Section 12

# THE SRC-I COAL REFINING DEMONSTRATION PLANT

by

S. M. Morris
E. P. Foster
International Coal Refining Company

# The SRC-I Coal Refining Demonstration Plant

S. M. Morris and E. P. Foster

International Coal Refining Company

P.O. Box 2752

Allentown, Pennsylvania 18001

The International Coal Refining Company, a joint venture between Air Products and Chemicals, Inc. and Wheelabrator-Frye Inc., is engineering, constructing, and will operate the SRC-I Coal Refining Demonstration Plant. This Department of Energy and industry sponsored 6000 ton/day facility should be among the first large-scale coal liquefaction projects to be completed in the U.S. The plant will be designed to permit much operating flexibility, particularly in the yield and quality of products. Solid fuels, light and heavy liquid fuels, and coke will be produced over a wide range of product specifications to be used in a number of industrial and utility operations. Following a demonstration period, the plant will be expanded fivefold to product a nominal 100,000 bbl/day of products from 30,000 tons/day of coal.

The Solvent Refined Coal (SRC-I) Process, one of the most advanced direct coal liquefaction processes available, has attracted considerable national attention as a partial answer to the continuing energy crisis. A 6000 ton per day (tpd) coal feed Demonstration Plant is now being designed and will be constructed and operated by the International Coal Refining Company (ICRC)--a partnership of Air Products and Chemicals, Inc. and Wheelabrator-Frye Inc.--under contract to the U.S. Department of Energy (DOE).

* * *

Air Products and Chemicals, Inc. and Wheelabrator-Frye Inc. both bring much research, development, and engineering experience in coal liquefaction technology to the Demonstration Plant program. Air Products' subsidiary, Catalytic, Inc., engineered, built, and operates the SRC Pilot Plant at Wilsonville, AL, while Wheelabrator-Frye's subsidiary, Rust Engineering, designed and built the DOE SRC Pilot Plant at Fort Lewis, WA. These two plants have logged over 10 operating years and have provided the data base upon which the Demonstration Plant design rests.

Early in 1977, Wheelabrator-Frye and the Commonwealth of Kentucky entered into an agreement for the design of a 2000-tpd SRC plant. Part of this work resulted in the selection of the current Demonstration Plant site at Newman, Daviess County, KY. A year later, the Air Products/Wheelabrator-Frye Joint Venture was formed to act as the sole prime subcontractor to Southern Company Services, Inc., which was the principal contractor to the DOE for the initial phase (Phase 0) of the Demonstration Plant project.

During Phase 0, ICRC prepared the conceptual design, preliminary cost estimates, marketing assessments, economic evaluation, and environmental appraisal. Process options were evaluated, critical technology areas requiring additional data were identified, and the economics were assessed for both a "grass-roots" five-module, 30,000-tpd Commercial Plant ("grass roots" in the sense that it would be built on an undeveloped site) and a Commercial Plant of the same size expanded from the Demonstration Plant. The Phase 0 work was completed in July 1979, and in October 1979, the DOE authorized Phase I, the detailed engineering of the project.

On 7 August 1980, a cost-sharing agreement was signed between ICRC and DOE in Owensboro, KY, covering the remainder of the Demonstration Plant program through start-up and operation of the facility. Under the terms of the agreement, ICRC will invest $90 million in the project, the Commonwealth of Kentucky will invest $30 million, and the DOE will fund the balance. The contract states that ICRC will eventually own the coal refinery after buying out the federal and state governments' interest. At that time, ICRC plans to expand the facility fivefold to 30,000 tpd.

Under the cost sharing agreement, ICRC became the prime contractor on the project. As an important subcontractor to ICRC, Southern Company Services will continue its pioneering role in the development of the SRC technology by providing broad technical reviews and product use studies.

Since the signing of the cost-sharing agreement, Alcoa and Cities Services Co. have agreed in principle to become minority partners of ICRC. These companies have long-standing technical status in solvent refined coal and will lend further strength to the company.

* * *

## Project Status

At this time, essentially all major technology selections have been completed, and the engineering is moving rapidly. Also, the Construction Manager/Constructor selection is imminent. ICRC has five engineering subcontractors: Air Products, Catalytic, CE-Lummus, R. M. Parsons, and Rust Engineering. The scope of work for each engineering subcontractor is detailed in Figure 1. In addition, ICRC is utilizing the services of a number of technical organizations to provide critical data supportive of the design effort.

It is anticipated that construction will commence shortly after approval of the SRC-I Environmental Impact Statement, now estimated (after several delays) to be in April 1981. On the basis of this date, the Demonstration Plant will be fully operational in late 1984.

* * *

## Demonstration Plant Process Description

Figure 2 presents a schematic diagram of the major processes of the Demonstration Plant.

Coal preparation includes receiving, unloading, conveying, storing, reclaiming, drying, and grinding the coal as feed for the process units. Approximately 93% of the coal is ground, dried, and fed to the SRC Process Unit, and the remaining 7% is ground, dried, and fed to the Gasification Unit.

