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U.S. DEPARTMENT OF ENERGY
Division of Coal Conversion

QUARTERLY REPORT

July-September 1978

DOE/ET-0069/3

Publication Date: May 1979

COAL

DEFMON-ON STRAITS PLANTS

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COAL DEMONSTRATION PLANTS

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Washington, D.C. 20545

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FOREWORD

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EXECUTIVE SUMMARY

The United States has more energy available in coal than in petroleum, natural gas, oil shale, and tar sands combined. Nationwide energy shortages, together with the availability of abundant coal reserves, make commercial production of synthetic fuels from coal vital to the Nation's total supply of clean energy. In response to this need, the Division of Coal Conversion - U.S. Department of Energy (DOE) is conducting a research and development program to provide technology that will permit rapid commercialization of processes for converting coal to gaseous and liquid fuels and for improved direct combustion of coal. These fuels must be suitable for power generation, transportation, storage, and residential and industrial uses.

The technologies selected for development in the areas of gasification, liquefaction, and direct combustion will satisfy an urgent need for a particular type of fuel. The emphasis given each technology varies, depending on such things as technical complexity, development stage (laboratory research, including bench-scale tests and experiments with process development units, and pilot plant design, construction, and operation), variety of uses for the fuel produced, and urgency of the need that the technology is designed to satisfy.

The Department of Energy's demonstration plant program was started in 1974 by one of the Department of Energy's predecessor agencies: the Office of Coal Research, U.S. Department of the Interior. The objective of the program is to establish the technical and financial feasibility of coal conversion technologies proven during pilot plant testing. Demonstration plants will minimize the technical and economic risks of commercialization by providing a near commercial size plant for testing and production. Thus, DOE is sponsoring the development of a series of demonstration plants, each of which will be a smaller version of commercial plants envisioned for the 1980's. These plants will be wholly integrated, self-sufficient in terms of heat generation, and dependent only on feedstock of coal, water, and air.

Under the DOE program, contracts for designing, constructing, and operating the demonstration plants will be awarded through competitive procedures and will be jointly funded. The conceptual design phase will be funded by the government, with the detailed design, procurement, construction, and operation phases being co-funded, 50 percent from industry and

50 percent from the government. The cost involved in building and operating a demonstration plant will probably be between \$200 million and \$500 million, depending on the size of the plant.

The Department of Energy contracted with the Pittsburgh and Midway Coal Mining Company and Southern Company Services, Inc. this quarter for two separate contracts for the *Preparation of a Demonstration Plant Design and Cost Estimate for Solvent-Refined Coal (SRC)*. Pittsburgh and Midway is responsible for developing the SRC-II, liquid solvent refined coal while Southern Company Services, Inc. will develop SRC-I, solid solvent refined coal.

The Illinois Coal Gasification Group (ICGG) was selected to design, construct, and operate a *Pipeline Gas Demonstration Plant* with the objectives of demonstrating the commercial feasibility and economic attractiveness of a chemical process for conversion of high sulfur coal to clean pipeline gas. The primary process licensor is the COGAS Development Company, and the architect/engineering firm is the Dravo Corp., Synfuels Division. Certain work, which had been temporarily reduced the second quarter of 1978 by the DOE Suspension of Work Order was resumed and a contract modification authorized. The Process Evaluation Report was completed, and the Conceptual Commercial Plant Design Report is essentially completed.

Continental Oil Company will design a *Pipeline Gas Demonstration Plant* which may lead to cost shared construction and operation of the plant that would commercially supplement the natural gas supply to an industrial and residential area of Ohio. During the quarter, various tasks in Phase I continued to be slowed down at the request of DOE, pending the outcome of the technical support program at Westfield. In June, DOE authorized Conoco to restart Task I for the gasifier design. Volume I, Executive Summary and Volume II, Process and Project Engineering Design of the final Task I Report were issued.

Memphis Light, Gas, and Water, a municipal utility, was awarded a contract by the DOE to design an advanced *Fuel Gas Industrial Demonstration Plant* to convert coal into fuel gas for industrial use utilizing the U-Gas process developed by the Institute of Gas Technology.

A *Fuel Gas Industrial Demonstration Plant* program is also the responsibility of W. R. Grace & Company. The majority of the technical work effort for the quarter was directed toward finalization of design parameters. Efforts continued on various trade-off studies with resultant incorporation for recommendations into the commercial plant design.

A program for the *Development of Coal Feeders for Coal Gasification Operations* using second generation systems for pressurized coal conversion processing is being conducted by Foster-Miller Associates, Inc. Durability testing of the linear pocket feeder (LPF) prototype was resumed during the quarter and operated 130 hours without problems. The design of the 500 psi feeder continued and was completed in August. Assembly and check-out of feeder components is underway.

Ingersoll-Rand Research Inc. continued their *Development of a Continuous Dry Coal Screw Feeder*. The feasibility of spray feeding of fully plasticized coal was established against gas back pressure of up to 1,100 psig in the injection mode of operation. The single acting piston feed design was simplified and the procurement and experimental work progressed satisfactorily. The Phase I report was completed this quarter.

Lockheed Missiles and Space Company Inc. is also responsible for a *Coal Feeder Development Program*. Emphasis during the quarter was on the design of the first-stage kinetic extruder. Component evaluation tests also continued on seven and 50 ton-per-hour models.

Preliminary Design Services by the Ralph M. Parsons Company included the completion of the draft report on the Multi Process Demonstration Plant. The draft report on Prestressed Concrete Pressure Vessels was also submitted to DOE for review.

The objective of the *Lockhopper Valve Development Program* being conducted by Consolidated Controls is to design, manufacture, test and evaluate eight and 12-inch valves that would be compatible with operating conditions found in numerous coal gasification plants. The first type III valve was successfully assembled during the last quarter, and preliminary testing began. Work on Type I, II, and IV valves continues.

Fairchild Stratos Division is also responsible for *Valve Development for Coal Gasification Plants*. The Phase I Conceptual Design Summary Report was completed and submitted to DOE in April. Re-evaluation of the Type II valve design concept was completed also, and a revised concept layout of the stuffing box and yoke assembly was presented to DOE in May 1978. The Phase II Prototype Testing effort is about 10 percent complete as of this quarter.

Kennedy Van Saun is conducting a *Coal Grinding Equipment Development* program to produce reliable coal grinding equipment for the controlled grinding and preparation of feed coal for demonstration and commercial size plants.

Jet propulsion Laboratory has a contract for *Coal Pump Développement and Technical Support* to DOE in evaluating new feeder technology. Phase I effort was completed during the quarter and Phase II effort initiated. Testing and modifications of the 2.5-inch coal pump to prevent feed blockage continued. Extrusion of Pocahontas No. 3 coal and Kentucky No. 8 coal was also attempted.

Argonne National Laboratory is developing *Instrumentation and Process Control for Fossil Demonstration Plants*. The first draft of the updated State-of-the-Art Report of instrumentation for process control in coal conversion systems was 95 percent complete.

Water Purification Associates has the contract for the *Development of Conceptual Designs for Water Treatment in Demonstration Plants* in order to develop and determine water technologies for various coal conversion demonstration plants to minimize water use. Designs were completed for the water treatment units for the SRC and BIGAS plants.

The conceptual Design of a Coal-to-Methanol Commercial Plant is the responsibility of Badger Plants. Work continued on the design of the overall coal-to-gasoline plant.

Procon, Inc. was selected to design a *High-BTU Pipeline Gas, HYGAS Conceptual Basis Commercial Plant* based on Illinois No. 6 coal. Reports completing the Commercial Plant design effort were underway at the beginning of the quarter, and a final report is being prepared. Work on the Demonstration Plant continues.

I. SOLVENT-REFINED COAL (SRC) PROCESS DEMONSTRATION PLANT

THE PITTSBURGH & MIDWAY COAL MINING
COMPANY

SOUTHERN COMPANY SERVICES, INC.

