TECHNOLOGY ASSESSMENT GUIDE
NO. 9c
SRC-II COAL LIQUEFACTION

CHAPTER ONE: EXECUTIVE SUMMARY

1.1 OVERALL PROSPECTS FOR THE TECHNOLOGY

The Solvent Refined Coal (SRC) concept has been under investigation by a subsidiary of Gulf Oil Company since 1966. The project has proceeded from bench-scale investigations to long-term operation of two pilot plant facilities. The detailed design of a 6000 TPD commercial module demonstration plant was initiated in early 1980. The process produces a range of products from pipeline gas to heavy fuel oil all which appear to be well suited to the U.S. market. Technical problems have been encountered during the development of the process but do not appear intractable at this time. Although large capital commitments will be required for a full-scale commercial plant (as with many synthetic fuels plants), current cost projections are quite competitive with other technologies and would almost be competitive with imported oil at current prices. Funding from the U.S. DOE has recently been cancelled for the demonstration plant, but this should not be taken as a reflection of the technical merit or overall worth of the concept.

1.2 ENGINEERING ASPECTS

The SRC-II process converts coal to liquid and gaseous products by first dissolving the coal in a slurry which is recycled from the process, then hydrogenating and hydrocracking the dissolved coal in the presence of hydrogen at elevated temperature and pressure. Although no catalyst is added, these hydrogenation and hydrocracking reactions are enhanced by the catalytic activity of the mineral matter contained in the feed coal and in the recycle slurry. From the reactors, the raw product is separated into a gas stream, a light liquid and a heavy liquid. The gas stream is processed for sulfur removal, hydrogen recycle and production of C_1 through Cy hydrocarbons. The light liquid is fractionated to provide naphtha and middle distillates. Fractionation bottoms are combined with the heavy liquid and distilled in a vacuum tower to a heavy distillate and a mineral residue which is gasified to provide hydrogen. In many respects the SRC-II conceptual process design is similar to other coal liquefaction technologies, with major differences in reactor design conditions, and (no) catalyst.

1.3 CURRENT COSTS

The total capital requirement for this 125 x 10^{12} Btu/year plant is $1.78 billion, which is dominated by a plant investment of $1.1 billion. Interest during construction is the next largest expense at $486 million, followed by working capital ($68 million), start-up costs ($67 million), catalysts and chemicals ($16 million), and miscellaneous expenses totaling $23 million.

Annual operating and maintenance costs (at a 90% plant capacity factor), exclusive of coal costs total $76.7 million, and are largely comprised of taxes and insurance, supplies and labor (unlike several other technologies, labor is not the dominant operating expense for this plant assessment). Byproduct credits for sulfur, ammonia and tar acids total $14.4 million, bringing the net operating costs to $62 million.

When these operating costs are combined with a 20 percent capital charge, a total non-fuel product of $\$3.72/10^6$ Btu is obtained. With coal costs assumed to be $\$1.50/10^6$ Btu, an average product cost of $\$5.82/10^6$ Btu results. It must be remembered that the SRC-II process produces a wide variety of products, each with its own value. A considerable range of product values (on a Btu basis) may apply for any given plant according to prevailing market conditions.

1.4 RESEARCH AND DEVELOPMENT DIRECTIONS

Prior to the cancellation of Department of Energy funding on the SRC-II demonstration plant and non-renewal of the pilot plant support contracts, several demonstration plant features were to be tested at Fort Lewis:

- Dissolver effluent cooling and separation at higher temperatures
- Handling and pumping of hot vacuum bottoms to high pressure
- Mixing and pumping of hot slurries at the incipient gel stage
- Operation of the slurry preheater at flow rate and heat flux comparable to the demonstration plant design.

Each of these areas are important to large-scale plant operation, and will undoubtedly be investigated if funding for the project is renewed.

CHAPTER TWO: ENGINEERING SPECIFICATIONS

2.1 GENERAL DESCRIPTION OF THE TECHNOLOGY

Development work on the Solvent Refined Coal process over the past fifteen years has led to the emergence of two somewhat different processes. One process (now known as SRC-I) involves solution of most of the coal in a donor solvent derived from the process, separating the undissolved coal solids, distilling off the original process solvent, and recovering the dissolved coal as a low-ash, low-sulfur, pitch-like solid material known as Solvent Refined Coal. The other process (SRC-II) not only dissolves the coal, but hydrocracks it to liquid and gaseous products. The SRC-II process appears to be the preferred route for most applications, since it produces an ashless distillate fuel oil containing substantially less than the solid Solvent Refined Coal, and produces it at an indicated cost no greater than that for the solid product.

SRC-II is an advanced coal liquefaction process in which raw coal is mixed with a portion of the product slurry and hydrocracked to liquid and gaseous products. The dissolved coal unconverted to distillate and lighter products is sent to a gasifier, together with the undissolved mineral residue, to produce hydrogen for the process. Thus, a liquid-solid separation step is not required, and the primary product from the process is a distillate fuel oil.

The extensive hydrogenation and hydrocracking reactions of the SRC-II process are accomplished principally in two ways. First, recycle of the product slurry permits return of the heavier fraction of the dissolved coal to the reaction zone, so that its effective residence time is increased even at the same per-pass residence time. Secondly, the recyle of slurry results in an increase in the concentration of mineral residue in the reactor. Components of the mineral residue are active catalysts for the process reactions, thus the reaction rates are significantly increased.

Gas phase components recovered from the reactor effluent vapor-liquid separators contain most of the sulfur originally in the coal. This gas stream is treated for acid gas removal and then split, a portion being recycled to the slurry preheater for subsequent reaction, and the balance being cryogenically separated for recovery of reactor recycle gas, methane-range pipeline quality gas, and a "LPG"-range product.

2.2 PROCESS FLOW, ENERGY AND MATERIAL BALANCES

A simplified conceptual flow diagram of the SRC-II process, as reflected in recent designs, is shown in Figure 2-1, and corresponding plant area numbers are itemized in Table 2-1. Raw coal is pulverized and dried in the coal preparation area, then mixed with hot recycle slurry "solvent" from the process. The coal-recycle slurry mixture is pumped, together with hydrogen, through a fired preheater to a hydrocracking reactor.