In the SRC Process Unit, the coal is slurried in a process solvent, pumped to reaction pressure, mixed with a hot, hydrogen-rich gas stream, and heated, first against hot returning process solvent, and then in a fired heater. Within the fired heater, coal dissolution is accomplished and hydrogenation reactions begin. Additional hydrogen-rich gas is added at the exit of the fired heater and the mixture flows to the dissolvers, where hydrogenation and desulfurization reactions are completed. The high-pressure hydrogen-rich gas is separated from the product slurry, which is flashed and distilled to remove process solvent and lighter components. The remaining SRC/ash slurry is sent to the Kerr-McGee Critical Solvent Deashing Unit, where it is mixed with the deashing solvent and separated into a molten SRC stream and a solid residue stream. The Kerr-McGee solid residue stream, containing ash, undissolved coal, and about 20% of the SRC, is sent to the Coal Gasification Unit.

Gasification serves two purposes: (1) it converts the residue into an inert slag; and (2) through gasification of the carbonaceous components of the ash concentrate plus some supplemental coal, it generates the makeup hydrogen that is required for both the liquefaction and the expanded-bed hydrocracking processes. Gasification is performed at atmospheric pressure by a partial oxidation step, the oxygen being obtained from an Air Separation Unit.

The resulting gas is compressed and passed over a shift conversion catalyst to produce the raw makeup hydrogen stream. After the acid gases are removed, the purified hydrogen stream is divided, with approximately two-thirds going back to the SRC Process Unit and one-third going to expanded-bed hydrotreating.

Following its use in each of these units, the high-pressure hydrogen-rich gas passes through a series of treating steps before it is recycled to the SRC Process Unit. The combined gas stream is washed to remove chlorides and ammonia, scrubbed to remove acid gases, dried, and cryogenically processed to recover light hydrocarbons, which are used as plant fuel. Acid gases recovered after treating the combined gas stream and the makeup hydrogen stream are sent to the Sulfur Recovery Area, where molten sulfur is produced.

The molten SRC stream is processed in three separate units (Figure 3). The expanded-bed hydrocracking process receives between one-third and two-thirds of the molten SRC and converts it catalytically into naphtha, fuel oil, and low-sulfur solid SRC. Another third of the molten SRC goes to coking and calcining to produce anode coke for aluminum manufacture, and the balance of the molten SRC goes to the solidification unit to produce solid SRC.

* * *

## Technology Selection

Various trade-off studies were performed during Phase 0 and continued into Phase I to select major technologies for the Demonstration Plant. These studies are essentially complete. A recent paper (Tao et al., August 1980) discussed in detail the selection of the deashing, gasification, and solidification processes: the Kerr-McGee Critical Solvent Deashing Process was chosen over the Lummus Antisolvent Deashing and the Filtration Processes; the GKT Gasification Process--formally known as Koppers-Totzek--was chosen over the Texaco and Shell-Koppers Processes; and the vibrating tray solidification process was chosen over moving belt and direct water-bath contact processes.

* * *

## Process Flexibility

Much consideration has been given in the Demonstration Plant design for flexibility and future optimization. Typical examples are discussed below.

### Coal Particle Size and Maximum Slurry Temperature

The slurry mix system is designed to operate at 350°F with 38.5 wt % 200 mesh coal in solvent. Since the economics of the process would be greatly enhanced by the ability to operate at higher temperatures with a coarser coal, the flexibility of operating at temperatures up to 420°F with 20 mesh coal is being included. However, an increase in slurry mix temperature is limited by the formation at about 450°F of a viscous gel. The limit to coal size is difficult to quantify, but increasing coal size may increase operability risks due to mechanical wear in pumps and valves and sedimentation in the dissolver and in the Kerr-McGee CSD Unit.

### Slurry Heating

The slurry must be heated to reaction temperature--about 800°F--before introduction into the dissolver; this will be accomplished by heat exchange with process solvent and in multiple parallel fired heaters. The plant design allows bypass of the process solvent exchanger. One of the fired slurry heaters will have the ability to operate at flow velocities ranging from 12 ft/sec (design) to 30 ft/sec, and will be able to accommodate slurry rates up to three times the normal flow. This heater will be heavily instrumented to permit careful measurement of heat fluxes, skin temperatures, etc., to allow optimization of second generation designs.

### Dissolvers

The design currently calls for two dissolvers, operated in series, with a total residence time of 30 minutes in coal feed. Series dissolvers are preferred because it is believed that the dissolvers would be completely backmixed, and backmixing is thought to contribute to poorer solvent quality and decreased SRC yields. However, the

Demonstration Plant will be designed to permit parallel operation (with piping modifications), and also bypassing of one of the dissolvers. In addition, the amount and temperature of hydrogen introduced at the inlet of each dissolver will be variable.

Vapor/Liquid Separation

The dissolver effluent stream must be quickly cooled to below 780°F to minimize further chemical reaction. As designed, the vapor and liquid phases will be separated and each phase will be cooled. This design avoids the need to manifold a three-phase slurry into multiple parallel heat exchangers, which is potentially troublesome, or the need to quench by direct coolant injection, which is inefficient. However, at the dissolver effluent temperature of 840°F, retrograde reactions leading to coke formation can occur in short time periods. Therefore, the vapor/liquid separation system is being designed to allow quenching of the liquid phase below 780°F by recycling cooler liquid after downstream heat exchange.