Contract No.: ET-78-C-01-3055 —
ET-78-C-01-3054

Contract Funding: \$3,200,000 (each contract)
(100% DOE)

INTRODUCTION

In July 1978, DOE contracted with the Pittsburgh & Midway Coal Mining Company for the preparation of a demonstration Plant Design and Cost Estimate for a Liquid Product Solvent Refined Coal (SRC-II) Process Facility, identified as the SRC-II Demonstration Project, leading to the final design, construction, and operation of the SRC-II facility. Also in July 1978, DOE contracted with Southern Company Services, Inc for the demonstration of the Solid Product Solvent Refined Coal Process. Both plants would process an average of 6,000 tons-per-day into clean fuels primarily for use as utility boiler fuels.

A four-phase program is envisioned for each process. Phase Zero, the Initial Effort, is part of the four-phase program which consists of the following work items:

- Phase Zero — the initial report, consists of seven tasks:
 1. Preliminary Demonstration Plant Design and Cost Estimate
 2. Long Lead Procurement Planning
 3. Market Analysis
 4. Program Management
 5. Plan and Cost Estimate for Phases I, II, and III

6. Cost Sharing Plan
7. Environmental Analysis
 - Phase I — Detail/Final Design
 - Phase II — Procurement and Construction
 - Phase III — Operation and Evaluation of First Module Plant

Figure I-1 provides the schedule for the development of the project.

PROCESS DESCRIPTION

In the original SRC mode (SRC-I) the product is a solid fuel at ambient conditions, and serves as a direct clean fuel substitute for high-sulfur coal. In a modification of the process (SRC-II mode), using slurry recycle instead of distilled process solvent and increased severity of reaction conditions, a distilled liquid product results. The SRC-II mode product can be used directly as boiler fuel or, with further hydrogenation, as a refinery feed for conversion to conventional fuels.

Schematic process flow diagrams of the SRC-I and SRC-II process are shown in Figures I-2 and I-3, respectively. For operation in the SRC-I mode the coal

ACTIVITY	FISCAL YEAR							
	1978	1979	1980	1981	1982	1983	1984	1985
PHASE 0 PRELIMINARY DESIGN	△	▽						
PHASE 1 DETAILED DESIGN		△	▽					
PHASE 2 CONSTRUCTION			△	▽				
PHASE 3 OPERATION AND EVALUATION						△	▽	

Figure I-1. SRC-I & II DEMONSTRATION PLANT PROGRAM SCHEDULE

Figure I-2. SRC-I PROCESS SCHEMATIC

is pulverized and mixed with coal-derived distillate solvent. The slurry, after addition of hydrogen, passes through a fired preheater and into a dissolver which operates at a pressure of 1,500 to 2,000 psig and a temperature of about 850°F. Under these conditions, about 90 percent of the carbonaceous material in the coal is dissolved. The coal is depolymerized and hydrogenated

as well as hydrocracked, resulting in a decrease in molecular weight of hydrocarbon product ranging from methane upward. Much of the sulfur is removed by formation of hydrogen sulfide.

From the dissolver, the mixture flows to a separator for removal of gas from the slurry of undissolved solids

Figure I-3. SRC-II PROCESS SCHEMATIC

and coal solution. Raw gas is sent to hydrogen recovery and desulfurization units. Recovered hydrogen is combined with fresh makeup and recycled to the process. Hydrogen gases are recovered and hydrogen sulfide is converted to elemental sulfur.

After separation of gases, the slurry of undissolved solids and coal solution leaving the dissolver is routed to filtration or other deashing processes for separation of solids, after which the product is recovered by fractionation.

In the modified or SRC-II process mode, part of the slurry from the dissolver is recycled as solvent for the pulverized coal feed instead of the 480°F+ boiling range distillate used for the SRC-I mode. As a result of increased severity of reaction conditions, hydrogen reaction is greater and a major part of the coal is converted to a liquid-distillate product. The quantity of unconverted coal and vacuum residue is controlled so as to be in balance with the requirements. This permits use of distillation for the solid-liquid separation step, since all product is in the distillate boiling range.

HISTORY OF THE PROJECT

The SRC project was begun in 1962 when Spencer Chemical Company was awarded a research contract

by the Office of Coal Research (OCR, subsequently a part of ERDA, now DOE) to study the technical feasibility of a coal de-ashing process (now called the SRC process). In 1965, the process was successfully demonstrated in a 50-pound-per-hour continuous-flow unit, completing the work on the contract. During the term of the contract, Gulf Oil Corporation acquired Spencer Chemical Company. After reorganization, the contract was assigned to the research department of P&M.

To develop the SRC process further, a contract was awarded to P&M to design, construct, and operate a pilot plant capable of processing 50 tons of coal per day. In 1969, Stearns-Roger Corporation completed the design for the pilot plant, but funds to begin construction were not available until late 1971. In June 1972, OCR extended its contract with P&M to construct and operate the pilot plant. Rust Engineering Company began constructing the pilot plant in July 1972 at Ft. Lewis, Washington, near Tacoma.

The pilot plant began operation in October 1974 for process studies. Production of 3,000 tons of solid product for full scale combustion tests in a utility boiler were completed in 1976. Pilot plant modifications for operation the SRC-II mode were completed in 1977. The modified pilot plant produced over 5,000 barrels of distillate fuel oil for combustion testing in a utility boiler in the fall of 1978. Pilot plant operations are continuing in support of both SRC-I and SRC-II demonstration plants.

In March 1972, the Southern Company System and the Edison Electric Institute jointly began a pilot scale study of key steps in the SRC process. Southern Company Services, Inc., representing the Southern Company System, provides project management. In April 1973, the Electric Power Research Institute assumed the functions formerly performed by Edison Electric Institute. The United States Energy Research and Development Administration, now the Department of Energy, began cosponsorship of the Wilsonville operation in 1976.

The six ton-per-day SRC pilot plant at Wilsonville, Alabama, was designed, constructed and is being operated in the SRC-I solid fuel mode by Catalytic, Inc. Operation began in January 1974 and one subbituminous

and six bituminous coals have been tested. This installation provides a flexible test unit for screening coals and investigation of various process improvement options to supplement the Fort Lewis pilot plant.

PROGRESS DURING JULY-SEPTEMBER

The current contracts for the preparation of a demonstration plant design and cost estimate for a Liquid Product Solvent Refined Coal (SRC-II) Process Facility became effective this quarter.

II. PIPELINE GAS DEMONSTRATION PLANT

ILLINOIS COAL GASIFICATION GROUP
CHICAGO, ILLINOIS

Plant Site:	Perry County, Illinois
Contract No.:	EF-77-C-01-2012
Total Funding:	\$293,215,609
Phase I:	\$ 22,691,309 *(96% DOE/4% ICGG & CDC)
Phase II:	\$199,386,300 *(50% DOE/50% ICGG)
Phase III:	\$ 71,138,000 *(50% DOE/50% ICGG)

INTRODUCTION

The Illinois Coal Gasification Group (ICGG), consisting of a joint venture on the part of subsidiaries of the Northern Illinois Coal Gas Co., Peoples Gas Light & Coke Co., Central Illinois Light Co., Inc., Central Illinois Public Service Co., and North Shore Gas Co. was selected by DOE to design, construct, and operate a pipeline gas demonstration plant with the objectives of demonstrating the commercial feasibility and economic attractiveness of a chemical process for conversion of high sulfur coal to clean pipeline gas. The primary process licensor (pyrolysis, gasification and liquid product recovery) is the COGAS Development Company, and the architect/engineering firm is the Dravo Corp., Chemical Process Division.

This comprehensive program includes a number of specific objectives which are to:

- Confirm design criteria, demonstrate technology and obtain experience which will yield those characteristics

required to establish and/or define plant investment and operating costs for future clean pipeline gas commercial production plants.