The temperature of the reactants at the outlet of the preheater is about 700-750°F. Thus prior to entering the reactor the coal is already partially dissolved in the recycle slurry "solvent", and the exothermic reactions of hydrogenation and hydrocracking have just begun. The heat

Figure 2-1

Conceptual Flow Diagram for the SRC-II Coal Liquefaction Process

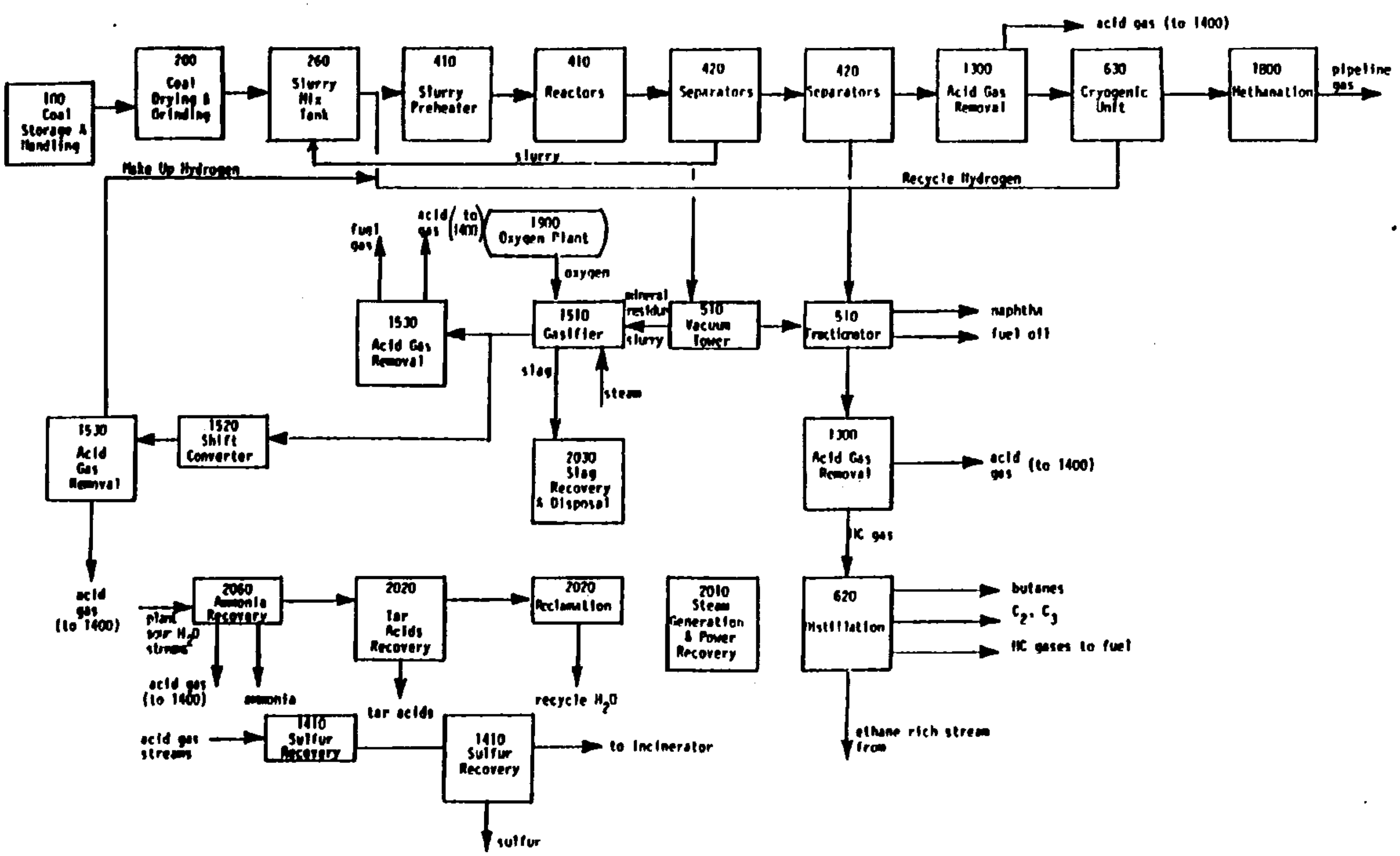

Table 2-1

Relevant Plant Area Numbers for The SRC-II Coal Liquefaction Process

100	COAL STORAGE AND HANDLING
	110 Coal Storage 120 Coal Handling and Transportation
200	COAL PREPARATION
	210 Crushing and Grinding 240 Drying 260 Slurry Preparation
400	HYDROGENATION
	410 Reaction (including preheat) 420 Primary Separation
500	PRODUCT SEPARATION AND PROCESSING
	510 Fractionation
600	LIGHT ENDS PROCESSING
	620 Gas Plant ("LPG") 630 Cryogenic Fractionation
1300	ACID GAS REMOVAL AND GAS PURIFICATION
	1310 H_2S Removal
1400	SULFUR RECOVERY AND TAIL GAS TREATING
	1410 Sulfur Recovery 1420 Tail Gas Treating
1500	HYDROGEN PLANT
	1510 Gasification 1520 Shift Conversion 1530 Acid Gas Removal
1800	METHANATION
1900	AIR SEPARATION
2000	UTILITIES AND SUPPORT SYSTEMS
	2010 Steam Generation and Power Recovery 2020 Wastewater Treating and Plant Water Supply 2030 Solids Disposal 2050 Aqueous Phenol Recovery 2060 Aqueous Ammonia Recovery

further generated by these reactions raises the temperature of the reactor to the range 820-870°F. Cold hydrogen is then utilized as a quench in the reactor for fine control of the reaction temperature.

The reactor effluent goes first to a hot high-pressure separator. The hot overhead vapor stream from this separator is then cooled in a series of heat exchangers and additional vapor-liquid separation steps. The condensed liquid from these separators goes to the fractionator. The non-condensed gas consists of unreacted hydrogen, methane and other light hydrocarbons, plus H_2S and CO_2. Following an acid gas treating step for removal of H_2S and CO_2, these gases are cryogenically processed for removal of much of the methane and other light hydrocarbons. The recovered hydrogen (about 90% pure) is utilized to satisfy a portion of the hydrogen feed requirement to the process. The methane and ethane recovered from the cryogenic unit are available for distribution as pipeline gas. Propane and butane are recovered by distillation from the heaviest cryogenic stream for distribution as LPG.

In the fractionator, the raw distillate from the vapor-liquid separation system is distilled at atmospheric pressure to separate a naphtha overhead stream and a bottoms stream which becomes part of the fuel oil product of the process. The heavier slurry from the hot high-pressure separator, after flashing to lower pressure, is split into two major streams. One of these streams comprises the recycle "solvent" for the process, while the other goes to the vacuum tower for separation of fuel oil. The overhead from the vacuum flash tower, together with the bottoms stream from the fractionator, comprises the major fuel oil product of the process.

The bottoms stream from the vacuum tower, consisting of all of the undissolved mineral residue plus the vacuum residue portion of the dissolved coal, goes to an oxygen-blown gasifier. Synthesis gas produced in the gasifier can go through a shift conversion step for conversion of H_2O and CO to H_2 plus CO_2, then through an acid gas removal step for removal of CO_2 and H_2S. The hydrogen derived from the synthesis gas comprises the principal source for the hydrogen requirements of the process. Synthesis gas produced in the gasifier in excess of that required for hydrogen production can be treated in an acid gas removal unit to remove H_2S and CO_2, then burned as plant fuel. Alternatively, a part of all of the excess synthesis gas can be separated into hydrogen and carbon monoxide, with the carbon monoxide used as plant fuel.

The overall material and energy flows for the SRC-II plant are given in Table 2-2.

2.3 PLANT SITING AND SIZING ISSUES AND CONSTRAINTS

This plant is a grass roots facility comprising all of the processing units and ancillaries, including storage for coal feed and liquid products, slag disposal and all utilities. Since specific sites have not been evaluated for the plant, the unit arrangement may need revision to conform to the topography of the site selected.

