gasoline
- Distillate Fuel Oil
- Coke; Premium Grade
- Electrical Power
- By-Products, including
  - Sulfur
  - Ammonia

Projected product yield structure for the process and power plant areas is shown in Figure 2. These yields are considered reasonably firm at this time but are subject to confirmation in the final design report. This indicates that approximately 45,000 tons per day (TPD) of clean coal is converted to a product mix consisting of approximately 150 million SCFD of SNG; about 13,000 barrels per day (BPD) of C_3-LPG; approximately 2,000 BPD of C_4-LPG; 35,000 BPD of gasoline; approximately 27,000 BPD of distillate fuel oil; approximately 1,600 TPD of a premium grade coke; and 1,000 megawatts of electrical power for sale.

For ease of description of the complex, it will be divided into five areas, each containing multiple units. The five areas and the units which make up the areas are:

1. Coal mining and preparation; see Figure 3
2. Coal conversion; see Figure 4
3. Product recovery and refining; see Figures 5 and 6

4. Offsites, ancillaries, environmental; see Figure 7

5. Power plant - fuel gas production and power generation; see Figure 8

Each area will be briefly described.

COAL MINING, PREPARATION

The complex contains a captive coal mine. The mine produces approximately 60,000 tons per day of run-of-mine coal from six operating faces. The coal is processed in a coal preparation facility which produces about 45,000 tons per day of clean, sized coal. Twenty-seven thousand tons per day is a fraction containing 6.5% ash and the remainder is produced as an 8% ash fraction which is fed to a fuel gas production unit which, in turn, supplies the power plant area. The utility portion of the complex will be described in detail later.

COAL CONVERSION

Key elements of the coal conversion section of the complex include an SRC-II type hydroliquefier (dissolver), a pressurized flash pyrolyzer, and a process gasifier. Additional process units include fractionation, acid gas removal, and shift conversion units.

AN IMPORTANT FACTOR: liquid separation equipment such as filters, hydroclones, centrifuges and related types of equipment are not required.

The coal conversion portion of the complex is depicted in Figure 4. Here we see the 27,000 TPD feed coal split with 20,000 TPD going to the SRC slurrying and dissolving unit and 7,000 TPD fed to the pyrolysis unit; this coal will contain approximately 6.5% ash. The process uses an SRC II operating mode involving recycled solids - containing solvent to slurry the coal feed to the dissolver. The purpose is to provide a pseudocatalytic effect resulting in higher hydrogen uptake, longer retention time in the dissolver, and production of a more liquid dissolver product than for the SRC II mode without recycle solids.

The dissolving reaction is accomplished by mixing hydrogen with the feed slurry, preheating to 700°F and reacting in the dissolver at 2025 psig pressure and an outlet temperature of 850°F. The resulting dissolver product slurry passes through a pressure letdown system where gases and light hydrocarbon vapors are flashed. The resulting liquid is fractionated at atmospheric pressure to produce naphtha, a 400-650°F cut, and a 650°F+ bottoms product. The naphtha is fed to a hydrotreating operation, the 400-650°F fraction is fed to a heavy liquids hydrotreater while the 650°F+ cut is split; a portion of it containing ash and unreacted coal solids is recycled to slurry the coal feed to the dissolver while the remainder is mixed with a similar boiling fraction produced in the pyrolysis section and fed to a vacuum distillation operation.

The vacuum distillation takes place at a pressure of 30 mm Hg absolute to produce a 650-1200°F distillate cut which is recycled as a portion of the solvent used to slurry the coal feed to the dissolver. The bottoms, a 1200°F+ cut which also contains solids produced in the dissolver, are fed to the pressurized flash pyrolysis section.

Approximately 7,000 TPD of the 6.5% ash feed coal is fed to the flash pyrolysis unit. Here it is combined with approximately 6300 TPD of the vacuum distillation bottoms just described. The purpose of the pyrolysis unit is:

1. To convert the vacuum distillation bottoms to (1) liquids which are recovered and treated to produce valuable fuel products and, (2) char, valuable for use in production of the required hydrogen.

   - It eliminates the need for filtration of fuel solids which are not converted in the dissolver and the ash contained in the dissolver feed coal.

2. To produce gases, a tar, and char from the feed coal.

3. To provide a valuable char interaction with the process gasifier.

   - It provides feed char to the gasifier for hydrogen production.

   - It improves thermal efficiencies for the pyrolysis-process gasifier combined system.

The pyrolysis operates at approximately 500 psig and 1100°F with a nominal retention time of less than one second. The pyrolysis products are separated into char and vapor; the gases are separated from the vapor and fed to an acid gas removal system. The liquids and tar are subjected to atmospheric distillation, the products being a naphtha cut which is fed to a naphtha hydrotreating unit, a 400-650°F fraction which is fed to heavy liquid hydrotreating, and a bottoms cut, 650°F+, which is fed to the vacuum distillation unit previously described.

Approximately 9,600 tons per day of char are transferred from the pyrolysis plant to the process gasifier where the hydrogen required for coal dissolving and hydrotreating is produced. This is an oxygen-blown, slagging, pressurized, entrained gasifier. The effluent gas is processed to recover heat, it undergoes a shift conversion to increase the hydrogen-to-carbon monoxide ratio, carbon dioxide and hydrogen sulfide are removed in a selective physical solvent acid gas removal system, and the hydrogen stream produced is fed to the SRC coal dissolving operation. Carbon dioxide separated in the acid gas removal is vented and a hydrogen sulfide-rich fraction is fed to a sulfur plant where it is converted to saleable elemental sulfur.

PRODUCT RECOVERY AND REFINING

Key processing units in the product recovery and refining section include:

- Hydrotreating heavy liquids
- Thermal cracking
- Coking
- Olefinic gas-acid gas removal unit
- Saturated gas-acid gas removal unit
- Naphtha hydrotreating
- Naphtha reforming
- Olefin recovery and polymerization
- Hydrogen recovery and purification
- SNG purification
- LPG fractionation
- Sulfur plant

The product recovery and refining sections are shown in somewhat more detail in Figures 5 and 6. Here we see that the naphtha produced in the pyrolysis, SRC dissolving, heavy liquids hydrotreating, thermal cracking, and coking operations are combined and hydrotreated to remove sulfur and nitrogen. The naphtha is then fractionated into heavy and light fractions. The heavy naphtha is reformed and the two naphtha fractions then recombined. Polymer gasoline, produced from olefins obtained from the recovery system, is added to make up the total of about 35,000 barrels per day of gasoline.

The 400-650°F cuts from the pyrolysis and coal dissolving atmospheric distillation operations are combined with the 650-1200°F fraction from the vacuum distillation to serve as feed to the heavy liquids hydrotreating unit. Here these distillate products are reacted with hydrogen at 2700 psig and 800°F to produce a gas which is subsequently treated in the saturate gas-acid gas removal unit, a 400-650° fraction, and a 650°F+ fraction. The heavy product is then thermally cracked to produce additional gas, naphtha, and a bottoms product which in turn is coked in a delayed coking unit to produce additional olefinic gas, naphtha, a distillate fuel oil, and product coke. The coke is a premium grade needle-type coke. The distillate fuel from the coker is combined with the middle distillate range material produced in the heavy liquids hydrotreater to produce a distillate fuel oil product.

The olefin containing gases are combined and treated in an amine type acid gas removal unit. The hydrogen sulfide removed is fed to the sulfur plant. The olefins are recovered and are combined with those produced in the thermal cracking step and fed to a "cat-poly" unit where they are converted to polymer gasoline.

Sweet gas from the saturate gas acid gas removal unit is separated in a cryogenic unit which produces:

- A hydrogen-rich stream for recycle to the hydroliquefaction section.
- A methane-rich gas containing some carbon monoxide and hydrogen which serves as feed to the SNG unit.
- A C_2+ fraction which is fed to the LPG fractionation unit.

In LPG fractionation, some ethane and propane are produced as an overhead product and combined with the effluent from the SNG purification unit to produce approximately 150 million SCFD of pipeline quality gas. C_3 LPG and C_4 LPG are also produced in the LPG fractionation section.

OFFSITES, ANCILLARIES, AND ENVIRONMENTAL

Key elements of these portions of the complex are depicted in Figure 7.

Oxygen Plant

Approximately 20,000 tons per day of oxygen are required for the process and fuel gas gasifiers. This is supplied from four 5,000 TPD single-train oxygen plant units. Over 40 percent of the required compressed air feed is extraction air from the power plant gas turbines. Compressor facilities for feeding oxygen to the process gasifier at 500 psig and to the fuel gas gasifier at 400 psig are provided. A portion of the nitrogen is utilized as plant instrument air and the balance is vented to the atmosphere.

Sulfur Plant

The sulfur recovery plant receives the combined streams of hydrogen sulfide containing gases from the acid gas removal units. The sour gases are first processed in two identical parallel three-stage Claus sulfur plants. Nearly 1,650 tons per day of elemental sulfur are produced here.

The effluent gases from the Claus plants are processed in a tail gas plant where the balance of the sulfur amounting to about 90 tons per day is removed; the Beavon process was used for this design. The effluent gas vented to the atmosphere meets air pollution requirements.

Water Systems

Potable and sanitary water is obtained from a deep well equipped with a 250 gpm pump. The water is treated and filtered. Raw water is pumped from a nearby river at a rate in excess of 20,000 gpm. It passes through a traveling screen for trash removal, then through a clarifier for removal of suspended particulates and finally passes through a sand filter into a 4 million gallon storage tank. The raw water is circulated through the plant where 95 percent is utilized as cooling tower makeup; the balance is used for coke quenching and, following deionization, as boiler feed water.

Effluent water, which is a combination of contaminated surface water and waste water from the process areas, cooling tower blowdown, demineralizer backwash, sanitary sewage effluent, and oily waters, is treated in a system of oil-water separators, filters, a neutralization basin, a settler-clarifier and a biological treatment pond. The final effluent water is used to supply the fire water circuit and dust control in the mine areas. Surplus is returned to the river. Sufficient treatment is provided to meet environmental regulations.

Product Storage

Three weeks' storage capacity is provided for liquid products. Propane and and butane storage is atmospheric and refrigerated. A sizeable tank farm is provided, properly diked, with service roads and loadout facilities. A gasoline blending area is included. Shipping to contract customers is via pipeline, barge, rail, or truck.

Plant Flare System

A flare system provides for combustion of vented gases on operation of pressure safety valves, or emergency manual venting. A knockout drum is provided to accumulate and return condensed liquid to the process system.

Shops and Buildings

A complete community of buildings is provided including administrative offices, laboratories, cafeterias, change houses, maintenance shops, warehouses, fire stations, medical building, security guard houses, control rooms, and field offices. The total floor area is approximately 250,000 square feet.

PLOT AREA

The estimated land requirement is 640 acres (a square mile).

POWER GENERATION

A most important goal of the design concept was inclusion of a large electrical power generation and steam system as an integral part of the coal refinery. Major elements of this area, as designed, are illustrated in Figure 8.

Properly designed and operated, the efficiency of the complex should be increased by maximizing the effective use of the energy potentials in streams which interface the coal mining, coal refinery, and utility areas. To illustrate, excess steam generated in the process areas can be efficiently converted to electrical power, and extracted compressed air produced in the power plant can be used to improve the efficiency of the air separation plant.

Steps taken during development of the final power generation area configuration are described below.

Objectives

The design objectives of the power section were:

- To select an improved power system, integrated with the coal mine and coal refinery, that will provide best overall efficiency for production of electricity for sale.
- To produce 1,000 megawatts for sale plus the power required to operate the coal mine, coal refinery, and support facilities.
- To utilize state-of-the-art equipment in a combined cycle configuration which can be readily adapted to use expected future improvements in power generating equipment.

Fuel Characteristics

Medium-Btu fuel gas with a higher heating value of about 320 Btu/SCF is available from an oxygen-blown gasifier at a pressure of 300 psig. The gasifier pressure was selected to be compatible with the requirements of the gas turbines.