- Project plant investment, operating and end-product costs for full-scale commercial production plants.
- Provide technology, performance, reliability and maintenance characteristics which will permit the design of a full-scale clean pipeline gas commercial production facility.
- Investigate the general applicability and limits of the selected process and plant design for a variety of coal types.
- Determine scaling parameters (with respect to the commercial production of the primary product) and sizing of major process components, such as those for gasification, hydrogenation, etc.
- Provide finished marketable clean pipeline gas in quantities sufficient for end-use evaluations.
- Determine the general characteristics, composition and quality of the end-product(s).
- Assess and/or evaluate characteristics and suitability of the product in actual representative end-use applications.
- Establish guidelines for by-product use and/or disposal.

*1975 Dollar Estimate (contract value) Phase I cost and schedule changes are now being negotiated. Phase II and Phase III costs will be renegotiated prior to unitization of these processes.

- Obtain data which will permit design of an environmentally acceptable commercial plant.
- Establish the design compatibility with Occupational Safety and Health Administration (OSHA) requirements.

PROGRAM PLAN

The overall effort on the program has been divided into three distinct phases. These are:

- Phase I — Development and Engineering — 22 months*
 - Stage 1 conceptual design
 - Stage 2 final engineering design
- Phase II — Demonstration plant construction — 34 months
- Phase III — Demonstration plant test, evaluation and operation — 42 months.

The following is a brief description, by phase, of the total program.

Phase I — Development and Engineering

Stage 1 — Conceptual Design

A conceptual design for a Commercial Plant using second generation gasification technology will be prepared. This design will be based on the maximum use of proven, commercially-available components and equipment. The capital and operating cost estimates, as well as the economic analysis, will consider various process trade-off and design studies. Based on a favorable economic evaluation of the conceptual design for a Commercial Plant, a conceptual process design for a Demonstration Plant will be developed. A site evaluation study and an environmental analysis, as well as preliminary plans for resources (coal, water, etc.) and water pipeline right-of-way acquisition, will be prepared. A recommendation for a Demonstration Plant will be submitted to DOE at the end of Stage I.

*Extension to 40 months has been proposed by ICGG, and is now being negotiated as part of the Cost and Schedule change proposal negotiations.

Stage 2 — Final Engineering Design

During Stage 2, bid packages, construction plans and an economic reassessment will be prepared. In addition to the possible procurement of long lead time equipment, plans for procuring raw materials, permits, and easements will be finalized.

Phase II — Demonstration Plant Construction

Phase II encompasses the actual detailed design and construction of the Demonstration Plant. The contractor will finalize the site acquisition and agreements related to feedstocks, product transportation, by-products sale, wastes, permits, licenses, easements and rights-of-way. After competitive bidding, the construction subcontract(s) will be awarded. The contractor will be responsible for procurement of equipment and facilities, preparation of the site, inspection of the work, and construction management.

Operation, training and maintenance manuals required for the start-up, testing and operating during Phase III will be developed. Training programs will be implemented with the specific objective of developing the necessary skills required for the operation and maintenance of the Demonstration Plant. The training program will emphasize both the safety features and the hazards of the equipment. A final economic reassessment of the investment and the operating costs of both the Demonstration Plant and a Commercial Plant will be performed.

Updated "as-built" drawings will be submitted to DOE. After the approval by DOE of a check-out and acceptance plan, necessary mechanical testing of the plant will be performed prior to start-up.

Phase III — Demonstration Plant Test, Evaluation and Operation

A plant shakedown test plan will be submitted to DOE for approval before the plant components are tested. A detailed report summarizing the six months of

testing will be submitted to DOE. Two months are planned for establishing the operating conditions and operating variables for the primary coal type, after which the plant will be operated for twelve months to demonstrate the long term operating characteristics of the plant. At the conclusion of the testing of the primary coal type, DOE may direct the contractor to test one or both of the alternate coals for a period of six months each. At the end of Phase III, DOE has the option to extend the period of performance for a period not to exceed

eighteen months in accordance with terms and conditions mutually agreed upon by the contractor and DOE.

As a result of the experience gained from constructing and operating the Demonstration Plant, the contractor will conduct process trade-off studies and an economic re-analysis for the optimization of the design, construction and operation of a commercial plant.

The program schedule is given in Figure II-1.

Figure II-1. ICGG PROJECT SCHEDULE

PROCESS DESCRIPTION

Technology to be used by the contractor includes the COGAS coal gasification concept, licensed by COGAS Development Company partnership comprised of the FMC Corporation; Consolidated Gas Supply Co.; Panhandle Eastern Pipe Line Co., and the Tennessee Gas Pipeline Co. The concept for pyrolysis and gasification (shown in Figure II-2) consists of three sub-units: multi-stage fluid bed pyrolyzers (adapted from the COED Process), a fluid bed gasifier, and a slagging char fines combustor.

The multi-stage fluid bed pyrolyzers are vertical cylindrical steel vessels. For most coals three pyrolysis stages are used. Coal is transported to the first stage using a suitable carrier gas. Temperature of pyrolysis increases from the first stage through the third stage. Coal is fluidized and pyrolyzed in the first stage by a portion of gas from the third stage. The char from the first stage flows to the second stage, where it is fluidized and pyrolyzed by the remainder of the gases from the third

stage. In the third stage, the char is fluidized and pyrolyzed by a portion of hot synthesis gas. Char from the third stage then feeds the gasifier, where the synthesis gas is produced. Gas from the first two pyrolysis stages, i.e. the pyrolysis gas, is water scrubbed and quenched to condense out most of the condensibles and water. It is then compressed and sent to the purification section for acid gas removal.

The char fed into the gasifier is fluidized by steam injected at the bottom of the gasifier. The hot char is more reactive than coal and reacts to produce synthesis gas by the following endothermic reaction:

The heat for this endothermic reaction is obtained by circulating a hot char stream through the combustor lift tube into the gasifier (See Figure II-3). As the hot char mixes with the char to be gasified, in the gasifier, it provides the heat for the endothermic reaction mentioned above. Char from the gasifier lift tube is recycled to the

Figure II-2. COED PYROLYSIS PROCESS SCHEMATIC

combustor for reheating. Char fines in the char stream and those collected in synthesis gas and flue gas cyclones are burnt in the combustor to produce hot flue gas and molten slag. The molten slag flows out of the bottom of the combustor into a slag quench tank where circulating water quenches the slag to a solid form. It is then settled and sent to disposal.

The hot flue gas from the combustor rises through the lift tube and heats the entrained circulating char. The char stream is separated from the flue gas at the top of the lift tube. The char is then fed to the gasifier. The flue gas, after passing through cyclones, is cooled in a waste boiler to produce high pressure superheated steam and expanded through power recovery turbines. The flue gas is then used in coal driers to dry and preheat the feed coal.

The char fines in the synthesis gas produced in the gasifier are eliminated by passing the gas through cyclones. A portion of the gas is sent to the third stage pyrolyzer to provide the heat for pyrolysis. The remainder of the gas is cooled in two waste heat boilers to pro-

duce high pressure superheated and low pressure saturated steam. The other processing steps are as shown in the overall process block diagram (Figure II-4). Liquid products are condensed from the pyrolysis gases and the heavier liquids are hydrotreated. The synthesis gas is processed as shown to produce pipeline gas.

PROGRESS DURING JULY-SEPTEMBER 1978

During this quarter, work continued in several of the Tasks previously opened in Phase I, Stage I of the Pipeline Gas Demonstration Plant Program. The work accomplished was performed within restrictions imposed by the continuation of the DOE Suspension of Work Order.

Figure II-3. GASIFIER/CHAR COMBUSTION SYSTEM SCHEMATIC

The major work activity was directed toward the completion of Task I, the Conceptual Design and Evaluation of the Commercial Plant. Process design studies, trade-off studies and selection of processes were completed and reported in the Process Evaluation Report (PER). The changes resulting from the design and trade-off studies were incorporated into the Revised Tentative Baseline Design Report (RTBD) for the Conceptual Commercial Design.