The coal stockpile is located about 1700 feet from the main plant area as a fire precaution and for dust isolation. Storage for 500,000 tons of coal, approximately one month's supply, requires an area of about 900 by 1500 feet (30 acres).

Table 2-2

Gross Material and Energy Flows For the SRC-II Coal Liquefaction Process*

Input	Unit Heating Value, Btu/lb (HHV)	Mass Flow Rate, TPD	Btu Content, MM Btu/day
Coal Feed	12,800	18,670	478,800
		Total Input	478,800
Output			
Fuel Oil	17,000	5,430	184,700
Pipeline Gas	23,120	579	26,780
Naphtha	18,270	1,454	53,160
Light Hydrocarbons	22,010	1,609	70,780
Butanes	20,900	168	7,030
Sulfur	3,970	658	5,230
Ammonia	9,810	102	2,020
Tar Acids	20,970	21	860
		Total Output	350,560

Overall Plant Energy Efficiency $= \frac{350{,}560}{478{,}800} = 73.2\%$

*Flows represent 100% plant capacity

The main plant area is approximately 2000 feet by 3200 feet (140 acres). The key process sections are Plant Areas 400 and 500 (Primary Process Plants), 600 (Gas Plant) and 1500 (Hydrogen Plant). These are centrally located in the main plant on an area about 900 by 1500 feet (30 acres). The auxiliary equipment includes Plant areas 1900 (Air Separation) and 2000 (Utilites and Support Systems). These are placed around the key areas 400, 500, 600, and 1500. The product storage area is located at one end in an area about 900 by 900 feet (about 18 acres).

Development of a plot plan must be done following the sizing of individual unit operations within each Plant Area, and then combining them in accordance with good engineering practice. Consideration must be given to the logic of flow patterns between units to minimize plumbing and power. Safety requirements for such items as flares, cooling towers, oxygen plant, sulfur plant, storage for flammable liquids, and fired heaters must be considered. The centrally located control building should be designed to provide overall control of process operation using advanced instrumentation technology including computer based data acquisition and microprocessor controllers.

Control systems for the steam and power generation, water treatment, cooling water, and other utilities should be coordinated separately at the power house which is located adjacent to key Plant Areas. Spacing between Plant Areas provides for maintenance access roads and fire-fighting lanes.

The Area 400 dissolver plant is the heart of the SRC-II process, and requires an area of approximately 600 by 650 feet. It contains four parallel dissolver-high pressure letdown trains, each fed through two fired heaters and charge pumps. These four trains combine into two parallel trains as the flow enters the low pressure letdown section. The dissolvers and high pressure separators are the heaviest equipment in the plant, requiring massive foundations. These foundations, in addition to the requirements of piping expansion, maintenance and pump-out, dictate the physical arrangement of these vessels.

Area 1500, Hydrogen production, is near the dissolver plant and is close to the fractionation plant. The arrangement is advantageous to the piping systems, particularly the mineral residue slurry system which must be kept hot and circulating. This equipment, together with the tanks for mineral residue slurry and diluent solvent (part of fractionation) are located next to Area 400.

The fractionation and gas plants are placed in a logical grouping of areas, with sulfur recovery. Based on an assumed prevailing wind, this area is somewhat isolated to prevent possible air contamination of other areas.

The ammonia recovery operation, part of Area 2000, is located near Tar Acids Recovery (also part of Area 2000) and near storage tankage, while wastewater treatment is located adjacent to raw water treatment. Area 1900 (air separation) is located at the upwind corner of the site to insure best air intake conditions.

Area 2010, the steam generation system, has the most central location possible for economical distribution of utilities. The cooling towers for Area 2010 are located at the periphery of the main plant area.

The miscellaneous systems and ancillary facilities, such as the maintenance and warehouse area, the laboratory, change house, storage, surface drainage and disposal systems, etc., are located in accordance with usual plant design practice.

2.4 RAW MATERIAL AND SUPPORT SYSTEM REQUIREMENTS

2.4.1 Coal Quantities and Quality

As it is presently designed, the SRC-II plant will consume approximately 6.8 million tons of coal per year. A considerable amount of experience has been gained using West Virginia panhandle coals, and a Powhatan coal has been selected as the basis for this assessment. The properties for this feedstock are shown in Table 2-3, and represent an expected average for blended properties of these coals.

The coal analysis shown is on a moisture-free basis. The plant is designed for a maximum of 9 percent coal moisture. Material balance and thermal calculations are based on an average coal moisture of 7.0 percent. Conventional coal analysis is used, but certain procedures for handling this basis of analysis are required. For material balance calculations which are consistent with laboratory expressed results, ash in equals ash out. In the coal charge composition, the sulfur and chlorine components are arithmetically removed from the ash value and are included in the elemental breakdown of the ultimate coal analysis.

Table 2-3

Feedstock Composition
Powhatan Coal Case

Coal Composition, wt % (Moisture-Free Basis)

Carbon		70.49
Hydrogen		4.88
Nitrogen		1.12
Oxygen		7.87
Sulfur		3.59
Pyrite	2.00	
Organic	1.54	
Sulfate	0.05	
Chlorine		0.05
Ash		12.00
Contained Iron	1.75	
TOTAL		100.00

2.4.2 Catalysts and Other Required Materials

No catalyst is added to the SRC-II preheat or reaction sections to enhance coal liquefaction rates. However, a variety of catalysts and chemicals are used throughout the plant in different unit operations. Table 2-4 summarizes their use.

2.4.3 Water Requirements

The plant water balance accounts for all water entering, leaving, or consumed on the site. The system is based on recovery and recycling of waste water streams so that no contaminated effluent is discharged to the natural drainage system.

As a result of recovering and recycling liquid streams in Area 2020, makeup water required from the river source is reduced by 6000 gallons per minute, or 36 percent. Total water consumption is approximately 10 million gallons per day.

The plant water balance is listed on Table 2-5.