PREFERENCE STUDIES

Following a screening analysis of candidate power plant configurations, seven generating cycles were selected for more detailed analysis; each of these included gas turbines in the combined cycle mode capable of providing a portion of the air separation plant's compressed air requirements plus a steam system able to accept steam generated in the process area. For reference, the primary energy flows between the power plant and other parts of the complex are summarized in Figure 9.

The seven systems studied are listed in Table 1. Three basic types of cycles were included which were:

CYCLE I. Seventeen (17) gas turbines, zero supplementary firing of seventeen (17) steam boilers, four (4) steam turbines, and variable air extraction from the gas turbine compressors. This system is illustrated in Figure 10.

CYCLE II. Thirteen (13) gas turbines with supplementary firing of thirteen (13) steam boilers, four (4) steam turbines, and variable air extraction from the gas turbine compressors; see Figure 11.

CYCLE III. Four (4) gas turbines, four (4) fully fired waste heat steam generators, two steam turbines, and zero air extraction from the gas turbine compressors. The system uses the highest Rankin cycle efficiency currently available; see Figure 12.

Key heat rate results are summarized in Table 2. All results are based on 1,000 MW power for sale. Credit is included for the power equivalent of the compressed air supplied to the oxygen plant.

Table 2 results indicate that the number I-c Cycle has the lowest heat rate -- 8,885 based on coal fed to the gasifier, and 7,810 based on fuel gas to the power system. These correspond to net power plant fuel to electricity efficiencies of 38 and 44 percent, respectively. These efficiencies have been improved by about 5 percent over more conventional power cycles because of the integration of the compressed air and steam supply systems between the power and process areas.

Further review of Table 2 leads to the conclusions that:

1. The use of supplementary firing in the waste heat boilers reduces efficiency, the amount of extraction air available for the oxygen plant, and the number of machines required to meet load conditions.

2. Unfired waste heat boilers increase efficiency, requires less cooling water, and provides more extraction air for the oxygen plant.

3. The use of complex Rankin bottoming cycle with high pressure and reheat steam conditions results in a lower overall efficiency than the combined cycle systems.

Economics

An economic comparison for the separate systems is summarized in Table 3.

Tables 2 and 3 results show that Cycle I has the best efficiency and lowest total energy cost per KWH. Within the Cycle I group, System I-c has the best efficiency, a power cost as low as any system studied, and also provides 40 percent of the feed air requirement for the oxygen plant. It therefore was selected for inclusion in the final design.

The results also indicate that significant variations in quantity of extracted compressed air can be tolerated without seriously affecting overall efficiency or operating cost. This provides desired flexibility during transient operating periods.

System I-c also offers advantages because reduced mass flow through the gas turbines minimizes NOX control requirements.

Additional definition of advantages for the system I-c include:

1. The compressed air supplied to the oxygen plant saves approximately 140 MW; this is about 30 percent of the total power required to operate the complex.

2. The combined cycle plants offer low installed cost when compared to other power plant alternatives; for example, the I-c system fixed capital investment is about 30 percent less than a comparable conventional steam cycle system.

3. Use of standard gas turbines offers full dual fuel capability. This is important during startup and also during times when supplementary fuel must be used to produce maximum power when production of fuel gas is curtailed.

4. The gas turbine portion can be in service within 10 - 15 minutes from cold start; it then can provide the power needs for operation of the complex.

   The waste heat steam generators can produce maximum steam within 60 minutes if maintained in a stand-by condition.

5. It can provide steam to the process during startup when fuel gas generating facilities are shut down.

6. The cooling water requirements are significantly less than other power generation alternatives; for example, they are about 700,000 GPM less than required for a conventional steam cycle system.

THERMAL EFFICIENCY

The projected thermal efficiency for conversion of coal to synfuels and by-products plus fuel gas feed to the power plant is approximately 75 percent. The distribution of energy between feed and product streams is shown in Figure 13. The efficiency for conversion of the fuel gas to electricity is about 44 percent.

The high thermal efficiency is the result of analysis of key factors in the 30 major units in the complex. A number of these analyses included development of comparative economics for candidate configurations in addition to process and performance factors.

SUMMARY AND CONCLUSIONS

A conceptual design for a coal refinery which will produce SNG, LPG's, gasoline, fuel oil, premium grade coke, and electrical power has been completed. Designs were developed for three locations in the U.S.; these were in the eastern, midwestern and western U.S. coal regions. This work was done under contract to ERDA-Fossil Energy, who have designated the design POGO as an acronym for Power-Oil-Gas-Other.

The refinery complex contains a captive coal mine. In the Eastern Region of the Interior Coal Province (midwestern region), approximately 60,000 TPD of run-of-mine coal would be produced and processed to produce about 45,000 TPD of coal feed to the process plants. The coal conversion area would include hydroliquefaction, pressurized flash pyrolysis, and process gasifier units plus product recovery/refining units. It would produce about 150 MM SCFD of SNG and 80,000 BPD of liquid products; also premium grade coke.

The complex produces 1,000 megawatts of electrical power for sale plus 400 megawatts to operate the coal mine, process area and ancillaries. A power plant configuration consisting of a combined cycle plant without auxiliary firing of the waste heat boiler and with extraction of 10 percent of the compressor air for feed to the oxygen plant was selected after analysis of seven candidate configurations. The system integrates well with the process areas and indicates an efficiency of the order of 44 percent in converting clean intermediate Btu fuel gas to electrical power, taking credit for the energy supplied to the oxygen plant in the form of extracted compressed air.

The overall thermal efficiency of coal to synfuels and by-products plus intermediate Btu gas feed to the power plant is projected to be about 75 percent. This high efficiency results from selection of high efficiency components.

The report describing the design, and projected economics, is scheduled for publication in 1978.

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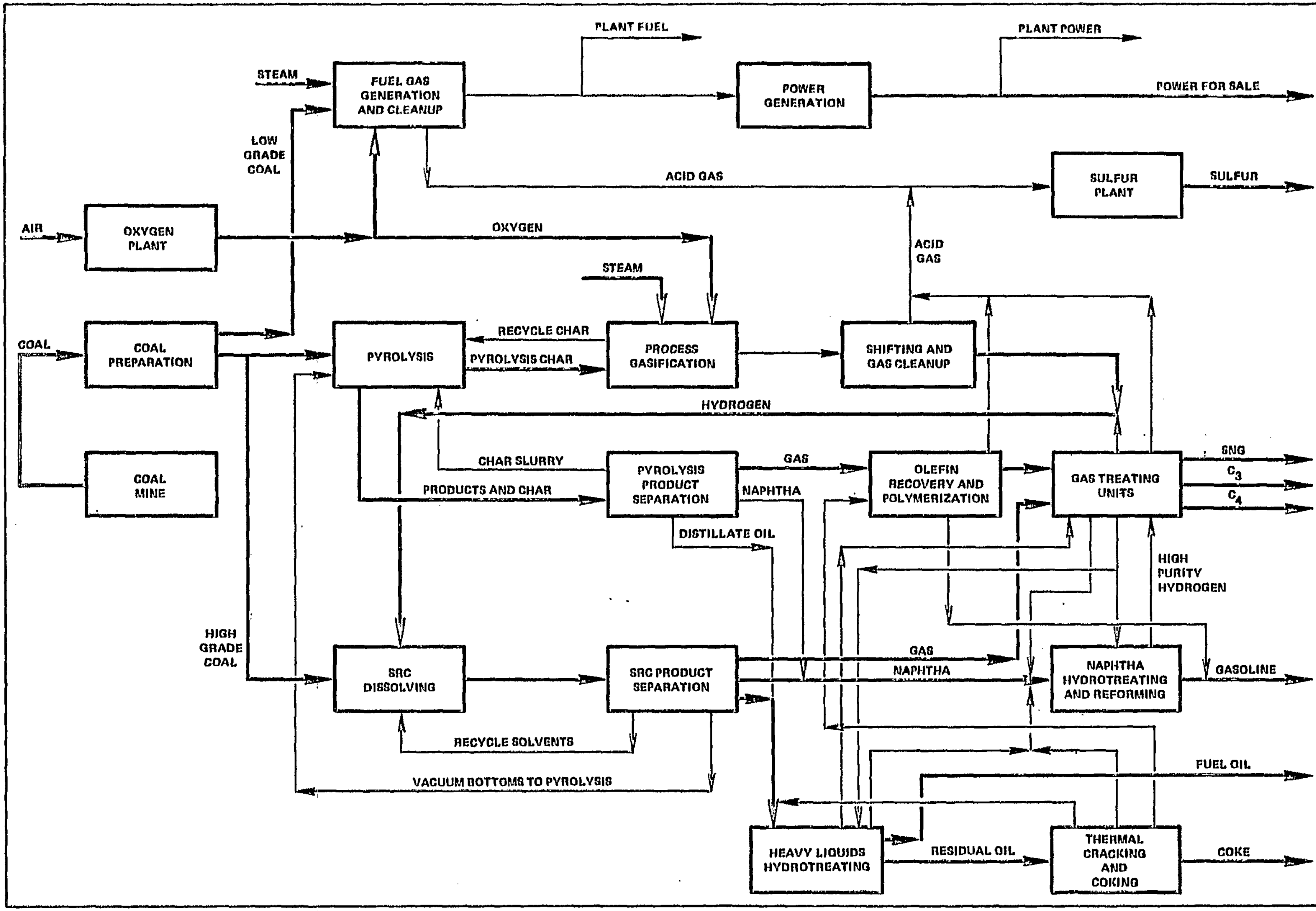