The Conceptual Commercial Plant Design Report, submitted to DOE on September 30, 1978, included, on

a plant wide basis, overall process integration reflecting the subsystems selected in the PER and RTBD. These changes in the data base optimize the process concept resulting in improved thermal efficiency, operability and reliability and reduced capital expenditure and operating cost for a commercial plant.

ICGG reports that as a result of this work, it is confident that the concept is viable and the data base sufficient for the completion of the Demonstration Plant Design.

III. PIPELINE GAS DEMONSTRATION PLANT — "A"

CONTINENTAL OIL COMPANY

STAMFORD, CONNECTICUT

Plant Site: Noble County, Ohio
Contract No.: EF-77-C-01-2542
Total Funding: \$371,590,000
\$198,790,000
(U.S. Government)
\$172,800,000 (Industry)

INTRODUCTION

The Conoco project is part of the DOE high-Btu gasification program which will develop new and improved second generation gasification technology necessary to build commercial scale plants for processes that convert coal to Substitute Natural Gas (SNG) of pipeline quality. The project will utilize the slagging British Gas Lurgi gasification process and will employ Foster Wheeler Energy Corp. as the architect-engineering firm.

Other than Conoco, who is the managing operator for the plant, the participants include: Consolidated Gas Supply Corporation; Natural Gas Pipeline Company of America; Texas Gas Transmission Company; Texas Eastern Gas Transmission Company; Trans Continental Gas Pipeline Corporation; Panhandle Eastern Pipeline Company; Sun Gas Company; EPRI; Gulf Mineral Resources Company. Although most of the above companies do not distribute gas in Ohio; they are contributing to the program for possible future application of the technology in their distribution areas.

As with the other demonstration plants, the project will be conducted in three phases. Phase I will consist of commercial plant conceptual design and demonstration plant detailed design. Phase II will involve three major tasks which are demonstration plant final design,

initiation of long lead procurement, and demo plant construction. Phase III, the end result of the project, will be shakedown and operation of the plant. The project schedule is shown in Figure III-1.

PROCESS DESCRIPTION

The technology chosen to be demonstrated in this project is the slagging British Gas Lurgi process. This process (shown in Figure III-2) is a modification of the existing Lurgi process which has been commercially operated for over 35 years. Modifications are being made to accept caking coals and operate at higher temperature over a slagged ash bottoms. The slagging process reduces the carbon content of the molten ash stream and thereby increases the conversion of coal to gas. The process also produces less tar, phenol, and heavy hydrocarbons than the older commercial Lurgi process units; however, high boiling carcinogenic hydrocarbons will be recycled to the gasifier to be destroyed by gasification to produce a higher yield of gas than competing processes.

Gases leaving the gasifiers are cooled by quenching with a gas liquor (recycled water) spray. The H_2/CO ratio as required for downstream methanation is adjusted

Figure III-1. CONOCO PROJECT SCHEDULE

Figure III-2. CONOCO HIGH-BTU PIPELINE GAS "A" PROCESS SCHEMATIC

by shift conversion. A major portion of the crude gas passes through the converter while the remainder bypasses the converter. In the purification step, naphtha, oil and water are separated by condensation, while hydrogen sulfide and carbon dioxide are removed by the Lurgi rectisol process. In the methanation step, methane is formed from carbon monoxide and hydrogen over a fixed-bed nickel catalyst. The conversion to methane produces a gas similar in heat content to natural gas for pipeline distribution.

In the gas liquor separator, coal fines, tar and tar oil are removed from water. The fines with tar and oil are recycled to extinction in the gasifier. The Lurgi Phenol-solvan process extracts phenols from the water. Ammonia is removed from the gas by the CLL process to produce aqueous ammonia. An air separation plant will produce oxygen which is a necessary part of the process in making pipeline quality gas.

In addition to tar precipitation, oil separation, and phenol extraction processes, the plant will include all the service sections required, such as steam production, water purification, air separation plant, incineration, waste treatment, as well as product loading, tankage, and buildings.

As currently planned, the plant will have a feed rate of 3,783 tons of coal per day producing 58.9 million standard cubic feet per day of 950 Btu/SCF pipeline gas. Although a demonstration plant, the product will commercially supplement the natural gas supply to an industrial and residential area of Ohio.

HISTORY OF THE PROJECT

This project for the design, construction and operation of a Demonstration Plant capable of converting bituminous coal into pipeline quality gas was initiated in mid-1977. The process design of the gasification section and some of the downstream processing units were completed. A 1,200 acre tract in Marion and Center townships in Noble County, Ohio was proposed for the location of the demonstration plant.

Fifteen runs of a technical support program being carried out by British Gas Corporation at its Westfield Development Center have been completed. Data from this program will be used to design the downstream gas processing units for the plant.

On January 6, 1978, DOE requested that work on Task II be deferred for the present, and work on Tasks

III, IV, and V be continued at a reduced rate. Work on Task VI which was stopped in September 1977, was not restarted. Work on the remaining tasks, particularly Task I and Task IX, continued as planned. Plans are being made to reprogram and restart the project.

PROGRESS DURING JULY-SEPTEMBER 1978

Summary

On January 26, 1978, DOE requested that work on Task II (demonstration Plant design) be deferred and that work on Task III (site evaluation and selection), Task IV (demonstration plant environmental analysis), and Task V (materials and licenses) be continued at a reduced rate. In accordance with this request, Work on Task VI was not restarted during this quarter. Work on the remaining tasks continued.

Technical Support

The Westfield Development Centre in Scotland was on holiday for the month of July. During the first half of August, however, the final run of this plant was made. The run (Run C) successfully met the goals of repeating Run B-1 at a high oxygen level, above 130,000 SCFH, on Pittsburgh No. 8 coal, of investigating the tolerance of the system to fines, and of gathering data on tar injection at the top of the gasifier. All runs at Westfield have now been completed.

Technical Approach

Conoco considered four alternatives to the project. They were:

1. Continued Present Program — Full size Demo, Ohio #9 coal, Noble County.
2. One-third size Demo — Ohio #9 coal, Noble County.
3. One-third size Demo — Pittsburgh No. 8 coal, Noble County.
4. One-third size Demo — Pittsburgh No. 8 coal, new site.

During August, Conoco proposed to DOE that Phase I of the project continue by designing a plant about one-third the size of the one originally proposed on Ohio No. 9 coal at the Noble County site.

In addition to proposing the project alternative discussed above, Conoco evaluated other technical alternatives which might be employed to reduce the cost of gas. The original base case was developed under a conservative risk/benefit philosophy, using many processes already proven in coal gas applications. A number of alternative processes exist which could improve the project economics with a moderate increase in the technical risk. These alternatives are:

- Improve the power cycle; The base case Commercial Plant design is self-sufficient in steam and power, utilizing a 1,500 psig industrial-type boiler. A potential improvement in fuel usage is possible by using a high pressure utility-type power generation system; typically producing steam at 2,600 psig and 1,000°F with one reheat cycle at 1,500 psig and 920°F.
- Eliminate the zero discharge requirement; The base Commercial Plant was designed for zero discharge of aqueous pollutants in accordance with the national goal of achieving zero discharge by 1985. This requirement increases both capital and operating cost of the plant. The zero discharge constraint also increases the overall risk factor by increasing the complexity of the plant equipment. Furthermore, the disposal of the solid residue may pose yet another problem. Conoco suggests eliminating the evaporation stage of the waste water system and discharging a treated water stream which does not down grade the existing environment.
- Combined shift and methanation processes; The base Commercial Plant uses a conventional gas processing system, downstream of the gasifiers. The processing units, in order, are shift conversion, gas cooling, gas purification, and finally methanation.