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Table 2-4

Usage of Catalysts and Chemicals in the SRC-II Process

Plant Area	Catalyst or Chemical	Estimated Consumption Rate
500 Primary Solids Separation	Diatomaceous Earth Filter Precoat	64 tons/day
1300 Acid Gas Removal	Hi-Pure Solution	825 gal/month
	Monoethanolamine	11,500 gal/month
	Cellulose, Asbestos and Diatomaceous Earth	50 lb/day
	Corrosion Inhibitor	60 gal/month
	Antifoam Agent	160 gal/month
1400 Sulfur Recovery	Sulfur Recovery Catalyst	2100 ft^3/yr
1500 Hydrogen Plant	CoMo Catalyst	150 ft^3/yr
	ZnO Catalyst	2000 ft^3/yr
	Reformer Catalyst	600 ft^3/yr
	Shift Catalyst	1900 ft^3/yr
2010 Power Generation	NaOH Solution	925 lb/hr

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Table 2-4 (cont'd)

Usage of Catalysts and Chemicals in the SRC-II Process

Plant Area	Catalyst or Chemical	Estimated Consumption Rate
2020 Raw and Wastewater Water Treating	Sulfuric Acid	5200 lb/hr
	Lime	8500 lb/hr
	Aluminate	2300 lb/hr
	Polymer Dispersant	130 lb/hr
	Caustic Soda	830 lb/hr
	Cooling Tower Chemicals	$325,000/yr
	Chlorine	85 lb/day
	Hydrazine Compounds	2 lb/day
	Chelant	2 lb/day
2060 Aqueous Phenol Recovery	Isopropyl Ether	14 lb/hr

Table 2-5

Plant Water Balance for SRC-II Facility

Water In	GPM
Coal Moisture	185
Air to Oxygen Plant	66
Rain	619
River Water	6,087
TOTAL	6,957
Water Out	
Cooling Tower Evaporation and Drift	5,611
Process Consumption	877
Slag	72
Sludge	20
Gas Turbine NO_x Control	105
Water Reclamation Incinerator	97
Steam Losses	56
Nitrogen and CO_2 Vents	35
Miscellaneous	84
TOTAL	6,957

2.5 EFFECT OF COAL TYPE

The SRC-II process is inherently versatile and is capable of processing varying coals. Some coals consume more hydrogen and therefore produce a lighter hydrocarbon yield (more 350°F and lower boiling material and less 350°F and higher boiling material) than the design coal. A bottleneck would probably be in the recycle gas treating and separation and the gas plant areas of the plant. Overcapacity has been included in the design of the equipment and it is expected that close to design throughput could be achieved.

Other coals consume less hydrogen and therefore produce a heavier hydrocarbon yield (less 550°F and lower boiling material and more 550°F and higher boiling material) than the design Powhatan coal. There is a limit in the ability to handle the mineral residue. Although the plant is capable of processing the coal, the amount of coal charged might be less than the design rate.

Because of the natural variability of the feed coal the plant design includes provisions for coal blending to insure that the feed coal is as close as possible in composition to the design basis.

2.6 AIR POLLUTION CONTROL TECHNOLOGY

2.6.1 Ability of Existing Technology to Meet Regulations

The plant is designed to comply with all applicable Federal, state and local regulations. Inasmuch as all fuels burned in the plant are to be free of ash, the emission of particulate matter is not expected. There would be dusting of the raw coal during unloading, grinding, and transfer, and the coal-handling systems are to provided with dust-collecting devices. Experience at the Fort Lewis plant has shown that air emissions from an SRC-II plant are controllable to minimal levels.

The raw coal selected for SRC-II contains sulfur in quantities which make it unacceptable for direct firing in steam boilers not having extensive sulfur dioxide removal equipment. However, the SRC-II process removes sulfur as a by-product. Even so, a small amount of sulfur dioxide must be burned in a flare in the plant. Design calculations show that this can be accomplished in a manner complying with regulations and will avoid unacceptable concentrations.

During startups and process upsets, flammable hydrocarbons are to be flared. Two systems would be installed to recover liquid hydrocarbons and to burn the flammable gases in smokeless flares.

Most of the plant fuel requirement is met by burning excess internally produced syngas. The hydrocarbon-rich and hydrogen-rich gases are treated within these plants by absorption processes to produce a sweet fuel with only trace amounts of hydrogen sulfide or other sulfur-bearing gas compounds.

The combustion units within the plant will have high combustion efficiencies to eliminate hydrocarbon and carbon monoxide emissions fronm plant combustion stacks. All hydrocarbons which are normally vented from the process will be completely and cleanly burned in the plant flare system.

The storage and shipping facilities within the plant incorporate closed-system designs. The API cone roof tanks used for storage of naphtha and fuel oil are connected to vapor recovery systems which prevent the release of hydrocarbons to the atmosphere.

The coal preparation and handling facilities are equipped with dust suppression and collection equipment to prevent the release of fugitive coal dusts to the atmosphere. Dust suppression water is contained and is reused for dust suppression in the coal storage piles.

Acid gas produced in treating the dissolver recycle gas is fed to Areas 1300 and 1400 for acid gas removal and sulfur recovery. The Claus process used in sulfur recovery employs a two-stage reactor design followed by a selective hydrogen sulfide removal step utilizing a Shell process which reduces the SO_2 content in the offgas to less than 100 ppm. This SO_2 concentration is believed to be within the environmental standard for any plant site selected.

2.6.2 Impacts on Process Efficiency

For the most part, air pollution control systems are employed on the SRC-II process to meet air pollution goals and not to protect sensitive process catalysts or processes. No estimates are available on process efficiency loss attributed to the operation of these systems. However one may speculate that their impact will be more important in terms of capital cost rather than energy consumption.

2.7 WATER POLLUTION CONTROL TECHNOLOGY

2.7.1 Ability of Existing Technology to Meet Regulations

The SRC-II process design examined in this assessment incorporates the concept of zero liquid discharge. All liquid waste streams are reclaimed and recycled to the extent practicable. Those portions of the waste streams that are not recycled are either dewatered or incinerated. Dewatered solids are disposed of in an environmentally acceptable disposal site.

The major waste streams going to the waste reclamation area include cooling tower blowdown, dissolver area wastes, gasifier blowdown wastes, and contaminated rainwater runoff.

Rainwater runoff includes coal pile runoff, gasifier slag pile runoff, and miscellaneous plant area runoff. The rainwater runoff guideline used was taken from the proposed EPA power plant coal pile runoff regulation. The collection ponds and treating equipment are sized to retain and treat the amount of water equivalent to the 10-year 24-hour storm. Any rainfall in excess of this amount is diverted from the holding pond and is discharged into the river. The slag disposal area is sealed and all rainfall into it is collected and treated.

2.7.2 Water Recycling Systems

The wastewater streams in the SRC-II plant can be classified under four general categories:

- oily water
- storm water
- chemically contaminated water
- sanitary water

The oily water sewer is designed to handle all of the non-corrosive process wastes drained periodically from process equipment during maintenance shutdowns and process upsets. Drainage from paved and unpaved surface drainage areas adjacent to process equipment should be diverted to this sewer, where process waste spillage is considerable. Fire water runoff should also be diverted to the oily water sewer.

The storm water sewer is designed to collect the maximum surface drainage. Water accumulation is 100 percent from paved areas and 50 percent from unpaved areas. Part of fire water runoff may be included in this sewer if flooding occurs to prevent interference with fire fighting operations and damage to process equipment. Oily water drain and part of storm water runoff are pumped to an oil separator drum. The oil recovered from this step is processed before mixing with recycle solvent, while the water is sent to a floating aerator tank.

The chemical sewer collects heavily contaminated and corrosive process chemical wastes from process equipment. Boiler and cooling tower blowdown water, high in scale-forming salts, is also added to this sewer. After neutralizing this waste, the water is fed to an aerator tank.

The sanitary sewer is designed to handle the waste of sanitary facilities only. After sewage treatment, the water is supplied to an aerator tank, in which floating aerators remove dissolved gases from the water. This water provides feed to the plant water system. A storm water drain is provided for excess water.