Recycling--Key to Major Process Improvements

The Kerr-McGee CSD process has the ability to separate the molten SRC products into "light" SRC and "heavy" SRC. The light, but nondistillable, SRC is thought to be an especially powerful hydrogen-donor process solvent, which might allow operation at lower reaction severity. For a given product yield, operating at lower reaction severity can have a major impact on hydrogen consumption, gas vs. liquid yield, and, therefore, overall economics. The Demonstration Plant will be able to recycle the light SRC.

Likewise, there has been much interest in utilizing solvent-boiling-range oil that has been processed through LC-Fining for a portion of the SRC-I recycle solvent. This oil has been catalytically hydrotreated and may be a superior hydrogen donor. The Demonstration Plant will be able to recycle this hydrotreated solvent to the process solvent system.

* * *

## Product Flexibility

The necessity for varying product yields and qualities has been the foundation of ICRC's approach to coal liquefaction, and we believe that the two-stage liquefaction process (dubbed TSL) of SRC-I, followed by expanded-bed hydrotreating, will ultimately prove to be superior to the less flexible one-stage direct liquefaction processes currently under development. The TSL should be able to treat a wide range of coals and produce a more varied product slate with lower gas by-product production than other direct liquefaction processes.

Figure 4 illustrates the expected net products from the Demonstration Plant when operating in the design basis mode. Of the plant output of 3380 tpd, 29% is solid SRC, 18% is calcined coke, 6% is sulfur, and the balance is product oils. Note, however, that the product oils are actually a mixture of oils with different properties, which come from the SRC-I process, the coker, and the LC-Finer. The same is true of the Solid SRC. In addition, the plant is designed to be able to produce varying amounts of these products, depending on market demands.

### SRC-I Solids

The SRC-I coal refinery produces Solid SRC in two forms: "classical" SRC Solid, or SRC made directly from the SRC Process, and "TSL Solid," or SRC subjected to hydrotreatment in the LC-Finer. In the latter operation, two-thirds of the solid SRC is sent to the LC-Finer, the conversion is decreased to a 50% yield of 850°F- distillate liquids, and the remaining one-third is still 850°F+ SRC Solid. A comparison of properties between the two (Table 1) shows that the major difference is in sulfur content: the SRC Solid is typically 0.85 wt % S, while the TSL Solid is usually 0.26 wt %. The Demonstration Plant will be able to produce varying ratios of SRC to TSL Solids, which will enable the plant to respond to the different sulfur requirements of its customers.

### Liquid Products

Table 2 indicates the amounts and qualities of liquid products that can be produced by either the first or second stage of the SRC-I coal refinery (SRC Liquids or TSL Liquids). The quantities of naphtha, medium oil, and heavy oil are typical, but it will be possible to shift these values somewhat by varying the severity of either the SRC-I or LC-Fining reactors. In addition, the sulfur and nitrogen contents can be changed either by blending SRC and TSL oils or by changing reactor severity.

* * *

## SRC-I Coal Refinery Product Markets

The solids, liquids, and gases produced from solvent refining of coal can all satisfy traditional fossil fuel energy demands. However, because of both their origin and the conversion process technology, each product will require evaluation in terms of its final use and the traditional fuel that it will displace. The unique engineering properties of the coal-derived fuels can be a benefit and/or a disadvantage. For instance, the SRC Solid must be handled as a solid but may be used like a liquid in oil-designed combustors; the SRC naphtha has significant quantities of oxygen compounds not found in petroleum naphtha, but, once upgraded, is excellent feed for high-octane unleaded gasoline blendstock because of its high aromatics content.

### SRC-I Solids

Furnace/Boiler Fuel. The low sulfur contents of SRC and TSL Solids will comply with the most stringent environmental regulations, eliminating the need for flue gas desulfurization.

In addition to their low sulfur content, the SRC Solids have three unique engineering properties that favor their use in oil-designed boilers: a very low inorganic ash content, a low melting temperature, and a very high Hardgrove grindability index. These properties suggest three firing modes that would be applicable to oil-designed furnaces/boilers: (1) finely pulverized; (2) melted and atomized like oil; (3) mixed in SRC Liquids.

Firing of the finely pulverized (90+%, 325 mesh) SRC Solid in an oil-designed boiler is now being tested, but results are not yet available.

The firing of melted SRC Solid using a modified steam atomized oil burner in a 100-hp (3.5 MM Btu/hr) fire-tube Johnson package boiler designed for No. 6 Fuel Oil has recently been accomplished at DOE's Pittsburgh Energy Technology Center (Table 3). The combustion efficiency exceeded 99% with a boiler efficiency of 82% at full boiler rating, which compares favorably with a reference No. 6 Fuel Oil burn. The sulfur dioxide and uncontrolled particulate emissions were about 1 lb of $SO_2$/MM Btu and 0.3 lb of particulates/MM Btu, respectively. Nitrogen oxides and hydrocarbons were higher than desired, so future burn tests will study ways to decrease these species. Babcock and Wilcox also successfully burned melted SRC Solid in a 40 MM Btu/hr water-wall, oil-designed test tunnel in a short duration burn in the mid-1960s (Sage, 1964).

The firing of 30% SRC Solids mixed with 70% SRC Liquids has also been tested in the fire-tube boiler at full rating with greater than 99% combustion efficiency and 81% boiler efficiency, which compares well with the reference No. 6 Oil burn.