The conventional gas processing system incurs certain disadvantages when processing gas from the BGC/Lurgi Slagging Gasifier. The slagging gasifier produces a gas containing a high concentration of carbon monoxide and a low moisture content, compared to the Lurgi dry bottom.

In this application, the shift conversion unit requires a large amount of steam. Steam reacts with carbon monoxide to produce hydrogen and carbon dioxide. A large excess of steam forces this reaction to proceed to the extent that the ratio of hydrogen to carbon monoxide is suitable for producing methane. The excess steam leaves the shift converter unreacted and must be removed by condensation in the gas cooling train and increases the amount of liquids which must be treated in downstream units.

The combined shift-methanation process, while unproven commercially, offers numerous advantages. The raw gas from the gasifier is cooled and fed to the gas purification unit. The cooled gas contains only the carbon dioxide produced in the gasifier and since the carbon dioxide content of the gas is relatively low, only non-selective acid gas removal is required. Thus, the gas purification unit is greatly simplified, reducing the refrigeration load and eliminating the need for an incinerator to purify the carbon dioxide stream before it is vented.

- Sulfuric acid by-product; The base case Commercial Plant was designed to produce sulfur using the Claus process. If the Claus process is replaced with a sulfuric acid plant, the 820 long tons per day of sulfur by-product is replaced by 2,800 short tons per day of sulfuric acid. Assuming the sulfuric acid is worth \$56.00 per short ton and the sulfur is valued at \$40.00 per long ton, the cost of pipeline gas production is reduced by \$0.59 per million BTU. The risk in manufacturing sulfuric acid as a by-product depends upon the availability of a market. Conoco believes sulfur would be a more readily marketed product.

If all of the alternatives mentioned above were implemented under private financing, the potential savings in capital expenditure would be over \$250 million and an associated reduction in the cost of gas would be \$1.70 per million BTU. Under utility financing, the capital savings would be over \$250 million and the associated reduction in the cost of gas would be \$1.40 per million BTU. The alternatives and their individual effects on gas price are summarized in the following table:

	Dollars Per Million BTU	
	Private Financing	Utility Financing (20-yr. Average Price)
I. Improved Power Cycle	0.057	0.057
II. Eliminate Zero Discharge Requirement	0.162	0.133
III. Combined Shift and Methanation	0.998	0.710
IV. Sulfuric Acid By-Product	0.487	0.530
Total	1.704	1.430
Cost of Gas, utilizing all improvements	4.901	3.710

IV. FUEL GAS INDUSTRIAL DEMONSTRATION PLANT

MEMPHIS LIGHT, GAS, AND WATER
MEMPHIS, TENNESSEE

Plant Site:	Memphis, Tennessee
Contract No.:	ET-77-C-01-2582
Total Funding:	\$283,000,000
Phase I:	\$12,000,000 (100% DOE)
Phase II:	\$185,000,000 (\$154,000,000 DOE* \$31,000,000 MLGW)
Phase III:	(\$86,000,000, \$3,000,000 DOE* \$83,000,000 MLGW)

INTRODUCTION

Memphis Light, Gas, and Water, a municipal utility, was awarded a contract by the DOE to design an advanced demonstration plant to convert coal into fuel gas for industrial use. Under the terms of the contract, Memphis Light, Gas, and Water will prepare a conceptual design of a demonstration facility which would utilize the U-Gas process developed by the Institute of Gas Technology with DOE funding. If the DOE and Memphis decide to proceed with the project following the conceptual design phase, the plant would be built on city owned property adjacent to the Frank C. Pidgeon Industrial Park on the Mississippi River. Fuel gas produced at the plant would be distributed by relatively short (less than 15 miles) pipeline to industries on President's Island and new industry locating in Pidgeon Park. The medium Btu fuel gas produced by the facility would have a heat content of approximately 280 Btu's per cubic foot, converted from 2800 tons-per-day of high sulfur coal. Approximately 175 million cubic feet of an equivalent of 50 billion Btu's of fuel gas would be produced daily.

*These numbers reflect current dollars, contingency government support and front end government funding.

As with the other major demonstration projects, this program will be carried out in three phases. These will be accomplished as follows:

Phase I — Program Development and conceptual design.

Task I — Conceptual design and evaluation of commercial plant.

Task II — Demonstration plant process design.

Task III — Demonstration plant process and mechanical design package.

Task IV — Site evaluation and Selection.

Task V — Demonstration Plant environmental analysis.

Task VI — Materials and Licenses.

Task VII — Construction and Operation Planning.

Task VIII — Economic Assessment.

Task IX — Technical Support.

Task X — Long lead items.

Task XI — Program Management.

Phase II — Demonstration plant final design procurement and construction.

Phase III — Demonstration plant operation.

The program schedule is shown in Figure IV-1.

DEMONSTRATION PLANT PROCESS DESCRIPTION

The demonstration plant process will be based on the U-Gas process. The U-Gas fluidized-bed gasifier is of vertical cylindrical construction with external cyclones for returning elutriated fines to the bed. A sloped grid at the bottom, containing one or more inverted cones, serves as the oxygen and steam distributor and the agglomerated ash outlet.

The U-Gas process is shown schematically in Figure IV-2. Raw coal is crushed to 1/4 x 0 inch size. The feed may contain up to 10 percent -200 mesh material as generated in the crushing step. Non-caking, subbituminous coals or lignite can be fed directly to the gasifier from the crusher. Caking coals (Eastern bituminous, for example) may have to be pretreated by contact with oxygen and steam in a fluidized bed operating at gasifier pressure at 700° to 80° F. An oxidized outer layer forms on the coal particles, and this prevents agglomeration and possible blockage in the gasifier. However, experimental data to date indicate this step may be eliminated.

Coal fed to a gasifier is gasified with a mixture of oxygen and steam in a single stage fluidized bed. The

residence time of the coal is about 45 minutes to an hour. Fluidizing velocity is in the order of 2 to 4 feet per second.

The key to operation of a U-Gas gasifier is the agglomeration and separation of the low carbon content ash from the bed. The U-Gas gasifier concept accomplishes this while maintaining a bed of approximately 45% ash. This is accomplished by proper design and operation of the grid, the fines return system, and the agglomerate removal section in the bottom of the gasifier. The grid is sloped toward one of more inverted cones contained in the grid. Part of the fluidizing steam and oxygen flow through nozzles in the grid, while the remaining fluidizing gas flows upward at high velocity through a discharge at the cone apex. The ratio of steam to oxygen in the fluidizing gas fed to the cone is chosen so that the resulting submerged jet in the cone is hotter than its surroundings. The concept of agglomeration of coal presently being pursued suggests that the temperature of the material in the jet is maintained near the softening point of the ash particles for the specific coal being gasified. Ash particles preferentially stick together, and the agglomerates grow until they are heavy enough to move downward counter to the force of the gas stream in the apex of the cone and, thus, fall out of the fluidized bed.

One design suggests that fines elutriated from the fluid bed are separated from the product gas by two cyclones in series. Fines removed by the first cyclones are returned to the bed by a stand-leg. Fines removed by the external cyclone are entrained in the inlet oxygen/steam to the gasifier where they are instantly gasified.

The hot product gas, after fines removal in the two cyclones, is cooled via waste-heat recovery and the result is a medium-Btu fuel.

ACTIVITY	FISCAL YEAR							
	77	78	79	80	81	82	83	84
PHASE I - CONCEPTUAL DESIGN	△			▽				
PHASE II - ● DETAILED DESIGN ● LONG LEAD PROCUREMENT ● CONSTRUCTION				△		▽		
				△		▽		
				△		▽		
PHASE III - SHAKEDOWN & OPERATION						△		▽

Figure IV-1. MEMPHIS FUEL GAS DEMONSTRATION PLANT PROJECT SCHEDULE

Figure IV-2. MEMPHIS LIGHT, GAS & WATER DIVISION MEDIUM BTU FUEL GAS INDUSTRIAL "A"

HISTORY OF THE PROJECT

Work on the contract began in late 1977. A Plan of Interfacing Schedule and Test Work for Pilot Plant was prepared and submitted to DOE. The plan outlines the interface agreements between this program and DOE Contract EX-76-C-2336, Operation of the Atmospheric Ash-Agglomerating Gasifier (AAG). The plan described the schedule of operation and test work for use of the AAG in this project. On January 1, 1978, the AAG pilot plant was officially transferred by DOE to this project. AAG pilot plant runs were conducted through the first quarter of 1978.