2.7.3 Impacts on Plant Efficiency

Treatment of the various wastewater streams in the plant is necessary to prevent fouling and corrosion in process vessels using recycled water, to aid in the conservation of water supplies, and to maximize the recycling of process waters to meet the zero discharge (to surface waters) objective. Only a portion, therefore, of the total water recycling activity can be considered attributable to environmental goals. Although no estimates of impacts to process efficiency are available, it is probably safe to assume that the efficiency loss due to water treatment for environmental reasons, however defined, is negligible.

2.8 SOLID WASTE HANDLING

2.8.1 Disposal Requirements

Regulations covering the disposal of solids from coal conversion facilities have not yet been promulgated. Current plans provide for burial of slag produced from hydrogen plant gasification, and other solid materials such as wastewater treatment sludge.

The gasifier slag is transported by trucks to the slag disposal site which consists of a sealed disposal basin. The basin capacity is approximately 20 million cubic yards which will contain 25 years of slag production allowing for 5 feet of freeboard. Experience gained in the operation of the demonstration plant may show that other approaches are feasible, such as mine burial, however this approach should accommodate the worst situation.

Sanitary sewage will be given primary, secondary, and tertiary treatment with any remaining solids being incinerated. Solids that remain following evaporation of process waters are oxidized in an incinerator.

Sludge from the waste-water treatment systems will be disposed of in suitable landfill sites. Analysis of the sludge from demonstration plant tests will establish whether special disposal precautions are required.

2.8.2 Leachate Problems

The primary volume of solid waste requiring disposal is the slag produced by the Koppers-Totzek gasifiers in the hydrogen plant, Area 1500. Because of the high temperature of operation in the gasifier, the mineral matter is recovered as a fused, glassy slag material rather than dry ash. Disposal of material in this form will be much more resistant to the leaching of soluble components than finely powdered dry ash. However, the extent of the leachate problem depends on many factors, and can only begin to be answered after a laboratory study of the problem. Final characterization will require in addition a knowledge of typical rainfall rates and compositions once a specific site has been selected.

2.9 OSHA ISSUES

Handling and preparation of coal can expose the workers to coal dust and noise. Coal dust can cause respiratory ailments such as black lung. Fire caused by spontaneous combustion can also be a problem at coal storage areas.

Another potential hazard is the presence of toxic and carcinogenic chemicals in the SRC-II product stream. Carcinogens are concentrated in the higher boiling fractions of SRC-II liquids.[2-2] Gulf Oil, however, reports that only five cases of temporary skin irritation because of contact with SRC-II liquids were found in 5 years of pilot plant operation.[2-2] This evidence might not be conclusive because cancers often appear many years after exposure to the carcinogen. Therefore, exposure to the SRC-II liquids which could occur because of leaks or during maintenance and cleaning must be avoided.

2.10 PROCESS PERFORMANCE FACTORS

2.10.1 Product Characteristics and Marketability

The important products from the SRC-II process evaluated in this assessment are low-sulfur fuel oils, pipeline gas, butane, an aromatic naphtha stream and light hydrocarbon gases. By-products include sulfur, ammonia, and tar acids.

The fuel oils and pipeline gas will be used for domestic and industrial fuels, while the naphtha will be refined to produce a high octane blending stock for gasoline. The light hydrocarbon gases can be upgraded to ethylene, a basic raw material for the petrochemical industry. Sulfur, ammonia and tar acids can be sold as feedstocks for ancillary plants.

The fuel oil produced by the plant will be sufficient to supply a typical electric utility generating station serving a city of approximately two million. The pipeline gas will be equivalent to that consumed by a city of 200,000. The naphtha produced, when upgraded, will be the equivalent of approximately 9,000 barrels per day of motor fuel. The light hydrocarbons produced will provide sufficient feedstock for a one billion pound per year ethylene plant.

The slag is assumed to have no immediate use. In this study it is planned to dispose of the slag as landfill on the site.

Table 2-6 and Figure 2-2 show the expected product properties and product slate based on Powhatan coal feedstock.

2.10.2 Capacity Factors, Flexibility and Reliability

The plant is designed to process 6,133,000 short tons of coal each year, based on a 90 percent on-stream factor at 100 percent of design capacity. A change in either the on-stream factor or the actual capacity realized would have a considerable effect on process economics. It is possible that plant capacity could exceed design capacity, as has occurred with some petroleum refineries; however, the on-stream factor of 90 percent is probably optimistic for a plant with the corrosive and erosive process streams, coupled with the severe operating conditions of the SRC-II process. A better picture of commercial plant reliability will emerge as the process is tested at increasingly large capacities.

The SRC-II plant is designed as a base loaded plant; i.e., it would run at full capacity most of the time. The plant is capable of turn-down in the event of major equipment failure or if the coal supply becomes insufficient to run at full capacity. Most of the major processing areas of the plant consist of two or more trains of equipment. Based on the present design, it is expected that the plant could be turned-down to approximately 50 to 60 percent of design capacity. The major limit on turn-down is the single large fractionator.

Table 2-6

Properties of SRC-II Products[2-3]

Naphtha Properties

	Stabilized & Unhydrotreated	Stabilized & Hydrotreated
Nitrogen, wt. %	4,500 ppm	less than 0.2 ppm
Sulfur, wt. %	1,900 ppm	less than 0.5 ppm
Oxygen, wt. %	3.5%	
Hydrocarbon Analysis: vol. %		
Aromatics	34	14
Cycloparaffins	45	62
Paraffins	21	24
Distillation, °F		
IBP	100°F	
10%	150°F	
50%	290°F	
90%	350°F	
End Point	380°F	

SI Conversion: °C = (°F - 32)/1.8

Properties of Distillates

	Middle Distillate	Heavy Distillate
Specific Gravity	0.98	1.08
Viscosity, SUS	38 @ 100°F	200 @ 40°F 40 @ 200°F
Pour Point, max.	-50°F	50°F
Flash Point	170°F	300°F
Nitrogen, wt. %	0.8	1.1
Sulfur, wt. %	0.2 to 0.25	0.3 to 0.4
High Heating Value, Btu/lb	17,400	Approx. 17,000
Distillation, °F		
IBP	370°F	580°F
10%	390°F	610°F
50%	470°F	690°F
90%	570°F	800°F
End Point	600°F	900°F

SI Conversion: °C = (°F - 32)/1.8; kJ = Btu x 1.055; kg = lb x 0.454

Table 2-6 (cont'd)

Properties of SRC-II Products[2-3]

SRC-II Fuel Oil Properties

	SRC Fuel Oil	Typical Petroleum Fuel No. 4	Typical Petroleum Fuel No. 6
Gravity (°API)	8.3	23	12
Viscosity (CS, (100°F)	4	14-20	900
Flash Point (°F)	>150	>150	>150
Pour Point (°F)	-23	<-20	<+60
Sediment (%)	<0.03	0.05	0.25
Carbon Residue (%)	<0.3	5.5	6-16
Ash (%)	0.015	0.01	0.05
Sulfur (%)	0.25	1.00	0.3-2.2
Nitrogen (%)	0.9	0.2	0.4
Net Heating Value (Btu/gal)	148,000	135,000	141,000