The finely pulverized SRC Solid and the SRC-I Solid/Liquid mixture will be further tested in a 25 MM Btu/hr water-tube, oil-designed boiler early in 1981. Environmental emissions control (electrostatic precipitator and bag filter, $NO_x$ and HC control), furnace and boiler depositions, and combustion control will be investigated in more detail.

SRC-I Solids pulverized to a standard coal grind were successfully burned for 18 days at Georgia's Power Plant Mitchell in 1977 in a B&W 22-MW utility boiler designed to fire coal (Table 4) (Southern Company Services, 1979). The particulate production was about 1 lb/MM Btu controlled to 0.04 lb/MM Btu with an existing electrostatic precipitator. There was no slagging and essentially no bottom ash, soot blowers were not used, and $SO_2$ and $NO_x$ emissions met EPA New Source Performance Standards.

All these test results and economic evaluations suggest that SRC-I Solids are a viable fuel for the 1990s in the following markets: oil-fired, oil-designed utility and industrial boilers; oil-fired, coal-capable utility boilers with technological, environmental, or economic conversion problems; new intermediate-load utility boilers; new industrial boilers; and industrial furnaces and kilns.

Anode Coke. Laboratory work by Alcoa has shown that SRC Solid can be processed to produce green coke, which can be calcined to a high-quality anode coke for aluminum smelting. The SRC-derived product appears to be superior to conventional petroleum coke because it has less sulfur and may require lower power consumption during the aluminum-smelting process.

A need for SRC anode coke is anticipated because of the growing demand for low-sulfur, low-metals anode coke coupled with an expected shortfall in petroleum coke production. Conventional anode coke is made from petroleum coke, a by-product in the conversion of heavy fuel oil into lighter distillates. Petroleum coke is expected to decline in quantity and quality as refiners continue to upgrade the bottom of the barrel into gasoline and fuels.

SRC-I Liquids

An important part of the product slate from the SRC-I Demonstration Plant will be liquid distillates that can perform similarly to those derived from petroleum. It is expected that the Demonstration Plant will be producing a $C_5$-400°F naphtha fraction that can be upgraded via catalytic reforming to produce a high-octane unleaded gasoline blendstock, a 400-650°F cut that can be used as a fuel oil somewhat similar to No. 2 Fuel Oil, and a 650-850°F heavy oil fraction that can be used either directly as a substitute for No. 6 Fuel Oil or blended with pulverized SRC Solid to make a slurry, which can be fired as a No. 6 Fuel Oil substitute.

Since liquid products derive from three sources (the SRC-I first-stage liquefier, the LC-Finer second-stage liquefier, and the delayed coker), their compositions will vary, a factor which must be considered when evaluating markets. All of these coal-derived liquids have significantly higher oxygen contents, typically 2-4% oxygen, than petroleum distillates. Nitrogen compounds are prevalent in all of the SRC-I liquid streams and typically exceed the amount found in petroleum fractions, while sulfur levels are equal to or less than those in similar petroleum fractions.

To produce a suitable SRC-I naphtha reformer feed for conversion into a high-octane gasoline blendstock, sulfur, oxygen, and nitrogen contents must be lowered, typically to <1 ppm, to prevent deactivation of the reforming catalyst. Methods are being investigated to reduce these impurities. Preliminary bench-scale tests conducted with similar coal-derived naphthas have shown that a high-octane unleaded gasoline blendstock, typically with a research octane number of 103, results from mild catalytic reforming.

Because the SRC-I medium and heavy oils have a somewhat lower API gravity compared to similar petroleum fuels, they may handle slightly differently than No. 2 and No. 6 Fuel Oils. We presently expect our middle-distillate stream to be a good No. 2 Fuel Oil substitute and a stationary turbine fuel, and the heavy oil fraction could be used directly or blended with pulverized solids as a substitute for No. 6 Fuel Oil.

The market potential for SRC-I Liquids is also being evaluated in the following areas:

- Using SRC-I naphtha as a catalytic reforming feedstock to produce benzene, toluene, and xylene for the petrochemical industry

- Using the middle distillate (500-650°F fraction) as a hydrocracker feedstock (because of its low API gravity and relatively high aromatics content) to produce more gasoline, diesel fuel, and turbine fuel

- Using the heavy oil (650-850°F fraction) as a carbon black feedstock because of its high aromatics content and relatively low API gravity.

As the composition and end-use characteristics of these liquids are better defined, other markets can be identified and pursued where coal-derived liquids will substitute for imported petroleum.

* * *

## Commercialization

As already suggested, a great deal of flexibility exists in selecting the product slate for the Commercial Plant. An SRC-I facility would produce approximately 75 wt % of its product as Classic SRC Solid and the remaining 25 wt % as a range of liquid products. A Two-Stage Liquefaction facility based on low severity hydrocracking would produce approximately 40 wt % of the product as TSL Solids and 60 wt % as liquid products. A high severity hydrocracker would result in only 10 wt % of TSL Solids and 90 wt % of liquids.

Figure 5 depicts a schematic for a Commercial Plant based on a low severity hydrocracker. On the basis of 30,000-tpd (33,333 tpsd) raw coal feed, about half the product oils are produced in the hydrocracker along with 7578+ tpsd TSL Solids.