PROGRESS DURING JULY-SEPTEMBER 1978

During this quarter, no work was done on Demonstration Plant Process Design, due to a stop work order issued by DOE.

DOE has rescheduled Phase I to be completed as of December 1, 1979. Discussions were held to determine the engineering activities needed to start in order to maintain that schedule. A new pilot plant program, developed by DOE and the project team members, was started on September 20, 1978.

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V. FUEL GAS INDUSTRIAL DEMONSTRATION PLANT — "B"

W. R. GRACE & CO., AGRICULTURAL
CHEMICALS GROUP
MEMPHIS, TENNESSEE

Plant Site: Baskett, Kentucky
Contract No.: ET-77-C-01-2577
Total Funding: \$510,100,000
Phase I: \$12,000,000 (100% DOE)
Phase II: \$376,000,000 (\$284,000,000 DOE*
\$92,000,000 WRG)
Phase III: \$122,000,000 (\$4,000,000 DOE*
\$118,000,000 WRG)

INTRODUCTION

W. R. Grace & Co. has been chosen by the Department of Energy for design, construction, and operation of a demonstration plant for conversion of coal to synthesis gas for use in ammonia production. This synthesis gas/ammonia production portion of the overall DOE demonstration program is aimed at producing a synthesis gas that is a direct substitute for natural gas in ammonia production, thereby freeing this scarce natural resource for higher priority use. The overall objective of the program is the construction of an integrated facility that will convert 1,700 tons-per-day of coal into 1,200 tons-per-day of ammonia and yield 60 tons-per-day of sulfur as a by-product. Ebasco Services, Inc. is the architect and engineering firm and construction manager for the project.

As now planned, the project will be carried out in three phases. Phase I will be 100 percent funded by government with Phases II and III being 50-50 cost sharing with industry and government.

*These numbers reflect front end government funding, contingency current FY dollars, and government support.

The auxillary ammonia plant will be funded 100% by W. R. Grace at a cost of about \$40 million. A provision is also in the contract for W. R. Grace to ultimately buy back and have complete ownership of the entire facility.

Phase I involves eight major tasks which include:

- Conceptual design and evaluation of a commercial plant
- Demonstration plant conceptual design
- Current estimate of Phases II & III
- Site evaluation and selection
- Demonstration plant environmental analysis
- Demonstration plant construction and operation plan
- Economic reassessment of commercial & demonstration plant design
- Technical support, including pilot plant operations

The purpose of the preliminary commercial plant design is to obtain a detailed process design based on maximum use of proven, commercially available components and equipment on which to base detailed cost estimates. The end use of this design will be to evaluate the economic and technical feasibility for commercial

plants and to recommend changes to the overall commercial plant concept. The demonstration plant design will also be based on a system that will integrate commercially available components and equipment. This effort will include process flow charts and schematics for the plant, and for each major process train and subsystem. Major process and utility piping, electrical networks, process operating conditions, and mass and heat balances, will be a part of the effort.

The conceptual demonstration plant design will establish the basis for designing the actual demonstration plant. The conceptual design will include estimated operating life of the plant, selection of the plant size, and development of the preliminary heat and material balances for the plant using the coal selected.

Phase II work will involve the preparation of the complete plant design, including drawings, specifications, and definitive cost estimates. A bid package will be prepared and the physical plant will be constructed. Phase III, the ultimate objective of the project, will be the operation of the plant. Experience gained during this period will be used to determine the technical and economic performance and assess the project with regard to the scale-up of the operation to larger commercial plants. The project schedule is given in Figure V-1.

PROCESS DESCRIPTION

The Texaco Coal Gasification Process (TCGP) was chosen for use in the project. The process has been demonstrated on heavy oils and light feedstocks and is considered a second generation technology. The proposed plant will operate on Kentucky number 9 coal feedstock which is ground to 70 percent minus 200-mesh and then

slurried in water 50-60 percent solids for high pressure pumping and atomized injection into the gasifier. The slurry and pure oxygen enter at the top of the gasifier. In the presence of steam derived from the water of the coal slurry feed, they react to produce hot gases and molten slag, which are quenched in the lower section of the generator. The cooled gases leave the generator saturated with steam. The slag is removed through a lock hopper system to recover and recycle unconverted carbon.

The raw gas from the gas generator is rich in CO which reacts with water to produce H₂ and CO₂. The CO₂ and any hydrogen sulfide (H₂S) produced are absorbed in refrigerated methanol (Rectisol process) to remove them from the gas stream. The clean gas is scrubbed in liquid nitrogen which removes any residual CO, methane or argon. Adding the liquid nitrogen also produces the product gas, which is feedstock for the ammonia synthesis step.

The ammonia synthesis reaction in the proposed design is conducted at 3000 pounds-per-square-inch. The gas from the ammonia converter is cooled by heat exchange and refrigeration to condense the ammonia. The generalized process flow diagram is shown in Figure V-2.

HISTORY OF THE PROJECT

The project was initiated in mid-1977, and actual engineering work on the conceptual commercial plant design phase was begun in the third quarter of the year.

During 1978, work has focused on the further definition of commercial plant design parameters.

Figure V-1. W. R. GRACE PROJECT SCHEDULE
W. R. GRACE PROJECT SCHEDULE

NOTE: AREA INDICATED BY HATCHED LINES NOT COST-SHARED WITH DOE

Figure V-2. W. R. GRACE AMMONIA PROCESS SCHEMATIC

PROGRESS DURING JULY-SEPTEMBER 1978

Summary

The majority of the technical work effort for the quarter was directed toward finalization of design parameters. This was accomplished through continuing efforts on various Trade-Off Studies (TOS) with resultant incorporation for recommendations into the Commercial Plant design. During the reporting period, the final TOS IV report — Air Quality Control System Alternatives was issued. Also drafts of reports for TOS II — Gas Purification Alternatives and TOS V — Cooling Tower Optimization were prepared. Based on data thus developed, the preparation of design documentation in the form of process schematics, equipment lists and process duty specification sheets has progressed.

On site activities in support of the environmental effort are continuing and direction was given to proceed with an Air Quality Monitoring Program.

Other activities included completion of the Design Coal Investigation, initiation of work efforts on the part of Texaco Development Corporation's Houston engineering group and continuing incorporation of revisions to the Design Concept for the Demonstration Plant and the Plan for Obtaining Approval, Permits and Licenses from Agencies.

Technical Progress

Specific activities of a technical nature performed during this quarter included:

- TOS I — Gasifier Operating Pressure. While the TOS-I final report was delivered to DOE last quarter, an addendum had been considered a possibility. However, since information developed in the TOS-II study confirmed certain assumptions made in the TOS-I study, the addendum will not be required.
- TOS II — Gas Purification Alternatives. It was determined that a significant operating cost advantage favored incorporating the Rectisol acid gas removal system, rather than competing systems, in the Commercial Plant Design. A draft of the TOS-II report was prepared.
- TOS III — Method of Coal Preparation. While a draft of the TOS-III report was prepared, recent studies indicate that wet grinding may offer advantages over the dry grinding scheme contained in the draft report. A wet grinding test program has been initiated.
- TOS IV — Air Quality Control System Alternatives. The final TOS IV report has been prepared to exhibit a 99.5 percent particulate removal efficiency.
- TOS V — Cooling Tower Optimization. Preparation of the final TOS V report will commence during the next quarter.