Figure 1 - Simplified Block Flow Diagram

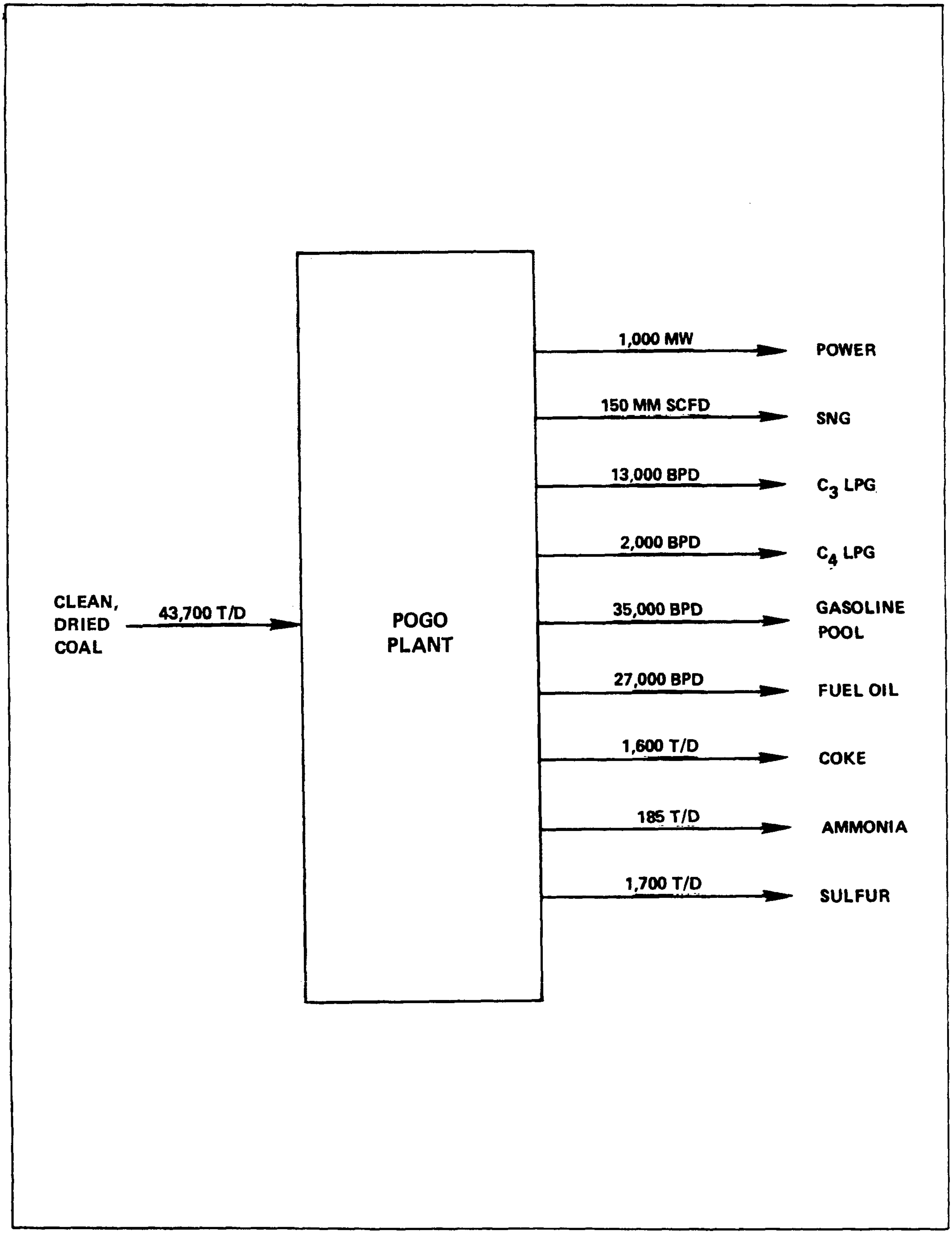


Figure 2 - Projected Plant Yields

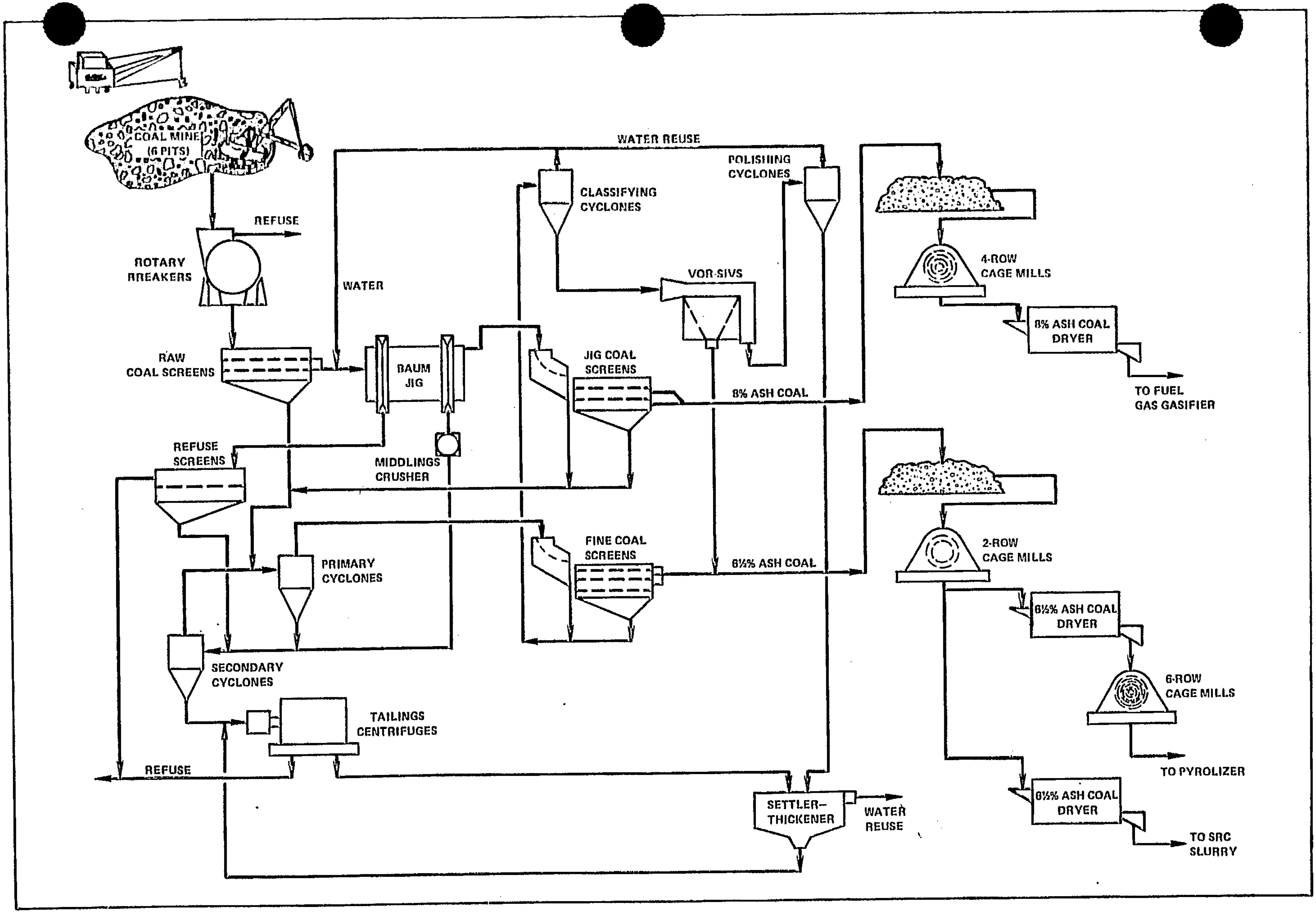


Figure 3 - Coal Mining and Preparation Areas

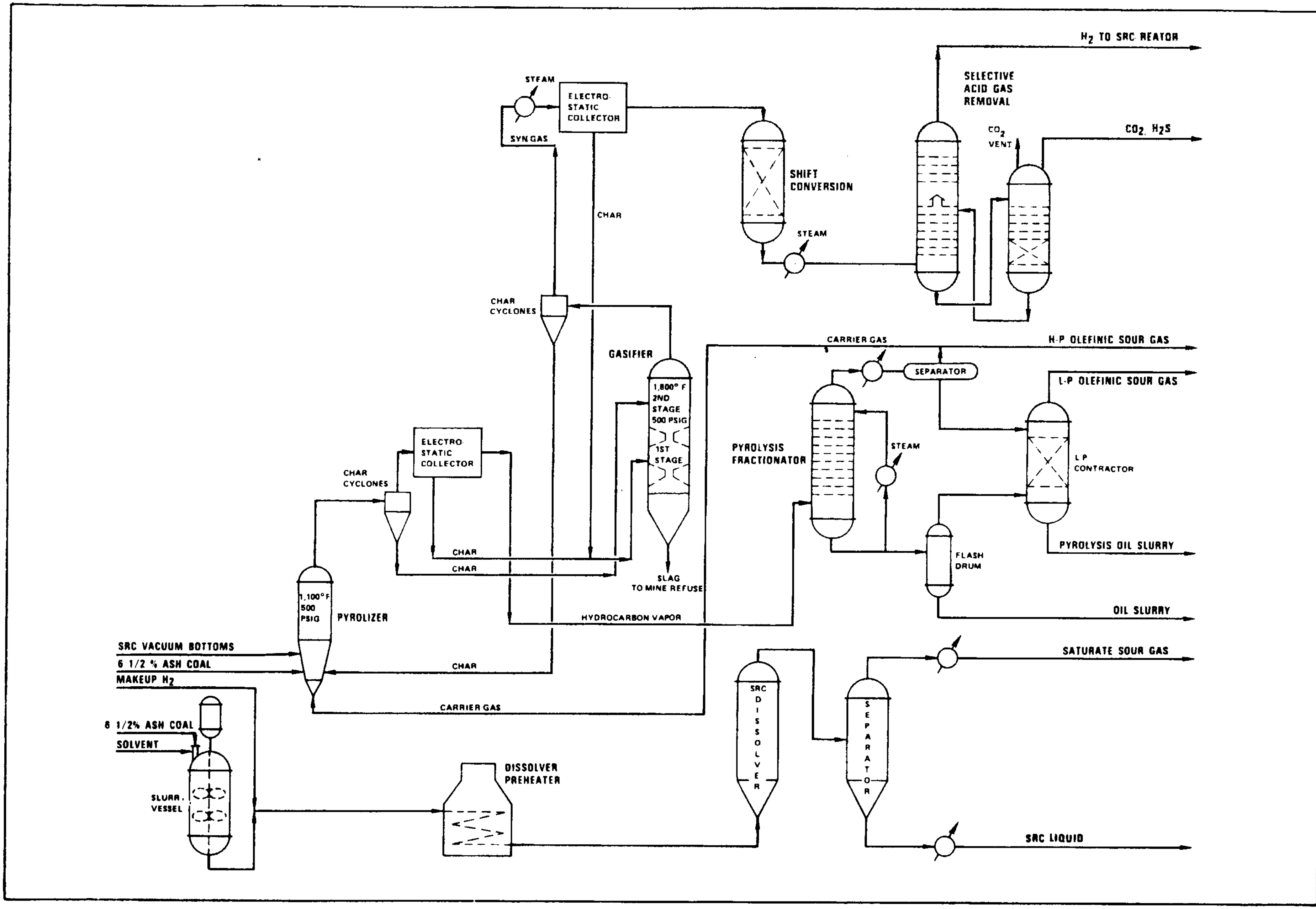


Figure 4 - Coal Conversion Areas

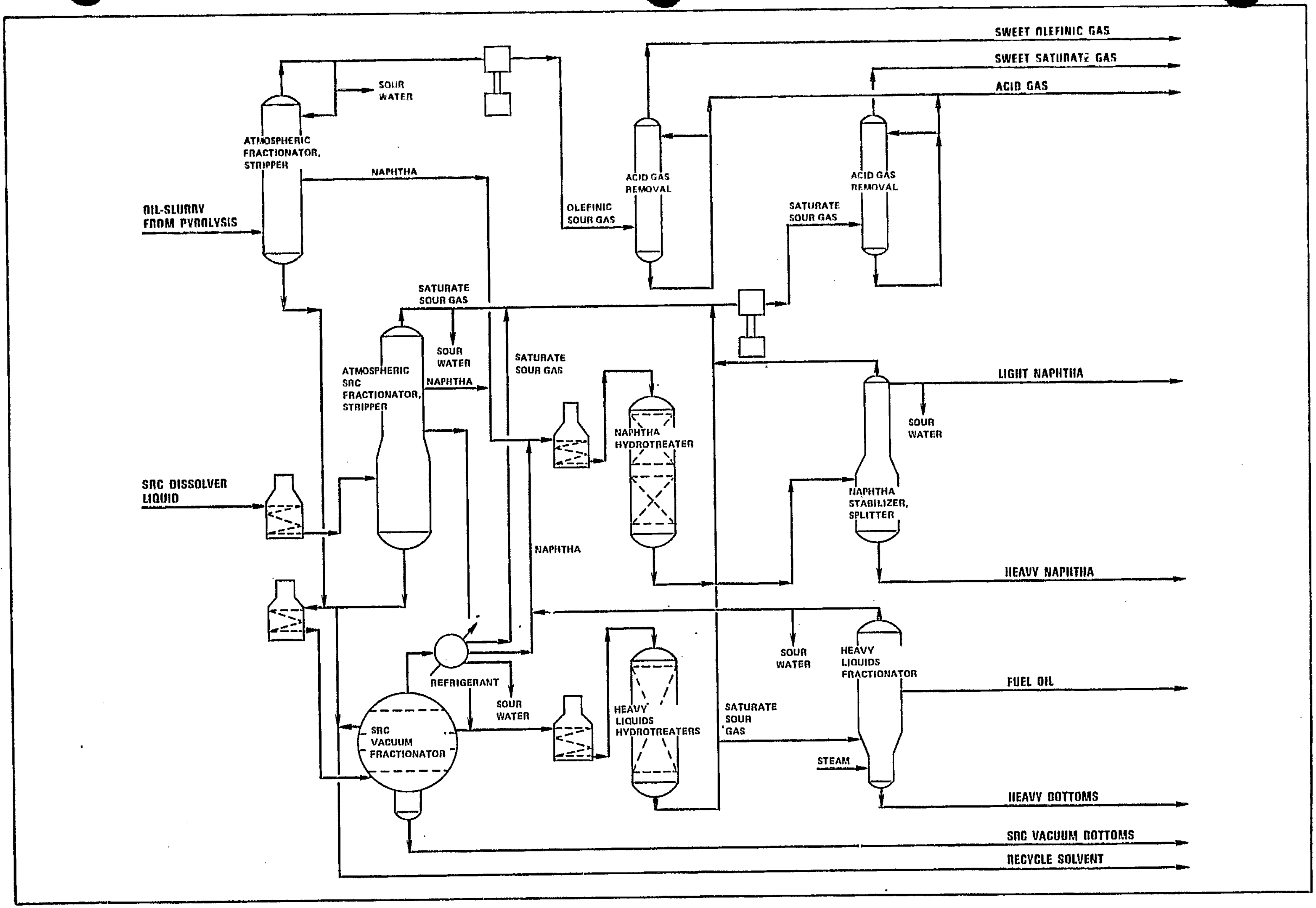


Figure 5. - Product Recovery and Primary Purification

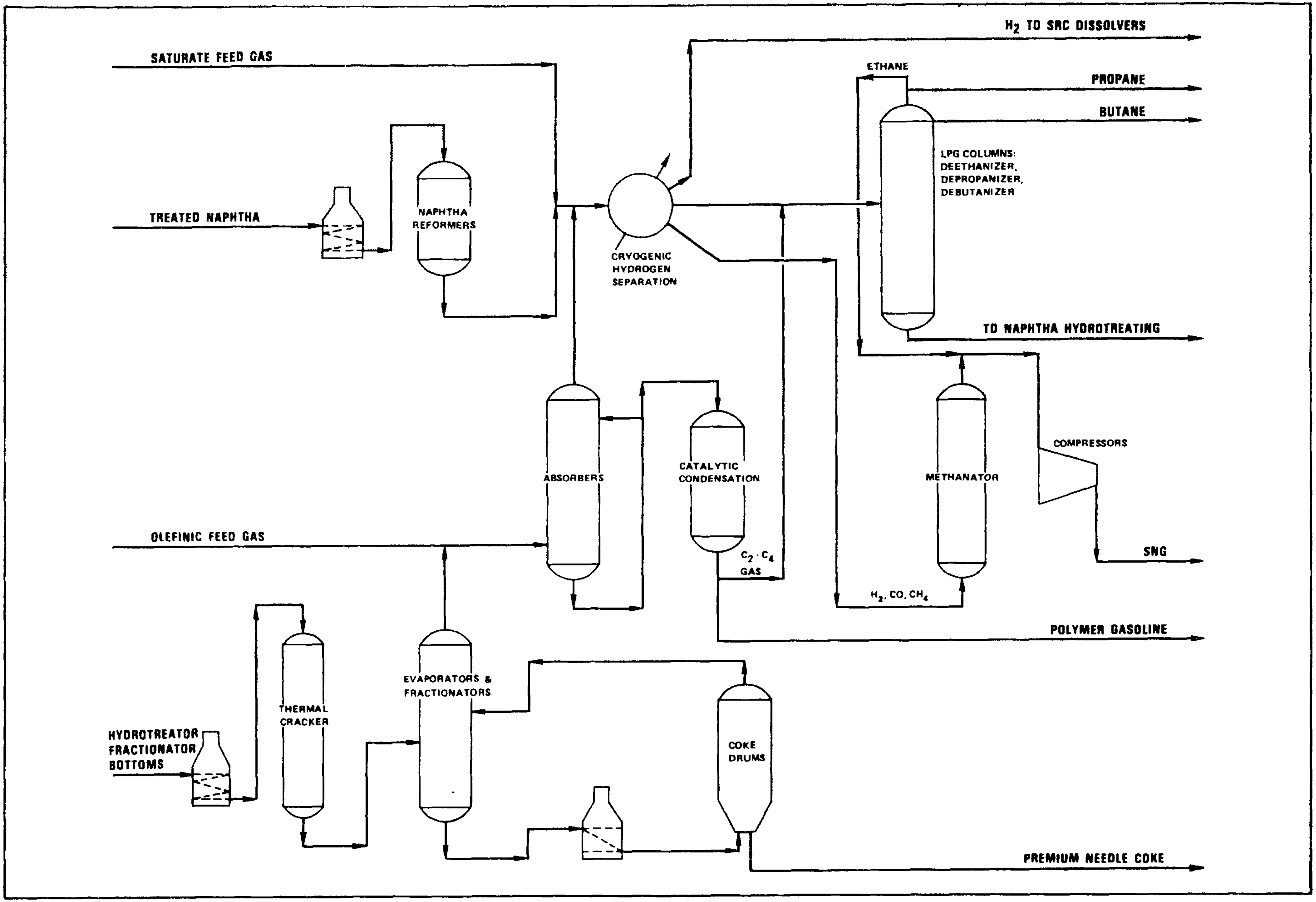


Figure-6 - Product Refining

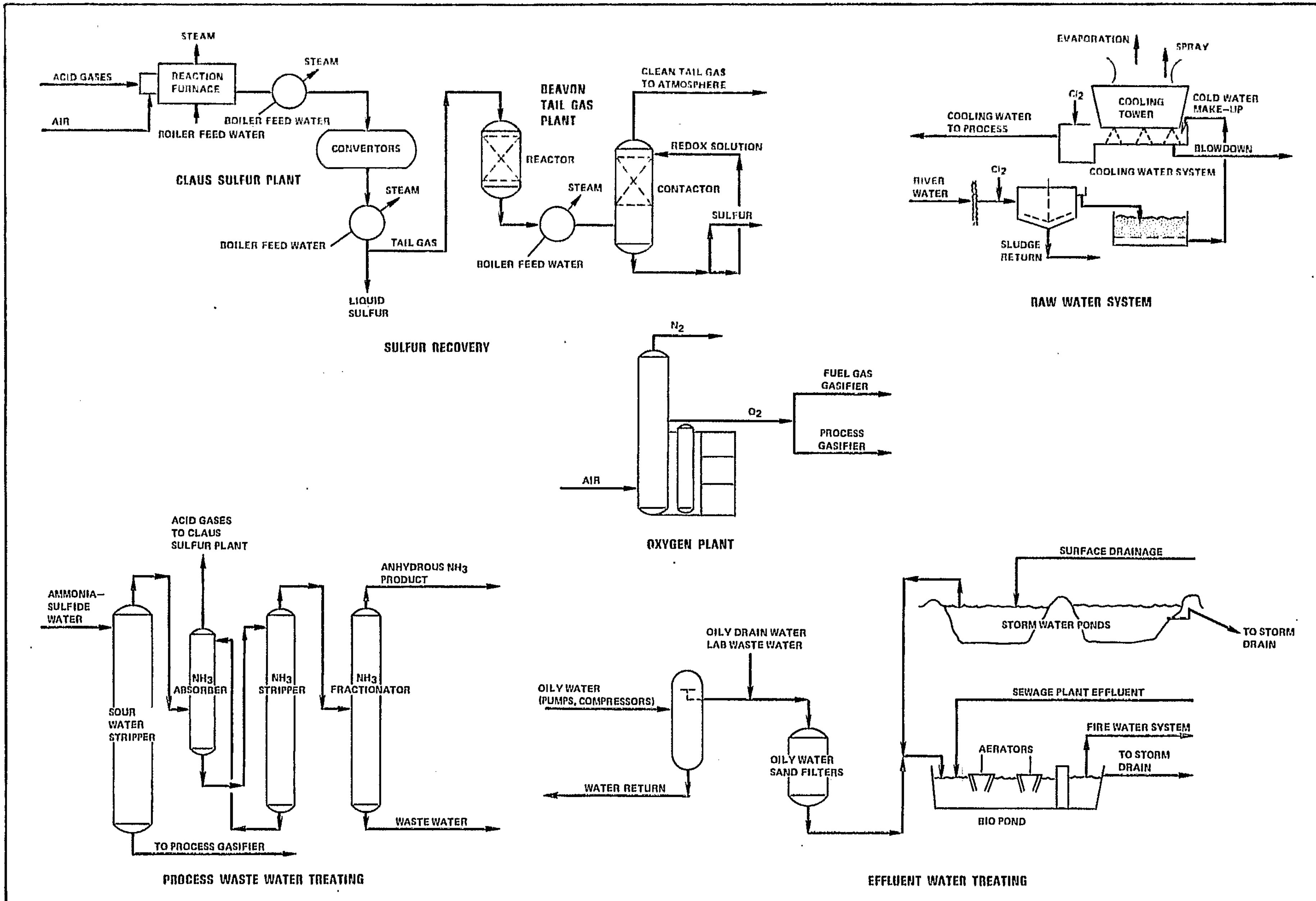


Figure-7 - Offsites

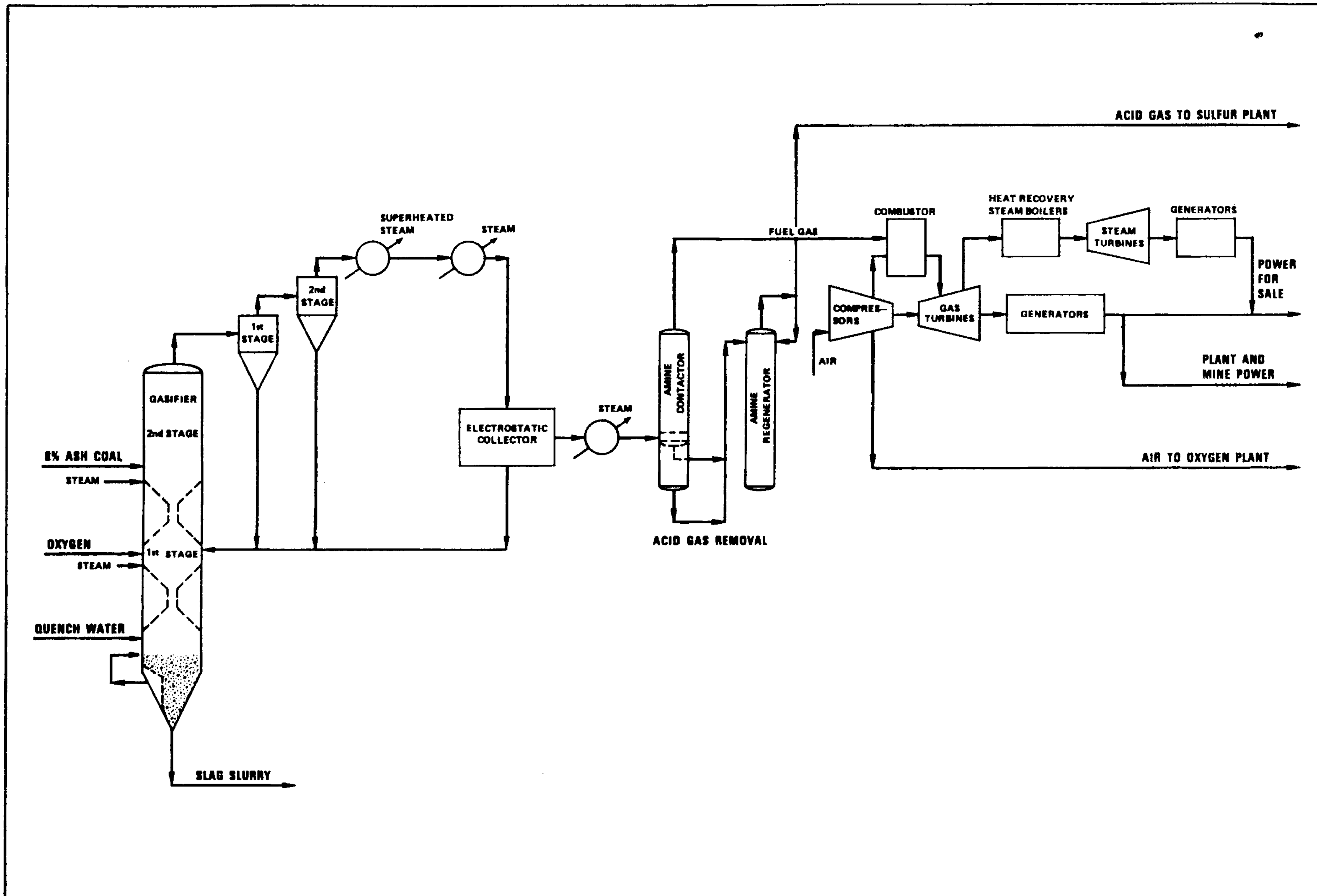


Figure 8 - Power Generation System

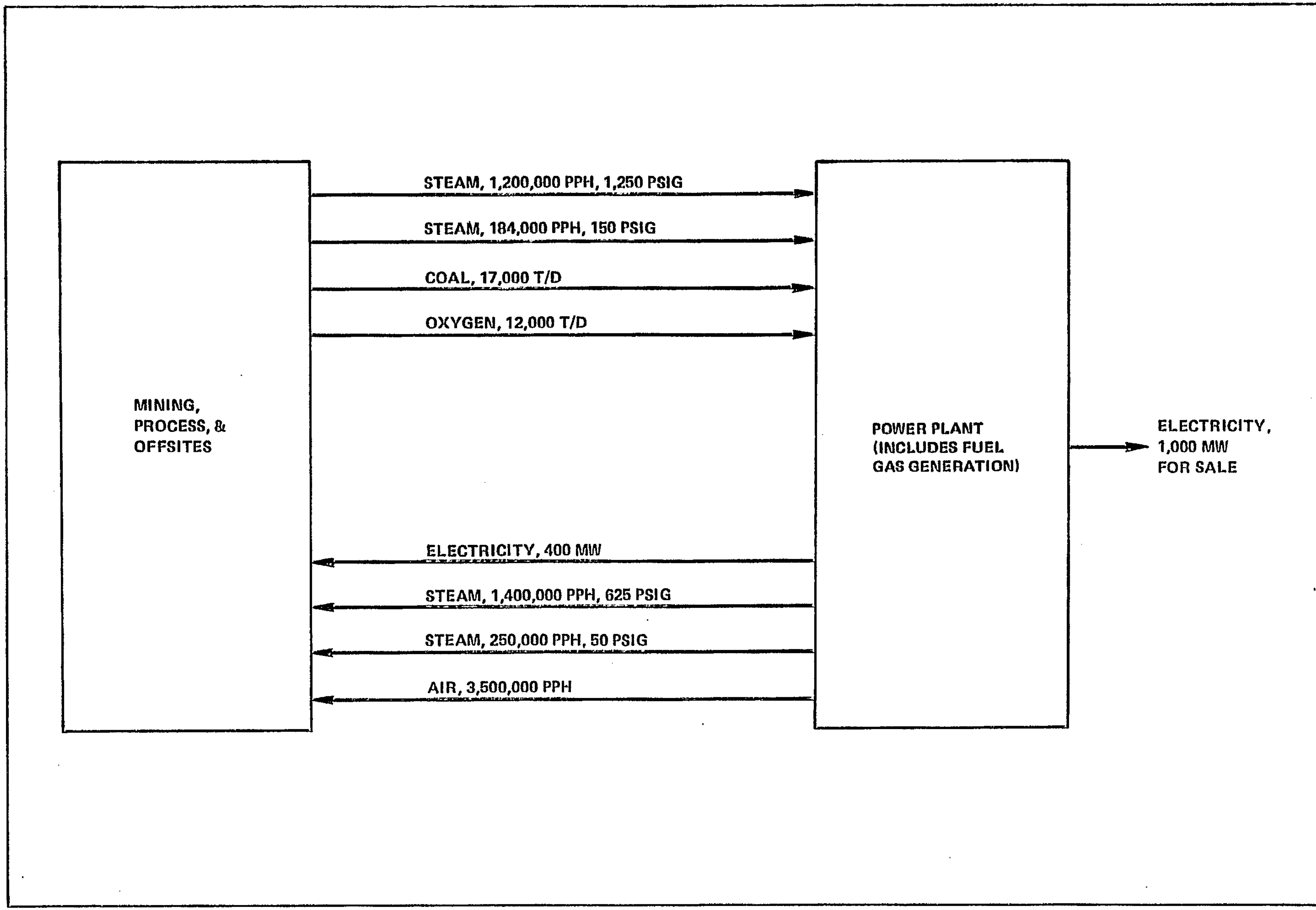


Figure 9 - Major Flows To/From Power Plant

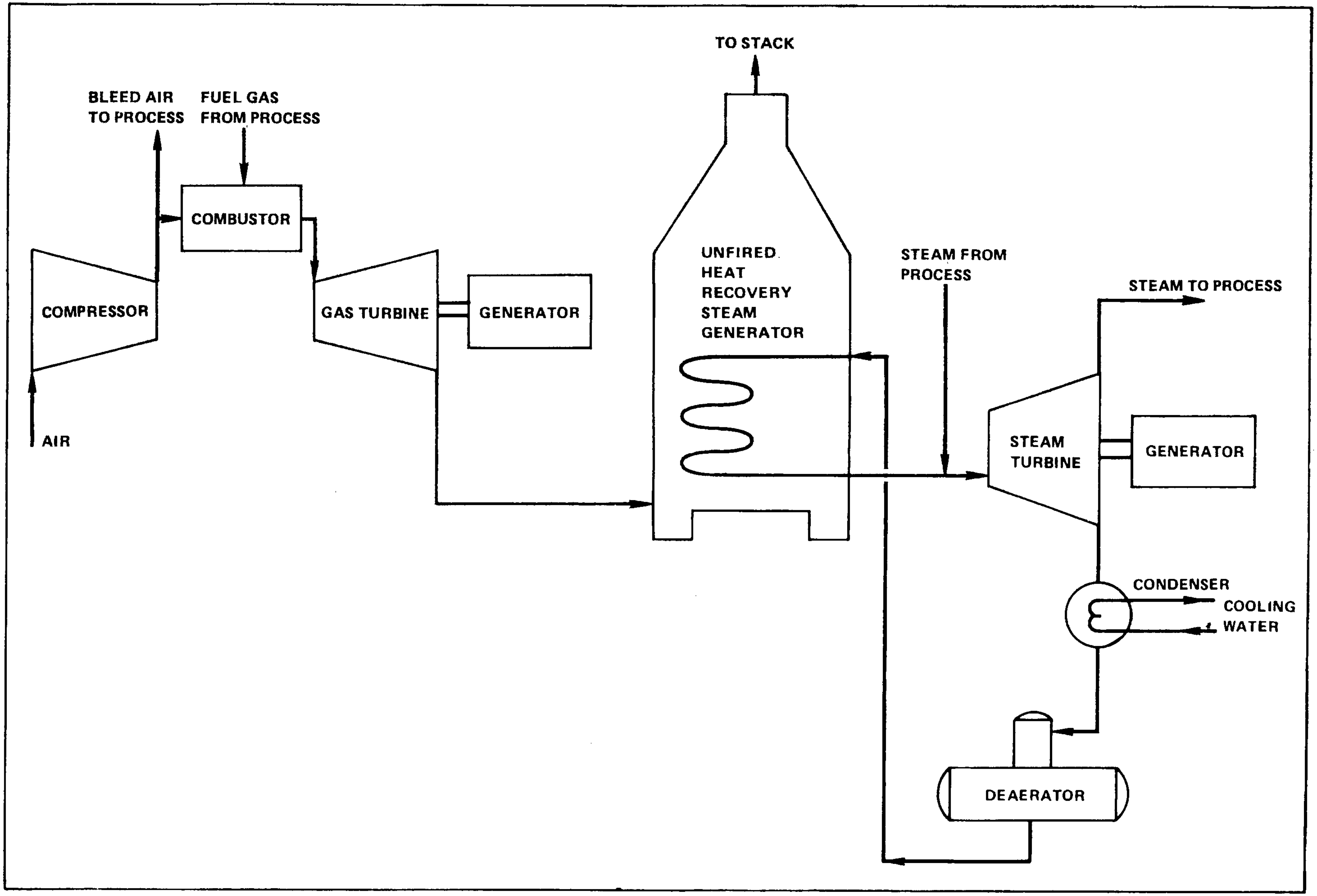


Figure 10 - Schematic of Power Cycle No. I

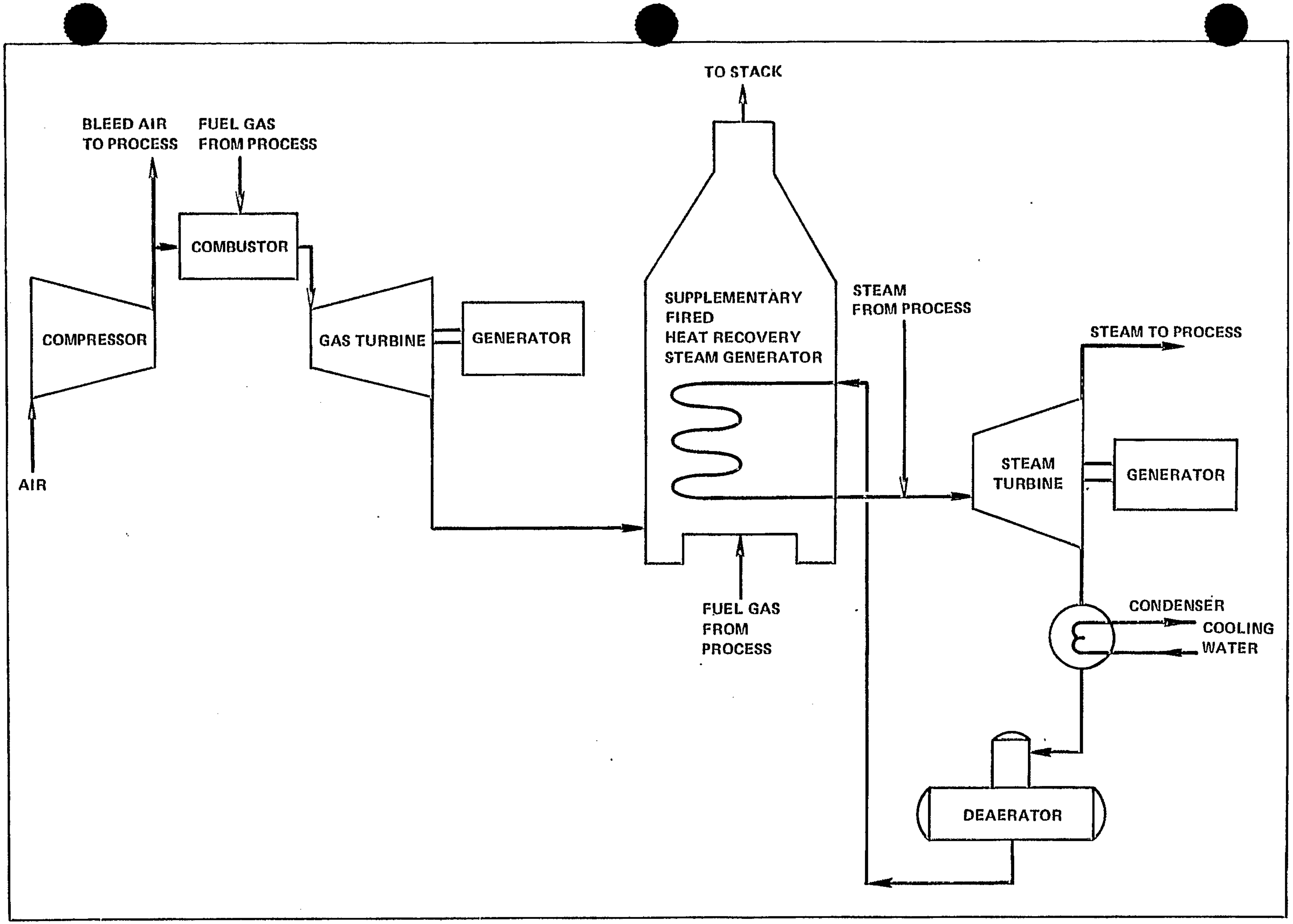


Figure 11 - Schematic of Power Cycle No. II

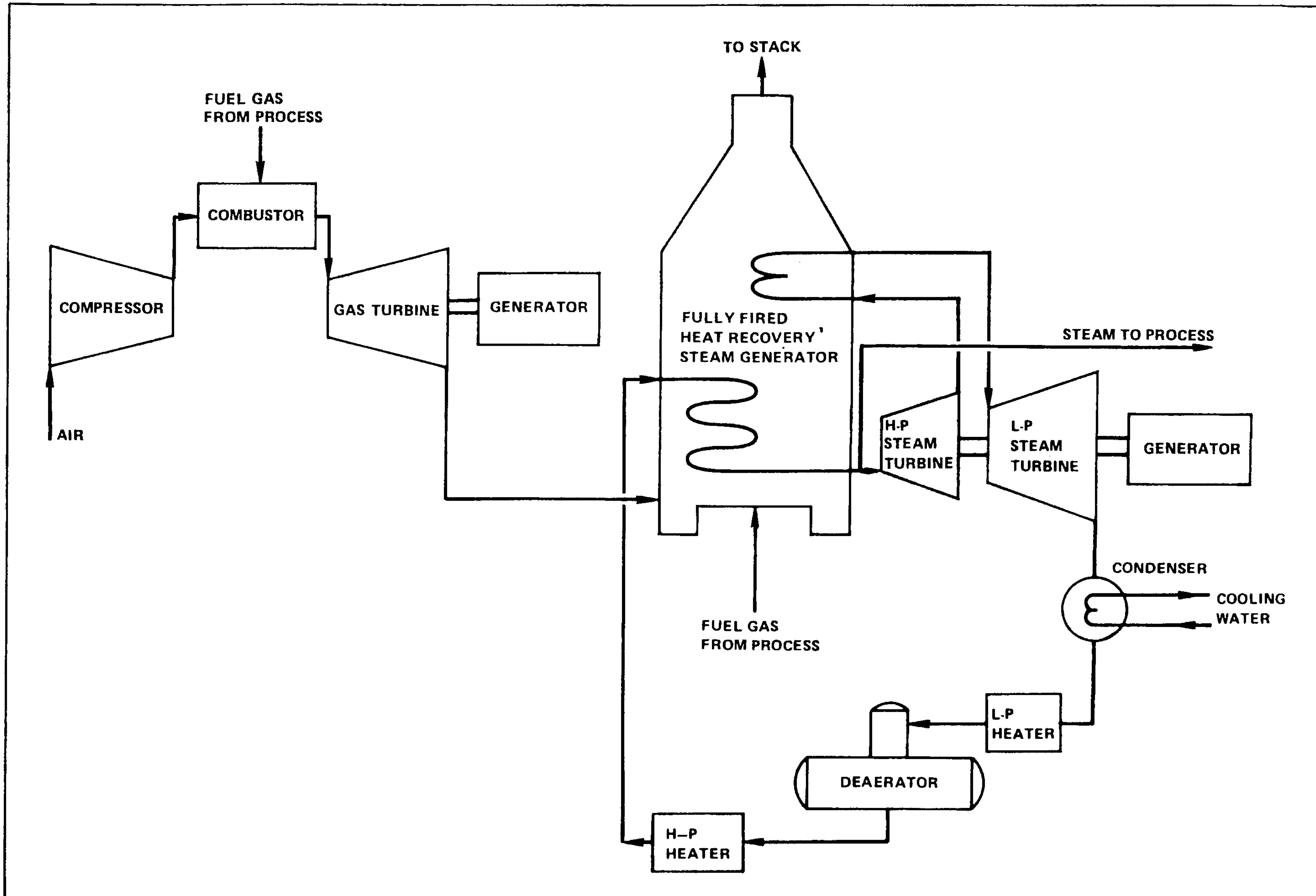
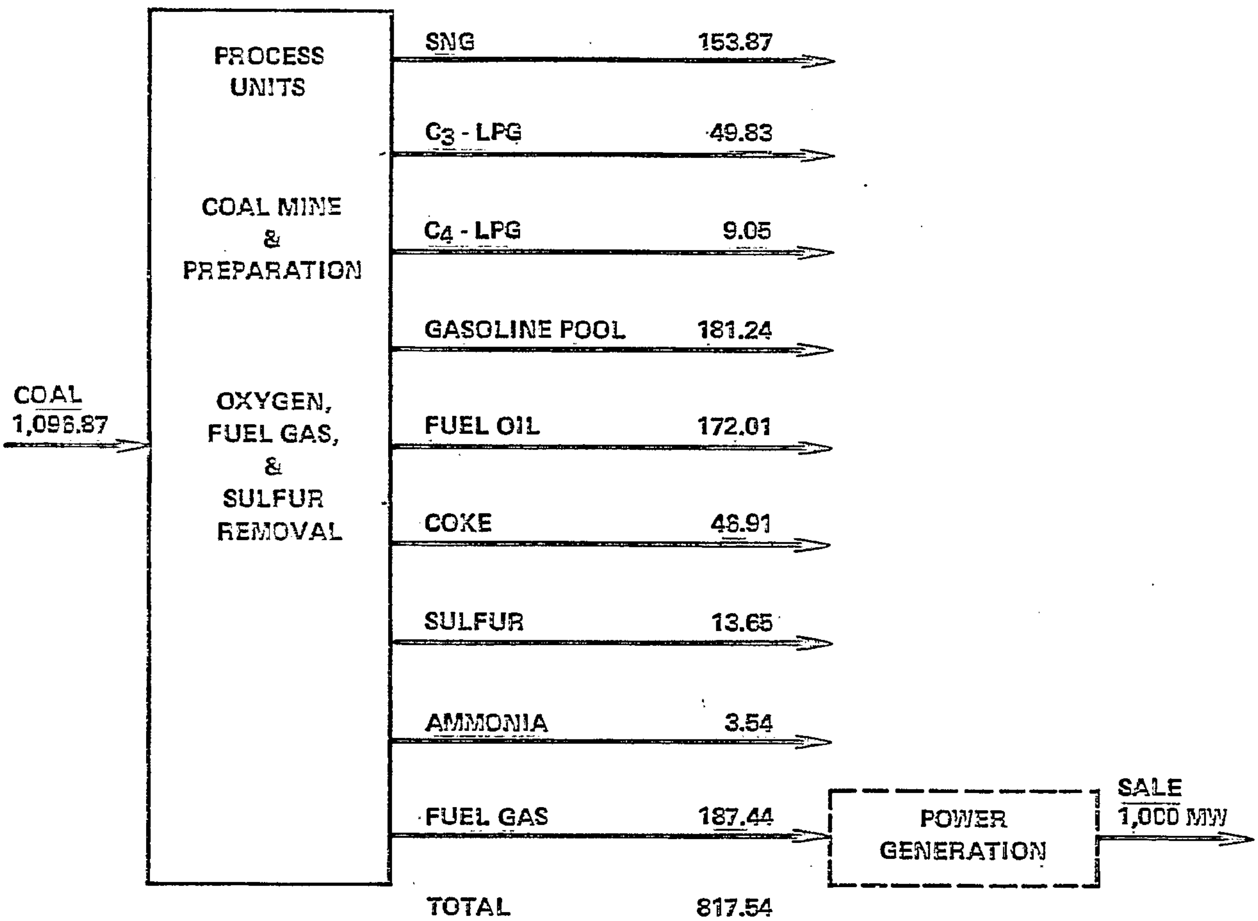


Figure 12 - Schematic of Power Cycle No. III



ALL FIGURES ARE MMM BTU/D HHV

PROCESS THERMAL EFFICIENCY:

$$\frac{817.54}{1,096.87} \times 100 = 74.5\%$$

POWER GENERATION EFFICIENCY (BASED ON GAS)

$$\frac{1,000,000 \text{ KW} \times 24 \times 3,413 \text{ BTU/KWH}}{187,440,000,000} \times 100 = 43.7\%$$

Figure 13 - Projected Thermal Efficiency