Tables 5, 6, and 7 summarize costs, all in 1980 dollars. The plant achieves a thermal efficiency of 70.3% at a total projected capital cost of $3.1 billion and an annual operating cost of $1.16 billion. The average required product price is $5.30/MM Btu.

Additional details on Commercial Plant economics can be found in the paper by Tao et al. (August, 1980).

An aggressive schedule for commercialization sets up a five-year design-and-construction period beginning in 1985, with the plant going onstream about 1990.

---

The authors wish to acknowledge the support of the U.S. Department of Energy under Contract DE-AC05-78-ORO-3054.

## References

Foster, E. P., et al., "Rheological Properties of Solvent Refined Coal-Oil Mixtures," 2nd International Symposium on Coal-Oil Mixtures--Pittsburgh Energy Technology Center, 27-29 November 1979.

Gupta, A. S., and Moore, F. L., "SRC-I Coal Refinery: Implication for the Coal Industry," Coal Conference and Expo V, Louisville, KY, 23-25 October 1979.

Gupta, A. S., et al., "Transportation Fuels from Solvent Refined Coal (SRC-I) Refinery," Symposium on Non-Petroleum Vehicular Fuels--IGT, Arlington, VA, 11-13 February 1980.

Moore, F. L., and Gupta, A. S., "SRC-I Coal Refinery: Markets and Commercial Efforts Summary," Coal Technology Conference '79, Houston, TX, 6-8 November 1979.

Morris, S. M., et al., "The SRC-I Project," 86th National AIChE Meeting, Houston, TX, 3 April 1979.

Phillips, E. M., et al., "A Comparative Study of Coal Liquefaction Performance and Economics for Solvent Refined Coal-Based Processes," 88th National AIChE Meeting, Philadelphia, PA, 10 June 1980.

Pryor, J. A., and Flask, A. P, "SRC Solids--A Building Block for the Coal Conversion Industry," 6th Energy Technology Conference, Washington, DC, 27 February 1979.

Rappe, G. C., "An Evaluation of Solids Separations Techniques in Coal Liquids," International Conference on Solids Separation Processes, Dublin, Ireland, April 1980.

Sage, W. L., Combustion Tests on a Specially Processed Low-Ash, Low-Sulfur Coal, Final Report Prepared for Office of Coal Research, Contract No. 14-01-0001-418, July 1964.

Skinner, R. W., and Givens, E. N., "Effects of Solvent Hydrogen Content in the SRC Process," American Chemical Society Fuels Division Meeting, Houston, TX, Spring 1980.

Skinner, R. W., and Givens, E. N., "Effect of Solvent Hydrogen Content upon SRC-I Coal Liquefaction," ACS Meeting, Houston, TX, March 1980.

Skinner, R. W., and Givens, E. N, "Approach to Steady-State Solvent Composition during the SRC-I Coal Liquefaction Reaction," 15th Intersociety Conversion Engineering Conference, Seattle, WA, 18 August 1980.

Southern Company Services, Solvent Refined Coal Burn Test, Final Report, July 1979.

Tao, J. C., and Yen, A. F., "Environmental Control Systems of the SRC-I Demonstration Plant," U.S. DOE Environmental Control Symposium, 17-19 March 1980.

Tao, J. C., et al., "Solid SRC--A Building Block," 6th International Coal Gas Conference, Pittsburgh, PA, 2 August 1979.

Tao, J. C., et al., "Demonstration and Commercialization of the SRC-I Technology," 7th Annual International Conference on Coal Gasification, Liquefaction, and Conversion to Electricity, Pittsburgh, PA, 5 August 1980.

Thorogood, R. M., and Yeh, C. L., "Coal Reactor Design for the SRC-I Process,". AIChE Meeting: Status of Synthetic Fuel Process, San Francisco, CA, 26-28 November 1979.

Van Driesen, R., Hastings, V., and Morris, S. M., "Upgrading Solvent Refined Coal by Hydrogenation," 88th National AIChE Meeting, Philadelphia, PA, 10 June 1980.

Table 1

SRC Rates and Quality

| Specification | SRC Solid | TSL Solid* |
|---|---|---|
| Demonstration Plant production rates, tpd | 0-2658 | 97-909 |
| Softening point, °F | 300 | 300 |
| Sulfur, wt % | 0.85 | 0.26 |
| Ash, wt % | 0.1 | 0.2 |
| High heating value, Btu/lb | 15,800 | 16,250 |
| Hardgrove grindability index | 176 | 176 |

*From LC-Fining.

Table 2

Liquid Products Quality

| Specification | Naphtha ($C_5$-400°F) SRC* | Naphtha ($C_5$-400°F) TSL** | Medium Oil (400-650°F) SRC* | Medium Oil (400-650°F) TSL** | Heavy Oil (650-850°F) SRC* | Heavy Oil (650-850°F) TSL** |
|---|---|---|---|---|---|---|
| Quantities, tpd | 480 | 250 | 430 | 300 | 80 | 70 |
| Sulfur, wt % | 0.39 | <0.01 | 0.39 | 0.03-0.06 | 0.43 | 0.05-0.15 |
| Nitrogen, wt % | 0.70 | 0.11 | 0.83 | 0.25-0.50 | 0.91 | 0.5-0.75 |

*Includes products from the SRC-I and coker facilities.