- TOS VI — By-Product Sales Analysis. A revised trade-off study plan was submitted to DOE this quarter. Subjects addressed are the sulfur versus sulfuric acid question and the possible sale of other by-products, primarily CO₂ and slag.
- TOS VII — Equipment Arrangement Studies. A draft trade-off study plan has been prepared.

Trade-Off Studies

A Coal Fines Briquetting Study was prepared for submitting to DOE. Conoco has proposed that no more trade-off studies be investigated.

Contract Objectives

The major emphasis of the work performed the latter part of the quarter was centered on completion of the Network Analysis (Task VI) and on preparation of the Task IX (Technical Support) report.

During this quarter, DOE gave notice that the two competing projects (the Conoco Pipeline Gas Demonstration Plant Project and the Illinois Coal Gasification Project) for constructing and operating a Pipeline Gas Demonstration Plant would be evaluated at a later date. This means that the slowdown on most tasks will continue. At the end of this quarter, DOE has not announced the results of its evaluation.

VI. DEVELOPMENT OF COAL FEEDERS FOR COAL GASIFICATION OPERATIONS

FOSTER-MILLER ASSOCIATES, INC.
WALTHAM, MASSACHUSETTS

Contract No.: EX-76-C-01-1793
Total Funding: \$2,729,149
(100% DOE)

INTRODUCTION

Under the sponsorship of DOE, coal feeders for use in all coal gasification plants are to be developed through the pilot plant stage by Foster-Miller Associates, Inc. The project recognizes the coal feeder as one element common to all processes and that no currently available system can handle the quantities of coal, about 1,000 tons per hour, that will be used in commercial processes. These processes require the injection of coal from an atmospheric-pressure hopper into a reactor whose operation pressure may be as high as 15,000 psi.

Feed methods currently being used in pilot and demonstration plants depend on the coal size and reactor pressure. Low-pressure units use lock hoppers which must be operated at low temperatures with batch feeding of the coal. Slurry-feed techniques used in high-pressure gasifiers require energy to vaporize the liquid used to transport the coal. Both of these techniques are inefficient but can be tolerated in small-scale gasifiers. It will, however, be necessary to develop a technique to provide a continuous, high-pressure flow of coal to commercial-scale units at reasonable efficiencies and capital costs.

PROGRAM DESCRIPTION

The project to develop coal feeders was initiated in May 1975. It consists of three phases, with Phases I and

II to be completed by December 1977. In Phase I, Foster-Miller visited and studied gasification plants and consulted with DOE personnel and consultants to prepare a list of coal feeder requirements for DOE approval. Foster-Miller then prepared a report based on information concerning existing equipment and new conceptual designs. This report included a list of candidate equipment and an evaluation of that equipment.

In Phase II, critical components of the equipment selected in Phase I were tested in the laboratory. Equipment of four different designs were constructed, and each laboratory-scale feeder was tested for approximately two months. These tests will be conducted to determine the ability of the equipment to control the flow of coal with accuracy, maintain stability, seal effectively against the gasifier pressure, provide economic operation in terms of equipment life and power requirements, and deliver to the gasifier coal having the desired characteristics. Data from laboratory research was used to design feeders compatible with existing and projected pilot plant operations.

During Phase III, feeder concepts that have demonstrated a strong possibility of commercial-scale usage will be integrated into current and projected pilot plants as directed by DOE. Feed rates will be in the range of three to five tons per hour. The final report of this phase will contain design specifications, assembly drawings and procedures, installation and functional test procedures, and operation and maintenance manuals.

A fourth phase, not part of this contract, design of demonstration scale feeders, will use the results of pilot plant testing. It is projected to include the development, design, fabrication, and delivery to DOE of coal feeders compatible with demonstration plant requirements. Feed rates in this phase are anticipated to be 50 tons-per-hour and greater.

PROJECT ACCOMPLISHMENTS

Foster-Miller Associates completed the Phase I program effort in March 1976, with the release of the Phase I report. The results from the evaluation of coal feeder requirements and existing feeders revealed that no suitable dry coal feeders were available that could operate at gasifier pressures above 300 psi. As part of this initial effort, literature searches, patent reviews, and consultation with manufacturers were made to determine what particular concepts should be studied in Phase II.

Based upon the results of the Phase I effort, four feeder concepts were selected and approved for the Phase II development. These concepts included:

- A centrifugal solids feeder
- A fluidized piston feeder
- A linear pocket feeder
- A compacted coal plug feeder

The Phase II program effort is essentially the hardware evaluation of the concepts developed in Phase I. In conducting this phase, two scaling steps have been carried out. Bench scale models of all four concepts were designed, built and tested. Following this work, pilot plant scale prototypes of three of the four concepts were designed and built and are being tested.

The bench scale centrifugal feeder model was used to perform coal flow studies and to determine if the required outlet limited (full sprue) flow mode could be achieved. This flow condition is necessary if the device is to be capable of sealing against pressure. For the piston feeder development, a glass model of the feeder was built and tested to study possible development problems. A full scale, two flight, sealing section model for the linear pocket feeder was developed to test leakage rates and drive forces. For the plug feeder, a small bench scale apparatus was tested to determine leakage, plug stability, driving forces, compaction forces required, etc. At the conclusion of the bench scale testing, essentially all four concepts were deemed to be technically feasible. However, because of funding limitations, the plug feeder concept development was suspended.

Upon completion of the bench scale testing program, the development of prototype pilot plant scale feeders were undertaken for the three remaining concepts.

A prototype centrifugal feeder unit was designed and built for feed rates of up to one ton-per-hour at pressure differentials to 200 psi. The unit has a 24-inch diameter feeder head. Testing of the prototype centrifugal feeder was initiated in mid-November of 1976.

A prototype fluidized piston feeder was designed and built and has been under test since March of 1977. The feeder has a four-inch bore and an adjustable stroke length up to eight inches. In testing the piston feeder, prototype problems were encountered with the intake and exhaust valves. The other components of the feeder operated reliably.

The design, fabrication, and assembly of a prototype linear pocket feeder designed for a feed rate of up to five tons-per-hour at 500 psig was also completed.

Phase III effort was initiated in October 1977. The selected feeder concepts for the Phase III effort are the Foster-Miller Linear Pocket and centrifugal feeders. The feeder concepts will be designed and built to pilot plant scale specifications. The feeders will be subjected to a performance test program on an expanded coal feeder test loop constructed for this task. Conceptual designs for the feeder systems will be prepared for pilot and/or demonstration scale applications.

PROGRESS DURING JULY-SEPTEMBER 1978

With installation of tungsten carbide rings in place of the original alumina seal rings, durability testing of the prototype Linear Pocket Feeder was resumed. The feeder operated 130 hours without encountering problems. It was shut down for installation of tungsten carbide bushings, after which durability testing will resume again.

All work on the 200 psig Centrifugal Feeder prototype was suspended to maximize effort on the 500 psig prototype development effort. The 200 psig prototype exceeded its original performance goals by feeding in excess of 1½ tons per hour of pulverized coal against a 200 psig back pressure with no loss of gas from the receiving vessel. The design of the 500 psig centrifugal feeder prototype was completed in August. Assembly and checkout of feeder components is underway.

VII. DEVELOPMENT OF A CONTINUOUS DRY COAL SCREW FEEDER

INGERSOLL-RAND RESEARCH, INC.
PRINCETON, NEW JERSEY

Contract No.: EX-76-C-01-1794
Total Funding: \$2,642,445
(100% DOE)

INTRODUCTION

The overall objective of this program is to develop pilot plant size coal feeder devices that can be scaled up for feeding large quantities of coal into pressurized, commercial scale reactors. The program is comprised of three basic elements.

- Development of a Dry Coal Screw Feeder
- Development of a Dry Coal Piston Feeder
- Feasibility of Spraying and Feeding Fully Plasticized Coal

This development work is of importance to the fossil energy program since current methods (lock hopper and slurry) of feeding coal to high pressure gasification processes are undesirable due to economic and technical considerations.