SI Conversion: kJ = Btu x 1.055; L = gal x 3.79; °C = (°F - 32)/1.8

Pipeline Gas Heating Value

940 Btu/scf, HHV

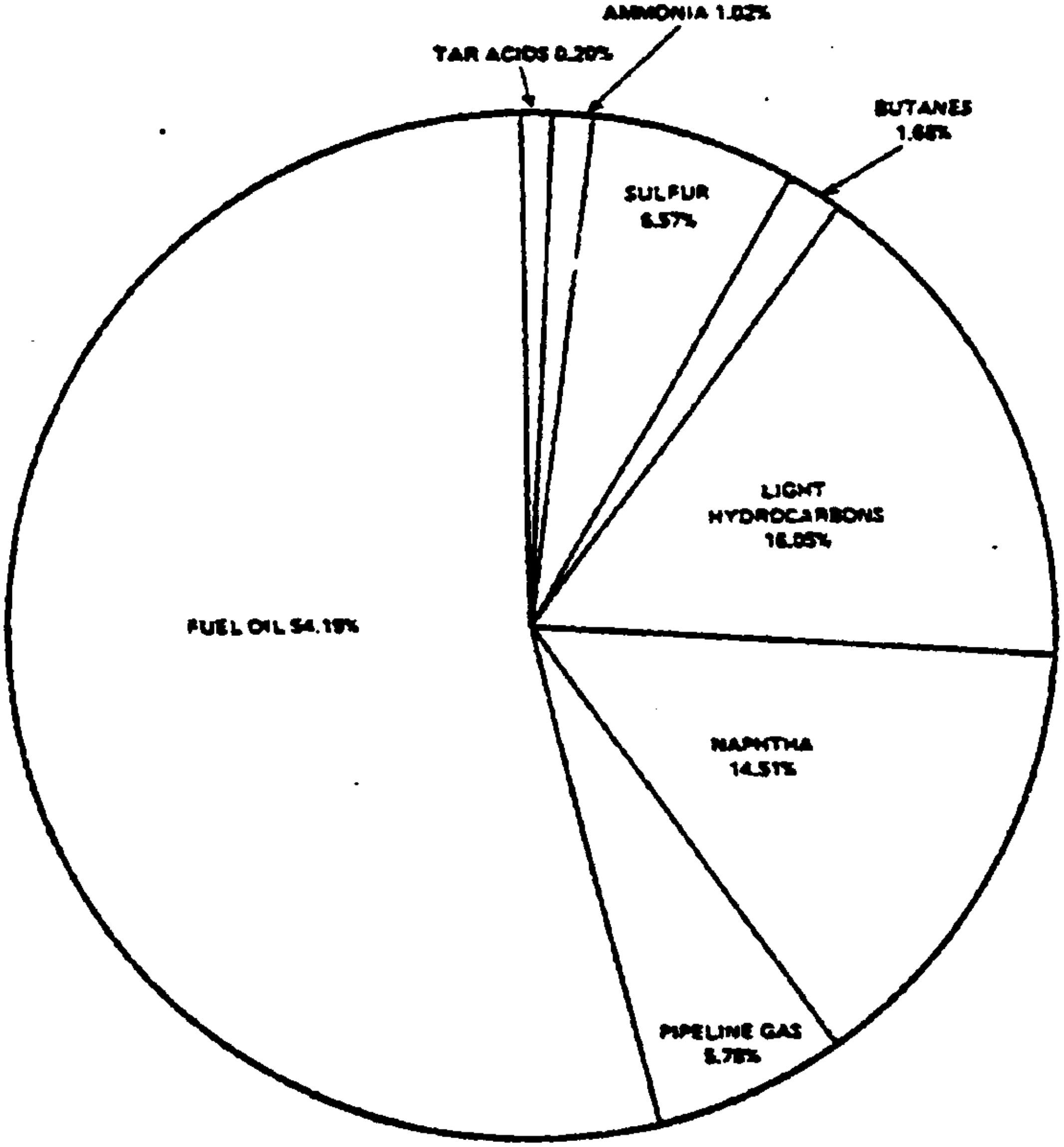
Butanes Composition

96% C_4 by weight

4% C_3 and C_5 hydrocarbons

Figure 2-2

Products (Mass Basis)



Recent pilot plant progress in development of the SRC-II process for the conversion of coal to liquid and gaseous products has been sufficiently encouraging that plans are now being made to design, construct and operate a 6000 TID demonstration plant in Morgantown, West Virginia. Pittsburgh and Midway is also handling the demo plant project.

Preliminary designs for the 6000 TPD demonstration plant have been prepared, background environmental studies have been carried out at the site, and economic evaluations have been made for a conceptual commercial plant based upon technology expected to be developed and proven during the demonstration plant project. In addition, market investigations have been made to assess potential future applications and demand for the products from the plant. However, as of June, 1981, plans for support of the demonstration project have been cancelled by the U.S. DOE. Gulf Oil was also notified that the support contract for the Fort Lewis facility (which expires in September 1981) will not be renewed. Gulf is conducting negotiations with Ruhrkohle of Germany and Mitsui of Japan (venture partners in the existing program) for continued private support of the project.

2.11.2 Key Technical Uncertainties

Since the failure of an air-cooled heat exchanger in the early days of operation, the Fort Lewis pilot plant has been using a water quench to cool the dissolver effluent to a temperature of about 370°C (700°F). This is about the maximum operating temperature allowable by the rating of the separator vessel immediately downstream.

2.11 TECHNOLOGY STATUS AND DEVELOPMENT POTENTIAL

2.11.1 Current Status

The earliest work on the solvent refining of coal was carried out in Germany in the 1920's. Work in the United States on the concept has been continuing since 1966 when the office of Coal Research awarded a multiyear contract to the Pittsburgh and Midway Coal Company (a subsidiary of Gulf Oil Co.) which included funds for a 50 TPD pilot plant.

The primary intent of the original SRC process (as developed in the United States) was the production of a low-sulfur, low-ash solid fuel. The SRC-II process is an extension of this technology to higher reactor temperatures with slurry recycle, promoting greater hydrogen addition to the feedstock and producing a substantial yield of liquid, rather than solid product.

Two pilot plants are currently in operation: one a 30 TPD unit at Fort Lewis, Washington (for SRC-II); and the other a 6 TPD plant at Wilsonville, Alabama (for SRC-I). The Fort Lewis work has generated data which will provide the design basis for planned demonstration plants for solid and/or liquid products. The Wilsonville pilot plant has provided supplemental screening of various coals and produced improvements in solid-liquid separation techniques. Supporting research at various facilities rounds out the SRC development effort.

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For heat economy in large-scale plants, however, it is advantageous to operate this separator at a higher temperature. This will allow the slurry to remain at a higher temperature during the let-down phase and will avoid the necessity of preheating the vacuum tower feed. Furthermore, heat can be recovered at a higher level from the hot separator overhead vapor stream and from subsequent downstream steps.