**Products from LC-Fining, actual values depend on reaction severity.

Table 3

SRC Solid Burn in Fire-Tube Oil-Designed Boiler

| Fuel | Boiler rating, hp | Combustion efficiency, % | Boiler efficiency, % | Uncontrolled emissions, lb/MM Btu | | |
|---|---|---|---|---|---|---|
| | | | | $SO_2$ | $NO_2$ | Particulates |
| No. 6 Fuel Oil | 100 | 99.7 | 82.4 | 0.65 | 0.24 | 0.14 |
| SRC-I Solid/Liquid mix | 100 | 99.8 | 81.3 | 0.64 | 0.76 | 0.17 |
| SRC-I Solids melt | 100 | 99.2 | 82.2 | 1.01 | 0.71 | 0.31 |
| NSPS Standards | -- | -- | -- | 1.2* | 0.5 | 0.03 |

*Or 85% sulfur removal, whichever is lower.

Table 4

Summary of Plant Mitchell Burn Tests

18 Day Firing Test of SRC Solid in a
22-MW Babcock & Wilcox Coal-Fired Utility Boiler

| Fuel | Pulverizer energy usage,* kWh/MM Btu | Boiler efficiency** | Combustion efficiency** | Emissions, lb/MM Btu | | |
|---|---|---|---|---|---|---|
| | | | | $SO_2$ | $NO_x$ | Particulates*** |
| Coal | 0.52 | 90 | 98 | 1.01 | 0.47 | 0.07 |
| SRC-I Solid | 0.37 | 89 | 98.5 | 0.97 | 0.40 | 0.04 |

*Fuel feed rate of 7000 lb/hr.

**At full load.

***Outlet of Secondary Precipitator.

Table 5

30,000-tpd Commercial Plant Facility Energy Balance

| | |
|---|---|
| Output, MM Btu/day high heating value | |
| LPG | 28,000 |
| Naphtha ($C_5$-400°F) | 165,000 |
| Medium oil (400-650°F) | 175,000 |
| Heavy oil (650-850°F) | 51,000 |
| TSL Solids | 246,000 |
| | 665,000 |
| Input, MM Btu/day | |
| Coal | 850,000 |
| Electricity | 96,000 |
| | 946,000 |
| Overall efficiency | 70.3% |

Table 6

30,000-tpd Commercial Plant Capital Cost Summary
Cost in $ Millions, De-escalated to 1980 Onstream

| | |
|---|---|
| SRC liquefaction and deashing | $ 685 |
| Expanded-bed hydrocracking | 355 |
| Hydrogen production and treatment | 605 |
| Utilities, offsites, and coal preparation | 445 |
| Subtotal plant and equipment | 2090 |
| License fees,* initial catalysts and chemicals | 70 |
| Contingency | 430 |
| Interest during construction | 280 |
| Startup costs | 110 |
| Working capital | 145 |
| Total project cost | $3125 |

*Paid out to third parties.

Table 7

30,000-tpd Commercial Plant Operating Cost Summary*
Cost in $ Millions, De-escalated to 1980 Onstream

| Item | Quantity | | Annual cost** |
|---|---|---|---|
| Coal at $1.30/MM Btu | 33,333 tpsd | | 365 |
| Power at $0.034/kWh | 422,000 kW | | 115 |
| Catalysts and chemicals | - | | 45 |
| Maintenance materials | - | | 50 |
| Operating and maintenance labor | 1,455 persons | | 85**** |
| Subtotal | | 660 | |
| Capital charges*** (16% of project cost) | | 500 | |
| Total | | 1,160 | |
| Total Btu produced, MMM Btu/yr | | 218,538 | |
| Average required price, $/MM Btu | | $5.30 | |

*Assumes 20-yr operating life.