Table 1 - Power Cycle Characteristics

System Number	Number of Gas Turbines with Steam Boilers	Number of Steam Turbines	Percent Air Extraction (Feed to Oxygen Plant)	Supplementary Firing
I-a	17	4	0	No
I-b	17	4	5	No
I-c	17	4	10	No
II-a	13	4	0	Yes
II-b	13	4	5	Yes
II-c	13	4	10	Yes
III	4	2	0	Yes

Table 2 - Summary of Power Production and Heat Rate Preference Studies

System Number	Net Power Produced (MW)			Power to Process	Power for Sale	Compressed Air to Oxygen Plant		Net Power Produced (Electricity + Air)	Heat Rate[a] in Btu/kWh Produced, Based on	
	Gas Turbine	Steam Turbine	Total	MW	MW	MM PPH	MW Equivalent	MW	Coal to Fuel Gasifier	Fuel Gas to Power Plant
I-a	1069	463	1532	532	1000	0	0	1532	8890	7815
I-b	993	463	1465	456	1000	1.6	71	1527	8915	7835
I-c	905	470	1375	375	1000	3.3	147	1522	8885	7810
II-a	832	702	1534	534	1000	0	0	1534	9365	8235
II-b	779	693	1472	472	1000	1.3	55	1527	9345	8215
II-c	714	692	1406	406	1000	2.5	116	1522	9280	8160
III	247	1295	1542	542	1000	0	0	1542	10,000	8795

(a) Includes Credit for Power Equivalent for Compressed Air to Process

Table 3 - Preliminary Economics Summary - Power Plant Preference Studies

System Number	Net Power Produced[a] MW	Fixed Capital Investment $MM	Operating Costs (Mils/kWh)					Fixed Charges[d] Mils/kWh	Total Cost Mils/kWh