The combination of high temperature, the presence of hydrogen, and the potential for vapor entrainment of solid particles, however,introduces uncertainties which must be addressed by actual operation, preferably prior to and on a unit smaller than the demonstration plant. The Fort Lewis pilot plant is being modified to gain experience in operation of the vapor-liquid separation system at higher temperatures than have been used at such a scale. This involves installation of a new hot separator vessel, as well as several downstream separators, pumps, and heat exchangers.

The demonstration plant design provides for gasification of the vacuum residue at high pressure to provide synthesis gas for process hydrogen and plant fuel. The pilot plant, however, has no gasifier and the vacuum bottoms stream has been cooled and solidified at atmospheric pressure on a stainless steel cooling belt. While this is a satisfactory means of handling the vacuum residue from pilot plant runs, it provides no information on pumping of the vacuum bottoms to high pressure (as to a gasifier).

To provide such information, a specially designed vacuum bottoms test loop is to be incorporated in the existing vacuum tower system at Fort Lewis. The new equipment consists of a vacuum tower surge drum and a high-pressure, reciprocating pump for handling the vacuum residue, together with a pumparound loop to allow the pumped fluid to return to the surge drum.

Mixing of the hot recycle slurry with pulverized coal should be carried out at as high a temperature as possible for reasons of heat economy, but the unique characteristics of the slurry put an upper limit on the temperature which can be used. The coal begins to swell and form a gel when first contacted with hot, coal-derived liquids. This is the first step in solution of the coal and results in a very pronounced increase in viscosity.

The rate of increase in viscosity increases with temperature, and is especially pronounced at high coal concentrations. The initially high viscosity of the recycle slurry, plus the rapid increase in viscosity upon mixing, makes this a very critical design problem to balance temperature, residence time, and coal concentration during the mixing operation.

Two separate mixing and pumping systems are now in operation at Fort Lewis. These are: 1) an eductor system where pulverized coal is drawn from the bottom of the hopper by the low pressure created by the slurry moving at high velocity past the bottom of the hopper; and 2) a small, highly-agitated mix tank feeding a larger slurry blending tank. The latter system is being considered for the demonstration plant, and the pilot plant system is being modified somewhat to overcome difficulties observed in initial pilot plant testing of the system.

Initial operations at the Fort Lewis pilot plant using the original preheater were carried out at lower velocities and lower heat flux than planned for the demonstration plant design. This was a result of a substantial overdesign built into the original pilot plant, primarily to allow for the uncertainty existing at that time. To provide more pertinent data, a new preheater, parallel to the original preheater, was installed at the Fort Lewis pilot plant in 1979.

Experiments are now being carried out on the new preheater at velocities and heat flux rates within the general range of the demonstration plant design. This work has given considerable support to the belief that the preheater could be successfully operated at the normal conditions of the demonstration plant design. Furthermore, the results indicated that at certain conditions the pressure drop through the slurry preheater was lower than expected on the basis of earlier information at lower flow rates.

2.11.3 Availability for Commercial Production

The demonstration plant is expected to begin operation in 1985 and continue until 1986. At the conclusion of this phase of work, enough data will be available to establish a detailed design for a full-scale commercial facility, which could become a reality within the decade.

2.11.4 Unit Design and Construction Times

The detailed design phase for a commercial plant will be simplified somewhat due to the availability of information from the design of the demonstration plant. Approximately a year should be required for design, with a 5-year construction schedule anticipated for the full-scale plant.

2.12 REGIONAL FACTORS INFLUENCING ECONOMICS

2.12.1 Resource Constraints

Although a site has been selected for the SRC-II demonstration plant, final siting for a full-scale commercial facility has not been determined. During the demonstration plant program, a variety of coals will be tested, the results of which will be used to some extent in siting future plants. Barge transportation is planned for coal haulage, and the proximity to this water source should prove an adequate source of water for plant operations.

2.12.2 Environmental Control Constraints

Gaseous, aqueous and solid effluents generated by the plant are described in Sections 2-6, 2-7, and 2-8 respectively. The ability of the plant to comply with applicable regulations covering types and quantities of pollutants produced would depend on meteorology, topography, and existing air and water quality for the site in question.

2.12.3 Siting Constraints

Approximately 200 acres of relatively flat land would be required for the construction of a full-scale commercial plant. The site chosen must be easily served by rail or barge and have adequate access to water supplies. The site must also have sufficient stability to support the heavy foundations and process equipment integral to the process.

References

2-1. Jackson and Schmid, "Commercial Scale Development of the SRC-II Process," Gulf Mineral Resources Co., August 1978.

2-2. Josephson, Julian. "Toxic By-products of Coal Conversion," Environmental Science and Technology, Volume 14, Number 11, November 1980, pp. 1283-1286.

2-3. Freel, J., D.M. Jackson, and B.K. Schmidt. "The SRC-II Demonstration Project," Chemical Engineering Progress, May 1981.

2-4. McNamee, G.P., N.K. Patel, T.R. Roszkowski, and G.A. White. Process Engineering Evaluations of Alternate Coal Liquefaction Concepts, AF-741, Electric Power Research Institute, April 1978.

2-5. Conceptual Commercial Plant, Plant Description, Volume 2, Pittsburgh & Midway Coal Mining Co., July 1978.

SECTION THREE

ECONOMIC ANALYSIS - SRC-II

This section presents data on the economics of the Solvent Refined Coal (SRC)-II process.

3.1 Introduction and Methodology

3.1.1 Introduction

The economic analysis relies on a preliminary plant design by Gulf Science and Technology (3-1). The economic data were adjusted for inflation and scaled to a plant size of 125 trillion Btu per year. Other adjustments were then made to the data to make the plant self-sufficient in electricity production and to make operating costs comparable to other technologies assessed in this report. The adjusted data were then used to compute product costs for the facility.

3.1.2 Scaling Exponents

The conceptual SRC-II plant design used as a reference had a total capacity of 224.25 x 10^{12} Btu/year. This capacity was scaled down to 125 x 10^{12} Btu per year in this assessment, and costs were scaled using a scaling exponent of 1.0. The scaling formula is explained in the Background section. A scaling exponent of 1.0 was used because the plant was composed of multiple production trains, so that scale-down would entail removing entire trains, not changing the size of existing trains. There are scant scale economies when the number of trains are increased or decreased.

3.1.3 Price Indices

Prices in the reference report (3-1) were corrected from 1978 dollars to 1980 dollars using the indices presented in the Background Section.

3.1.4 Economic Criteria

In general, the economic criteria are explained in the Background Section. In order to make the plant self-sufficient in electric power, one of the basic standards of this study, the cost of a coal-fired power plant able to provide 5.6 MW at a 90 percent capacity factor was added to the cost estimate (3-2). The price of the power plant is shown in Unit 2050, Electric Power Plant.

ERCO also estimated Local Taxes and Insurance at 2.5 percent of Total Plant Investment to make operating costs of this technology comparable to those of other plants.