**328.5 days/yr onstream.

***Based on 65% debt, 35% equity, 20% contingency on capital, 15% discounted cash flow return, 9% interest rate on debt.

****Includes manpower allowances for vacations and sick leave, fringe benefits, plant supervision, and overhead.

FIGURE 1

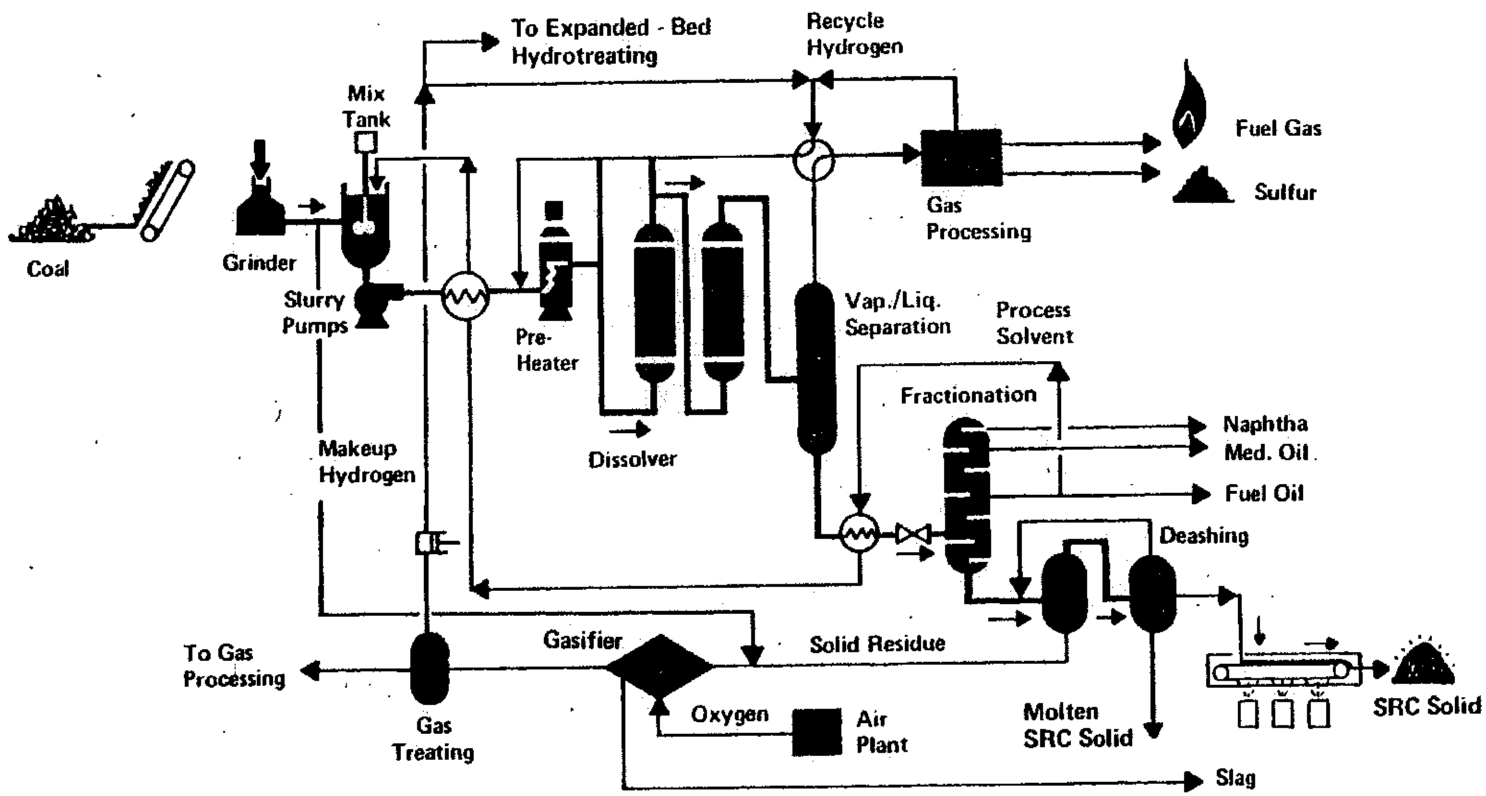
# SRC-I DEMONSTRATION PLANT MAJOR CONTRACTORS

| SUBCONTRACTOR | PROCESS AREA |
|---|---|
| APCI | OXYGEN PLANT<br>HYDROGEN PURIFICATION |
| CATALYTIC | SLURRYING, DISSOLVING, FRACTIONATION, SOLIDIFICATION AND DEASHING |
| LUMMUS | COKING AND CALCINING<br>LC-FINING |
| PARSONS | HYDROGEN PRODUCTION<br>ACID GAS TREATMENT<br>COMPRESSION<br>SULFUR RECOVERY |
| RUST | COAL PREPARATION<br>OFFSITES AND UTILITIES |
| TO BE DETERMINED | CONSTRUCTION |
| JOHNSON CONTROLS | INSTRUMENT SYSTEMS |