			Fuel[b]	Labor	Maintenance	Other[c]	Total		
I-a	1532	405	19.54	1.5	2.0	0.20	23.24	5.4	28.6
I-b	1527	405	19.59	1.5	2.0	0.20	23.29	5.4	28.7
I-c	1522	405	19.53	1.5	2.0	0.20	23.23	5.4	28.6
II-a	1534	389	20.59	1.5	2.1	0.24	24.43	5.1	29.5
II-b	1527	389	20.54	1.5	2.1	0.24	24.38	5.1	29.5
II-c	1522	389	20.40	1.5	2.1	0.24	24.24	5.1	29.3
III	1542	575	21.99	1.5	3.0	0.36	26.85	7.5	34.4

(a) From Table 2
(b) Fuel Gas at $2.50 per million Btu
(c) Includes cost of water at $0.20 per 1000 gallons
(d) 16% fixed charges

COLLECTED WORK NO. 23

FE-1775-13
Distribution Category UC-89

PROJECT POGO - COAL REFINERY COMPLEX CONCEPTUAL DESIGN/ECONOMIC ANALYSIS

POWER - OIL - GAS - OTHER PRODUCTS

R & D REPORT NO. 114, INTERIM REPORT NO. 6

Prepared by:
THE RALPH M. PARSONS COMPANY
Pasadena, California 91124

Date Published: December 1977

Prepared for
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OFFICE OF ASSISTANT SECRETARY FOR ENERGY TECHNOLOGY
DIVISION OF COAL CONVERSION
Washington, D.C. 20545

Contract No. EX-76-C-01-1775

SECTION 1

INTRODUCTION

This report presents the results of a conceptual design and economic evaluation for a commercial coal conversion complex that will mine coal and convert it into a product slate consisting of substitute natural gas (SNG), LPGs, unleaded gasoline, low sulfur distillate fuel oil, premium grade coke, and approximately 1,000 MW of electrical power for sale. The design was begun under the sponsorship of the Energy Research and Development Administration (ERDA), and completed under the Department of Energy (DOE). ERDA assigned the name Project POGO to the design; this is an acronym for Power-Oil-Gas-Other.

This is the sixth in the series of conceptual designs by Parsons.[1,2,3,4,5,6,7] Preceding conceptual design/economic analyses have included all major generic classifications of coal liquefaction; i.e., hydroliquefaction, donor solvent, pyrolysis, and indirect liquefaction. It also represents the third Parsons design using SRC-II technology. The first was published in 1973[2]; it produced a boiler fuel while consuming the fuel gases and light hydrocarbons generated during processing. A more recent version[7] developed the design and economics for a plant to convert 36,000 tons per day of feed coal to a product mix consisting of SNG, LPGs, naphtha, and a heavy fuel oil. Both of these earlier SRC-II designs used filtration to remove coal ash and unconverted solids from the fuel oil product. Predicted thermal efficiencies increased from 63.5% for the first design to approximately 77% for the second.