Finally, the expenditure schedule is 5 percent, 10 percent, 30 percent, 40 percent, and 50 percent for years one through five of construction.

3.1.5 Contingencies

A 15 percent project contingency was added to the total of area and unit costs to allow for cost increases as the design is made more complete.

A 25 percent contingency was added to the costs of area 400, Hydrogenation, and Unit 1510, Gasification. Both of these technologies have been proven only at the pilot plant stage in this application.

3.2 Capital Costs

3.2.1 Itemized Capital Costs

Itemized capital costs for the SRC-II plant are shown in Table 3-1. The Total Plant Investment adds up to $1,122 million, which includes a subtotal of plant erection costs of $888.6 million, a process contingency of $133.5 million, and a project contingency of $99.9 million. Within the plant, the Hydrogenation area (400) is the most expensive, at $347.7 million or 39.1 percent of costs before contingencies.

The total capital requirement is $1,782.3 million, as is also shown in Table 3-1. Besides the Total Plant Investment of $1,122 million, Interest During Construction is the most expensive cost, at $485.5 million.

3.2.2 Variability of Capital Costs

The capital cost estimate in the reference report (3-1) was prepared using the Stearns-Roger Computer-Aided Preliminary Estimating System (CAPES), which predicts equipment costs based on both input size and service data. The level of detail of the input data provided was not clearly specified in the report. Based on the apparent preliminary nature of the estimate, it should be considered accurate only within the ±40 percent range.

TABLE 3-1

TOTAL CAPITAL REQUIREMENT: SRC II[a]

AREA	UNIT	ITEM	COST (10^6 $)	PERCENT OF SUBTOTAL
100		Coal storage and handling	25.8	2.9
200		Coal preparation	12.2	1.4
400		Hydrogenation	34[illegible].7	39.1
1500		Hydrogen plant		
	1510	Gasification	51.8	5.8
	1520	Shift conversion	20.8	2.3
	1530	Acid gas removal	113.9	12.8
1600		Product gas compression	20.9	2.4
1800		Methanation	5.7	0.6
1900		Air separation	101.8	11.5
2000		Utilities and support systems		
	2010	Steam generation	21.8	2.5
	2020	Wastewater treating and water supply	82.5	9.3
	2030	Solids disposal	4.2	0.5
	2050	Electric powerplant	7.1	0.8
2100		Offsites and miscellaneous	79.5	8.1
	Subtotal		888.6	100.0
	Process contingency		133.5	
	Project contingency		99.9	
	Total plant investment		1122.0	
	Interest during construction		485.5	
	Working Capital		68.4	
	Start-up		67.3	
	Catalysts and chemicals		16.1	
	Land		8.7	
	License fees		9.0	
	Owner management		5.3	
	Total capital requirement		1782.3	

[a] Source: 3-1, updated to 1980 dollars and scaled by ERCO to 125 trillion Btu per year.

3.3 Operating and Maintenance Costs

3.3.1 Itemized Operating and Maintenance Costs

Itemized annual operating and Maintenance (O&M) costs are presented in Table 3-2. These costs total $76.7 million and exclude fuel. The gross O&M costs are offset somewhat by credits for by-product sulfur, ammonia, and tar acids, which total $14.4 million. Net O&M costs are $62.3 million.

3.3.2 Variability of Operating and Maintenance Costs

The O&M cost estimate contained no major exclusions, although there seems to be no allowance for administrative and support labor or utilities. Operating labor and maintenance costs are in accordance with estimates for other synthetic fuels plants. Therefore, the O&M cost estimate probably lies within the ±40 percent range of the capital cost estimate.

3.4 Effect of Technology Development on Costs

Areas 400, 1500, and 1800 (Hydrogenation, Hydrogen Plant, and Methanation) include immature technologies. As more synthetic fuel plants are built, the cost of these areas could decline due to improvements in these technologies because of experience. These three areas account for appxroximately 64.2 percent of the Total Plant Investment. The maximum experience factor for new energy technologies is approximately 10 percent, as was explained in the Background section. The experience factor for SRC-II technology is thus the 64.2 percent of costs accounted for

TABLE 3-2

NET OPERATING AND MAINTENANCE COSTS: SRC II[a]

ITEM	COST (10^6\$)	PERCENT OF TOTAL
Local taxes and insurance	28.1	36.6
General and administrative	4.5	5.9
Labor		
Operating labor	4.5	5.9
Maintenance labor	10.3	13.4
Total labor	14.8	19.3
Supplies		
Maintenance	22.4	29.2
Operating	0.5	0.7
Total	22.9	29.9
Catalysts and chemicals	6.4	8.3
Total Gross O&M Costs	76.7	100.0
By-product credits	(10^6 \$)	
Sulfur	(7.7)	
Ammonia	(4.7)	
Tar Acids	(2.0)	
Total	(14.4)	
Net O&M Costs	(10^6 \$)	
Gross O&M Costs	76.7	
By-product credits	(14.4)	
Total	62.3	

[a] Source: (3-1), updated to 1980 dollars and scaled to 125 trillion Btu/year by ERCO.

by the new technology times the 10 percent maximum, or approximately 6 percent. Each doubling of SRC-II production capacity beyond this first plant could reduce real capital costs by six percent.

3.5 Total Energy Costs

The total cost of the products has three discrete components: capital charges associated with plant capital costs, plant operating and maintenance (O&M) costs, and fuel (coal) costs. Both a total product cost and a non-fuel cost can be computed using the formulae given in the Background section.

The non-fuel cost is the cost of converting the coal to synthetic fuel, not including the cost of the coal itself. Non-fuel costs have a capital charge component and an O&M charge component. Based on the total capital requirement of $1,782.3 million from Table 3-1, and the yearly net O&M cost of $62.3 million from Table 3-2, the non-fuel product cost is:

$$P = \frac{\$1{,}782.3 \times 10^6 \times 20\% + \$62.3 \times 10^6}{125 \times 10^{12}\ \text{Btu} \times 90\%}$$

$$= \underset{\text{(capital charges)}}{\$3.17 \times 10^6\ \text{Btu}} + \underset{\text{(O\&M costs)}}{\$0.55 \times 10^6\ \text{Btu}}$$

$$= \underset{\text{(total non-fuel cost)}}{\$3.72 \times 10^6\ \text{Btu}}$$

Capital charges amount to $\$3.17/10^6$ Btu and O&M costs to $\$0.55/10^6$ Btu. The total non-fuel cost will be $\$3.72/10^6$. This non-fuel cost has an estimated accuracy of ±40 percent.

The non-fuel cost, combined with a coal cost, yields a total product cost for the plant's outputs. The overall coal-to-hydrocarbon output efficiency of the plant is 71.4 percent. With coal assumed to be $\$1.50/10^6$ Btu, the fuel component of energy costs would be $\$2.10/10^6$ Btu. When combined with the non-fuel cost, this yields an average product cost of $\$5.82/10^6$ Btu.

REFERENCE

3-1. Gulf Science and Technology, "SRC-II Commercial Plant Conceptual Design." 1978.