FIGURE 2

SRC-I

SOLVENT REFINED COAL



## FIGURE 3
## DEMO PLANT SRC PROCESSING

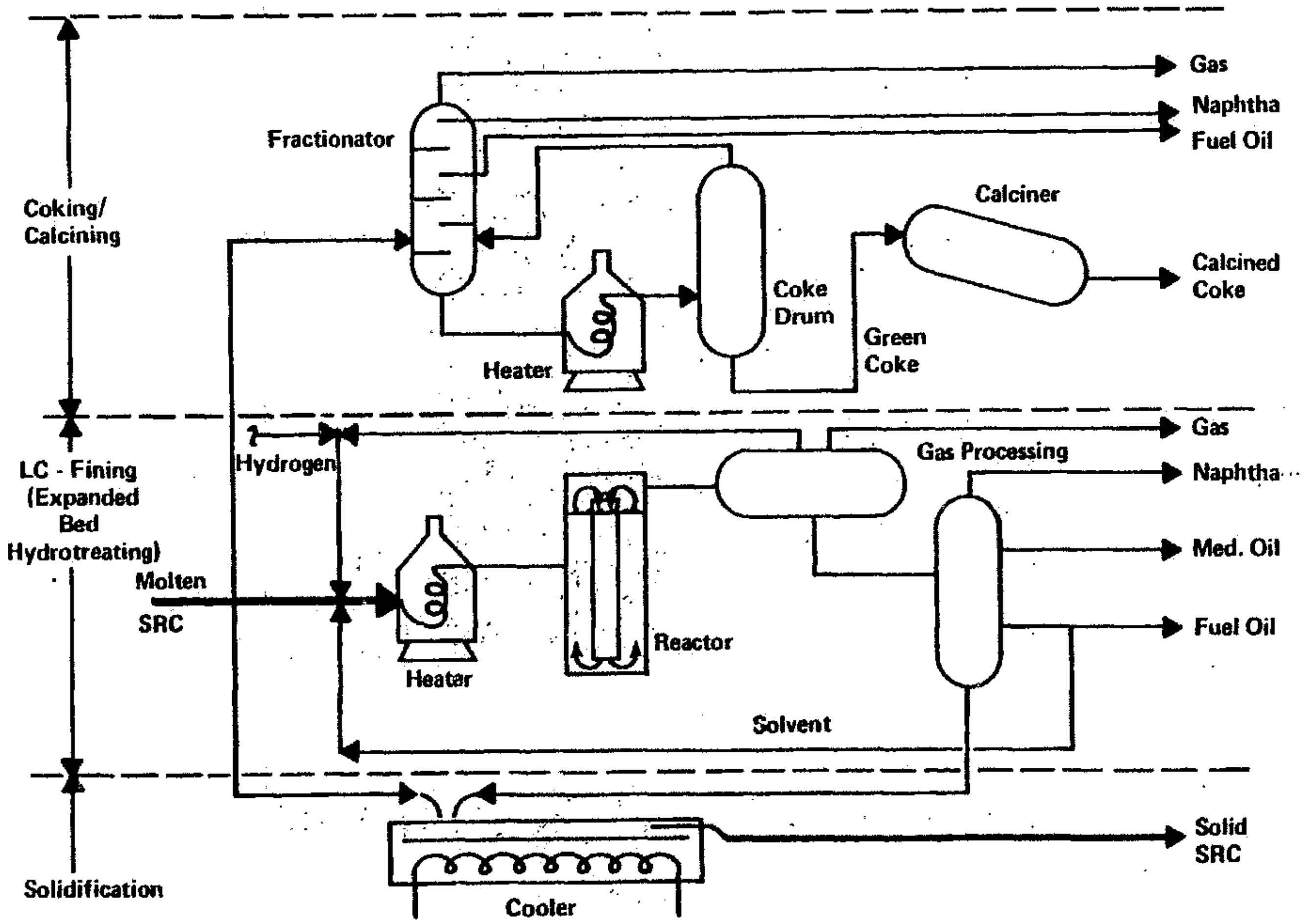
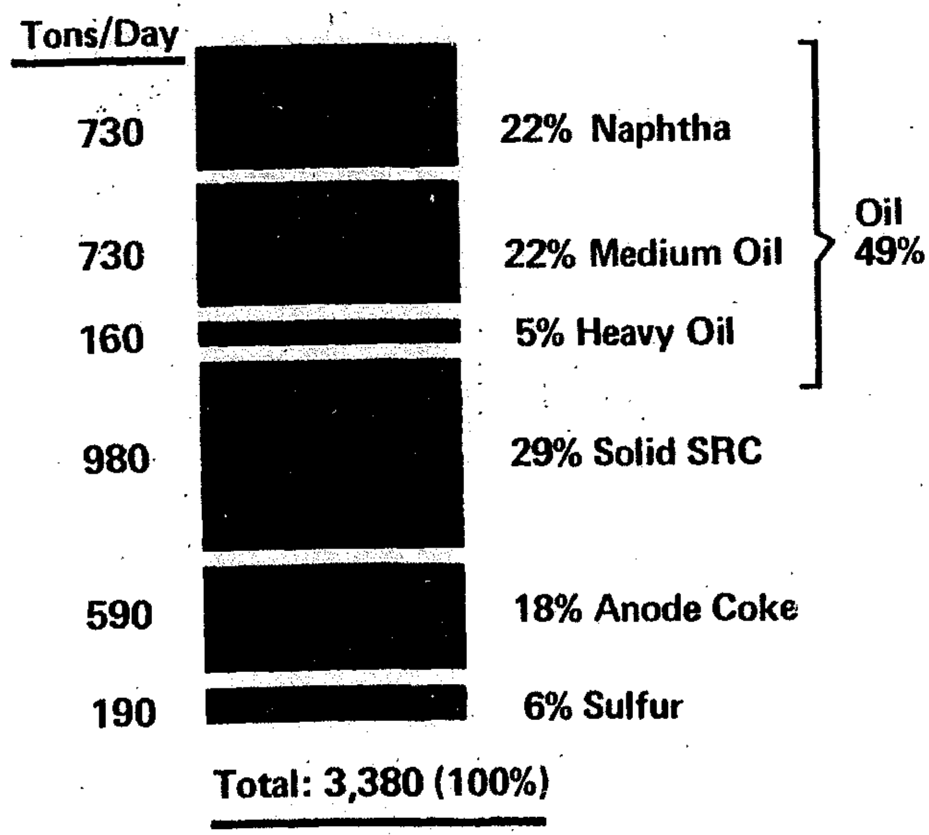


FIGURE 4

# NET PRODUCTS FROM PLANT



## FIGURE 5

## SRC-I WITH LOW SEVERITY HYDROCRACKING