This third SRC-II design incorporates procedures for elimination of the troublesome filtration step, produces products that have been refined to be directly marketable, and also produces significant electrical power for sale. A primary objective was to design an improved configuration for the electrical power generation section using combined cycle facilities; also to maximize the effective use of energy potentials between the power plant, the coal mine, and the process section of the coal refinery. The intent is that such a system properly designed and operated would provide improved efficiency of the complex and its economics.

The design presented is conceptual. As such, it incorporates certain potentially attractive operations, such as pressurized flash pyrolysis and pressurized entrained slagging two-stage gasifiers, which have not yet been fully operated on a pilot plant scale. The design is intended to show the potential performances and economics for the configuration defined; also to define additional development work required to convert the conceptual design to commercial reality. These caveats become a part of the design report and its interpretation.

The design presented here is the result of a multiphased program. During the first phase, preliminary technical and economic analyses of existing processes and process combinations were made and a preferred design configuration recommended.[8] The configuration used for this design is therefore the result of Phase 1 analyses.

1.1 OBJECTIVES

The objectives of the work described in this report are to:

- Develop a conceptual design for a commercial grassroots complex including all operations required to mine coal, use multiple coal conversion processes in a preferred combination, and use an improved power plant system. This complex is to produce industrially marketable products at a price competitive with alternative sources.
- Define the product characteristics and marketability.
- Define probable project and financial parameters for design, engineering, procurement, construction, and startup of the complex.
- Estimate the economics for the complex.
- Present recommendations regarding additional development effort to encourage commercial exploitation of the technology.
- Develop conceptual designs for three separate U.S. locations:
  - The Eastern Region of the Interior Coal Province
  - The Southern Appalachian Region of the Eastern Coal Province
  - The Powder River Region of the Rocky Mountain Coal Province

1.2 REPORT ORGANIZATION

Sections 3 through 17 describe the design for The Eastern Region of the Interior Coal Province location in detail. The characteristics of the two alternate location designs are described in Sections 18 and 19.

A summary of key elements is presented in Section 2 to aid in rapid assimilation of the report contents. Sections 3 through 6 present the main technical elements of the design. Design parameters/bases used are summarized in Section 3. Section 4 describes project scope and major units included in the complex. Here major plant units and material flows are depicted in the form of a block flow diagram. A plot plan of the plant complex is also presented. Section 5 contains detailed descriptions of the separate units that comprise the complex. The detailed process flow diagrams with material balances are presented in Section 6.

Sections 7 through 10 summarize product descriptions and energy utilization factors involved in the design. Section 7 presents the properties of the various products and marketability considerations. The material balance for the complex is depicted in Section 8. Overall energy balance is presented in Section 9. The utility summary, by units, is given in Section 10.

Important environmental factors are summarized in Section 11. Facilities that have been included to ensure that effluent flows are properly treated to meet environmental standards are described. Section 12 presents a summary of plant startup procedures.

The list of major equipment, sizes, and materials of construction are presented in Section 13. This equipment list, combined with design information previously summarized in the report, provides the basis for the fixed capital investment estimate. A parametric economic assessment is given in Section 14. This includes capital investment requirements, discounted cash flow (DCF) rate of return for three project financial structures, and key economic sensitivity factors.

Sections 15, 16, and 17 present supporting data, analyses, and recommendations for future development work to ensure that the plant will perform as projected.

Sections 18 and 19 present the characteristics and projected economics for the coal mine and process/power complex for the Alternates, the Southern Appalachian Region of the Eastern Coal Province and the Powder River Region of the Rocky Mountain Coal Province. These sections contain process block flow diagrams, material balances, and economics pertinent to these locations.

SECTION 2

SUMMARY

A conceptual design and economic evaluation has been completed for an industrial complex to mine coal and convert it to SNG, LPGs, naphtha, unleaded gasoline, distillate fuel oil, premium grade coke, and electrical power. The results are summarized in this report.

The work was begun under the auspices of the Major Facilities Project Management Division of the Energy Research and Development Administration - Fossil Energy and completed under the Department of Energy, Office of Assistant Secretary for Energy Technology, Division of Coal Conversion. Their support and guidance are gratefully acknowledged.

The design basis used is the result of the analysis of a number of candidate processes and process combinations. A report describing the predesign analysis results has been published.[8] These predesign analyses indicated that there are incentives for use of certain coal conversion operations that required further development and pilot plant testing prior to commercial plant operation. These operations include pressurized flash pyrolysis and pressurized, entrained, slagging, two-stage gasifiers. Analysis results indicate that these technologies offer economic incentives if they perform as defined in this design. The projected performances are considered practical and attainable if additional development work is successfully completed. The procedures for design, as well as recommendations for the additional development work considered necessary to ensure success in commercial operation, are presented in the report.

The greatest amount of detail is presented for the complex conceived to be located in the Eastern Region of the Interior Coal Province; i.e., Kentucky, Indiana, and Illinois. Projected modifications to this design for the Southern Appalachian Region of the Eastern Coal Province, and the Powder River Area of the Rocky Mountain Coal Province are included as Sections 18 and 19 at the end of this report. The principal summary that follows is based on the Interior Coal Province Case.

The scope of the industrial complex is a grassroots facility consisting of a large captive coal mine capable of producing 60,000 TPD of run-of-mine (ROM) coal. A coal preparation plant will produce approximately 45,000 TPD of clean, washed, sized coal from the ROM feed; the clean coal is fed to the coal conversion and power generation facilities.

The complex will produce the following approximate product slate:

- 150 million scfd of SNG
- 13,000 BPD of C_3- LPG

- 2,000 BPD of C_4-LPG
- 55,000 BPD of unleaded gasoline
- 27,000 BPD of distillate fuel oil
- 1,600 TPD of crystalline coke
- 1,000 MW of electrical power

In addition, about 1,700 TPD of sulfur and 185 TPD of ammonia are produced as byproducts.

Process flow sheets and accompanying heat and material balances are presented based on a typical coal analysis that is intermediate between the extreme analyses that might be encountered during a 20-year project life. The equipment was sized to handle this typical coal.

The process portion of the complex consists of four coal conversion steps and 21 additional processes to recover the products and refine them to marketable grades; also to treat the effluents to meet environmental standards.

The four coal conversion steps consist of:

- Hydroliquefaction using SRC-II technology.
- Pressurized flash pyrolysis.
- Synthesis gas production by gasification of char. The synthesis gas serves as a precursor of the hydrogen required for the coal hydroliquefaction as well as for hydrotreating naphtha and heavy coal-derived liquids.
- Fuel gas production by gasification of coal. The fuel gas, after cleanup, is used as fuel for the power plant and also as fuel for process furnaces.

An important point: This process configuration eliminates the need for filters for removal of coal ash and unconverted coal from the hydroliquefaction product stream; it also recovers a significant amount of liquids as salable fuel products, which are normally associated with the filter cake when filtration is used.

The power plant incorporates an improved configuration of a combined cycle system, which interfaces with the coal mine and process complex. It receives energy-containing streams and converts them to power and steam to supply all the utility requirements of the complex plus approximately 1000 MW of power for sale. Bleed air from the gas turbine compressor supplies approximately 40% of the air required as feed for the oxygen plant; taking credit for the power equivalent of this compressed air results in an efficiency of approximately 43% for conversion of fuel gas to electrical power.

The estimated thermal efficiency for the process portion of the complex is about 74%; this is the predicted efficiency for conversion of coal to products/byproducts plus fuel gas supply to the power plant.

The process plant and power plant complex would occupy about a square mile. The plant population, including the mines, process, and power plants, would be approximately 2,800.

The estimated fixed capital investment for the complex is approximately $2.4 billion; all economics are expressed in mid-1977 dollars. The total capital investment is estimated to be about $2.75 billion, exclusive of construction financing costs. The total capital investment includes the cost of initial raw materials, catalysts and chemicals, land acquisition, startup and initial working capital.

The schedule to design, engineer, and construct the complex is estimated to be 60 months. A probable fund drawdown schedule is also presented.

Annual operating costs are estimated to be about $305 million. The required revenue for a 12% discounted cash flow (DCF) rate of return with 65% debt at 9% interest is approximately $725 million. The predicted required average fob product fuel and bus bar power selling prices for these financial parameters, after taking credit for sulfur and ammonia byproducts, are:

Electricity Bus Bar Selling Price in mils/kWh	Average Fuel fob Selling Price In $/MM Btu	Average Fuel fob Selling Price In $/Bbl (6 MM Btu/Bbl)
20	2.50	15.00
30	2.10	12.60
40	1.75	10.50

Required product selling prices for 100% equity and 0% DCF (breakeven) are also presented.

The required product selling prices are most sensitive to fixed capital investment (capital associated costs) and less sensitive to operating and coal costs. Expressed as percent change in required product selling price per % change in parameters, the sensitivities for the 65% debt case are:

Parameter	Sensitivity
Capital Associated Costs	0.8
Operating Costs	0.4
Clean Coal Cost	0.4

Possible product market values were developed based on comparison of the coal conversion product characteristics with conventional crude oil-based products, and on discussions with petroleum, petrochemical, and utility companies. Using the possible product market values developed, the following possible profitabilities, expressed as DCFs resulted:

- For 65% debt/35% equity, the profitability could be 20% DCF after tax on the equity portion.
- For 100% equity, the profitability could be about 13%.

These economic projections indicate that the complex has the potential to be competitive with alternative energy sources based on incorporation of large efficient captive surface mines and performance of the process and power plant portions of the complex as described here.

Most encouraging is the recent successful performance of the DOE Tacoma, Washington, Pilot Plant while operating in the SRC-II mode. Liquid fuels, with sulfur contents in the range projected in this design, have been produced and the pilot plant has operated more than 60 days continuously.

The 3:1 solvent-to-coal ratio of feed to the coal dissolvers in Unit 12 in this design may be conservative. Recent pilot plant data indicate that a ratio as low as 1.5:1 could be used. This lower rate is a potential improvement and could reduce the fixed capital investment and required product selling prices by 3 to 5%.

Methods of scale-up were carefully considered. The scale-up factor from the SRC pilot plant to this conceptual design was of the order of 400. However, the scale-up factor for the critical dissolver, which liquefies the coal by reaction with hydrogen, is approximately 135. The dissolver vessels specified are the largest that can be fabricated with existing materials, fabrication, and code practices. Methods of scale-up were selected to provide efficiency, operability, and process control.

Concurrent with the development of the conceptual design reported here, the DOE Tacoma, Washington, pilot plant was operating using the SRC-II mode of operation. The potential economic impact of the comparison of recent pilot plant data with the POGO commercial coal conversion complex was evaluated. The comparisons are for the Unit 12 (Coal Dissolving) section of the plant; the fixed capital investment for this section is 10 to 15% of the total complex, and changes in the required product selling price are in the $\pm$5% range.

A comparison of recent pilot plant data with the POGO design showed that some factors would reduce and some would increase the fixed capital investment, and also the required product selling prices. The net change for all factors included in the comparison was essentially zero.

Sections 18 and 19 summarize the second-order technical and economic assessments of captive mines and plants at the two alternate locations mentioned on page 2-1. In both alternate cases, experimental data was limited, requiring extrapolations to complete the conceptual designs.

Alternate 1: Southern Appalachian Region of the Eastern Coal Province presents higher cost mining operations and a process plant comparable to that for the base case location with respect to total products. Compared to the base case, coal composition is lower in volatile matter and sulfur content and higher in fixed carbon content. The result is a lower quantity of SNG and higher quantities of liquid fuels. Overall thermal efficiency is comparable to that of the base case plant.

The required product selling price to achieve a 12% annual discounted cash flow is significantly higher than for the base case.

Alternate 2: Powder River Region of the Rocky Mountain Coal Province presents a lower cost mining operation with higher processing costs compared with the base case plant. The sub-bituminous western coal contains a higher inherent moisture content, averaging about 25%, which requires costly drying equipment and a larger steam and power generation system. The coal feed to the processing plant is higher in volatile matter and lower in fixed carbon content. The result is a product mix that contains proportionately less products in the lower and higher molecular weight ranges and more in the middle liquid fuel range. Overall thermal efficiency is appreciably lower because of the energy required for coal drying. Due to the water scarcity in this area, the design contains no cooling tower. Air cooling is extensively used. Moisture from the coal drying operation is recovered for use.

Required selling price for products from this alternate, for a 12% annual discounted cash flow, is higher than for the base case.

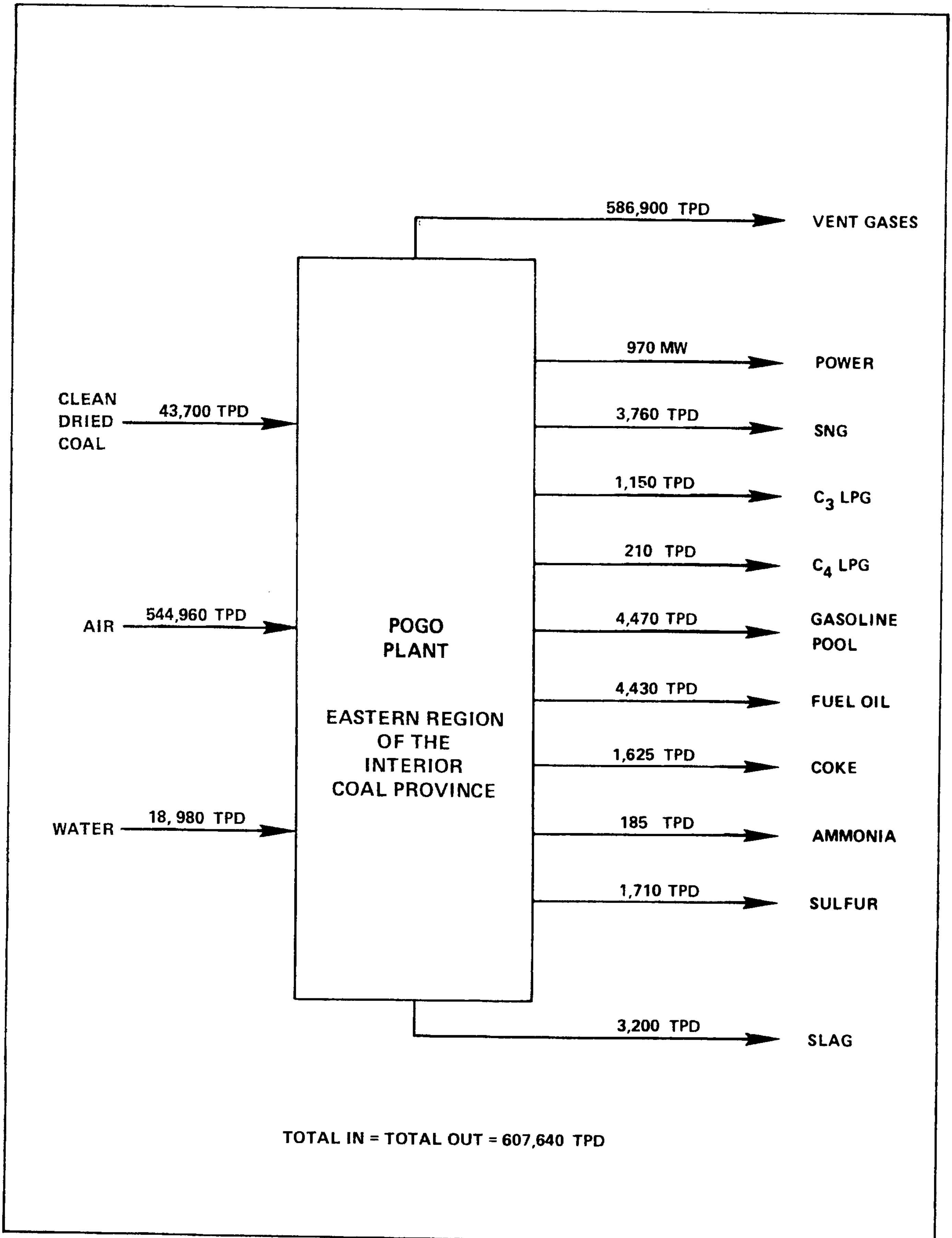

Figure 8-1 - Overall Material Balance – Process and Power Units

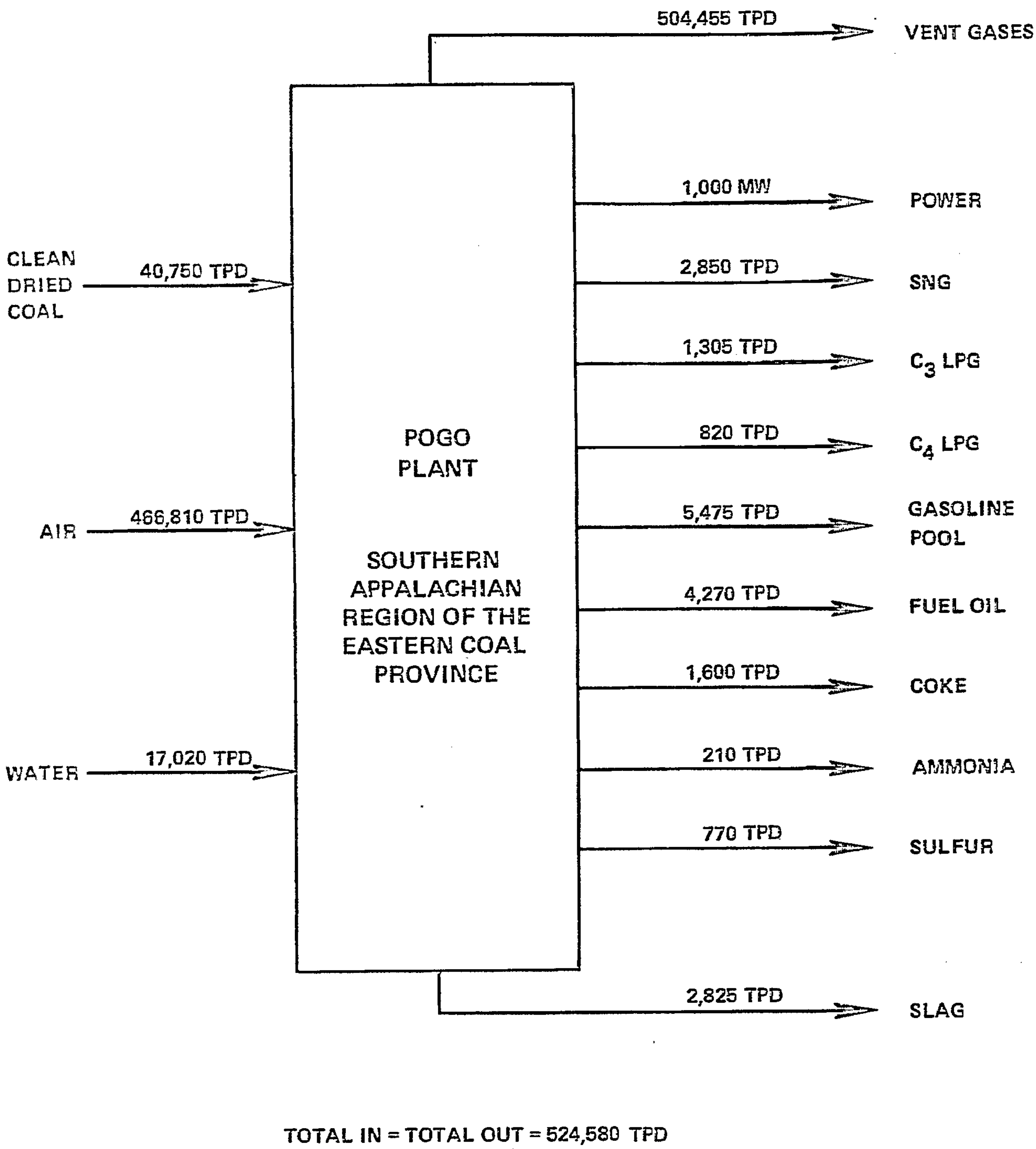

Figure 18-2 - Overall Material Balance — Process and Power Units

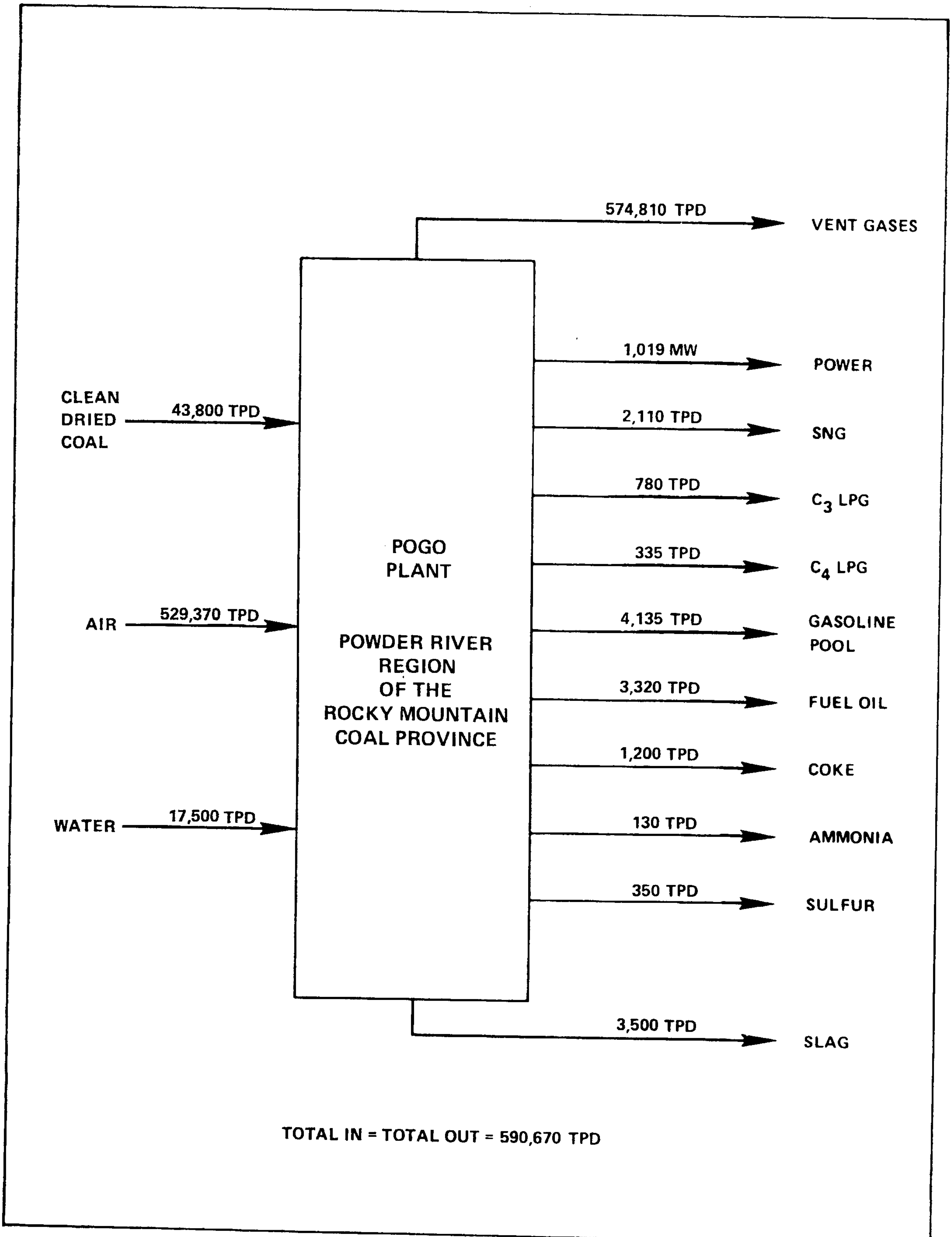

Figure 19-2 - Overall Material Balance – Process and Power Units

SECTION 3
PETROCHEMICAL FEEDSTOCKS AND CHEMICALS FROM COAL

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