The feeders are to be developed through the pilot plant stage, with the engineering and economic viability evaluated throughout the development process. The end result of the research will be a recommendation by Ingersoll-Rand of coal feed injector equipment that will be compatible with projected demonstration plant requirements. The equipment could be used in both high- and low-BTU gasification plants and also in coal liquefaction systems.

PROGRAM DESCRIPTION

Coal Screw Feeder

Under the current contract with DOE, started in June 1975, Ingersoll-Rand is conducting a three-phase development program to refine and scale-up a screw feeder that could be used in a demonstration plant. Tests initially conducted by Ingersoll-Rand indicated that screw feeders could be used in full size coal gasification and liquefaction plants in place of pressurized lock hoppers and slurry systems. The feeder currently being developed is a modified injection molding machine, operating like an extruder.

Phase I of the program involved the establishment of the coal feeder requirements imposed by the various processes being considered for commercial scale coal conversion operations. Literature searches, consultations with DOE personnel and consultants, studies of plant operations, etc. were used to obtain information on the feeder requirements.

In Phase II, critical components of the candidate equipment selected in Phase I were tested. In addition, two laboratory scale, coal feeder prototypes, a Negri-Bossi V-12 injection molding machine and an IMPCO

1500, will be designed, fabricated, and tested. Among the characteristics to be investigated are:

- Feeder stability and degree of control
- Seal effectiveness
- Coal metering accuracy
- Life expectancy of critical components
- Mechanical power requirements
- Methods for reducing the feed coal size to meet process requirements.

The data resulting from laboratory testing will be used to design feeders for use in existing and projected pilot plant operations. Recommendations will be made to DOE for further development of promising screw feeder concepts.

During Phase III, an IMPCO screw feeder will be installed and operated in a pilot development unit selected by DOE. Feed rates will be in the range of 0.5 to 5.0 tons-per-hour. A report will be prepared that will include design specifications, installation drawings, assembly procedures, installation and functional test guides, and operation and maintenance manuals. The performance of the feeder in the pilot plant tests will be assessed based on the test data. A final report will be prepared which will include the design of equipment sized for a demonstration plant.

A fourth phase, not part of the current contract, will use the results of pilot testing for development, design, fabrication, and delivery to the DOE of coal feeders compatible with demonstration plant requirements. Coal feed rates in this phase will be 50 tons-per-hour or greater.

Coal Piston Feeder

Activities on piston feeder concepts were initiated in late 1977 in a three-phase program, leading to a pilot plant demonstration of a selected piston feeder configuration.

Phase I of the piston feeder development program involved Concepts Evaluation. Phase II involves Laboratory Development of Selected Piston Concept, and Phase III will be the production of the Pilot Plant Piston.

PROJECT ACCOMPLISHMENTS

A comparative evaluation of coal feeder systems was completed, using the technical and economic criteria established during the fourth quarter of 1975. Existing

coal feed systems, lock hoppers and slurry pumps were compared with new feed system concepts. The evaluation indicated that the piston feeders as a class seem to offer advantages over the lock hopper and slurry pump methods of feeding coal to high-pressure gasifiers. The screw feeder concept, although not as dramatic, also showed advantages over existing methods.

Coal Piston Feeder

Ingersoll-Rand Research developed, during Phase I, three conceptual designs for coal feeding. These concepts included a single-acting piston feeder, double-acting piston feeder, and a rotary valve piston feeder.

The Phase I evaluation has been completed. A single-acting feeder, functionally similar to the original concept, has been selected for further development as a pilot plant feeder. This configuration is considered to be an excellent design to demonstrate that coal feeding by a piston type feeder is a viable approach.

The double-acting feeder was rejected primarily because of its relative complexity while the rotary feeder was rejected because of substantial seal, bearing, coal inlet and coal outlet design problems.

The piston seals, inlet and discharge port configurations and the coal transport cylinder material are critical to the successful development of the piston feeder.

Several seal configurations have been defined which offer promise of meeting all seal requirements. Initial tests on a three-inch diameter K-30M rings seal have shown very low leakage rates under simulated feeder operating conditions. However, test time accumulated to date on this seal concept is insufficient to predict seal life.

Experimental work with simulated inlet ports has indicated that good flow and filling characteristics can be obtained. Volumetric fill in excess of 90 percent has been demonstrated. An experimental discharge port has been configured that permits free fall of coal particles pushed out of the coal transport cylinder bore by the coal piston. Experimental work indicates that moist (12 percent) coal can be handled by the inlet and outlet ports under design.

Candidate materials of construction for the coal transport cylinder liner have been identified. These materials offer promise for meeting the requirements of seal compatibility and wear resistance. An initial choice of Xaloy has been made.

Alternate piston feeder configurations have been conceived which appear to offer significant advantages over the present concept with respect to sealing, loading and unloading.

Coal Screw Feeder

Testing began with the 1.5" diameter screw feeder (NB-V-12) in mid-1976. Coal has been successfully pumped under steady-state conditions against elevated back pressure in three operating modes:

- Extrusion mode, with external heat
- Injection mode, with external heat
- Injection mode, without external heat

A 5-1/2" diameter screw feeder (IMCO 1500) was designed and fabricated. Its coal feed rate ranged from one to five tons per hour against 1,500 psig back pressure. At a low feed rate of 300 pounds-per-hour, coal has been pumped against a back pressure of 300 psig.

The plasticized coal delivery program was initiated in July 1977. This approach utilizes the tendency of many bituminous coals to exhibit plasticity at elevated temperatures.

The design and testing activities of the 5-1/8" diameter coal screw feeder (IMPCO #1500) was continued in 1978. The injection mode of operation, without external heat addition, was found to offer the most promise with respect to power consumption, coal delivery rate and ease of operation.

In 1978 major development effort was directed towards meeting METC (Stirred fixed bed) coal gasifier pilot plant requirements. Emphasis was placed on providing maximum coal output through the feeder in the injection mode without external heat and minimizing the associated power consumption.

Stable, controllable operation of the feeder at a coal delivery flow rate in excess of 2,800 pounds-per-hour and sealing capability against a gas back pressure up to 900 psig have been demonstrated. In addition, tests were performed with various coal-pitch mixtures and significant reductions in power consumption were observed.

PROGRESS DURING JULY-SEPTEMBER 1978

Coal Screw Feeder

During this quarter, efforts to reduce the specific power consumption of the screw feeder continued. The performance testing in the injection mode (without external heat) continued after modifications in the hydraulic system were made to reduce hydraulic pressure in the injection cylinders during the filling part of the cycle and increasing injection speed.

The final report Feasibility of Spraying Fully Plasticized Coal was published, concluding this part of the feeder development program. The final report Feasibility of Spraying Fully Plasticized Coal was published, concluding this part of the feeder development program. The final report concludes that the technical feasibility of spraying fully plasticized coal and feeding it into gas at elevated back pressure has been successfully demonstrated in the injection mode of operation with the 1.5" diameter screw feeder.

The Extrudate Break-Up Development program was initiated during September, with several break-up modes being investigated.

Coal Piston Feeder

Design of the pilot plant scale piston feeder and associated test equipment was completed during this quarter. A final report on Phase I of the program has been published. Work on Phase II, Pilot Plant Scale Piston Feeder Development was performed in parallel with Phase I.

Seals have received a significant portion of the program effort, since performance and reliability depend directly on seal performance. A seal test facility has been developed, and tests are being conducted on 3" diameter seals.

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VIII. COAL FEEDER DEVELOPMENT PROGRAM

LOCKHEED MISSILES AND SPACE COMPANY,
INC.

SUNNYVALE, CALIFORNIA

Contract No.: EX-76-C-01-1792

Total Funding: \$2,591,640
(100% DOE)

INTRODUCTION

Lockheed Missiles and Space Company, Inc., a subsidiary of Lockheed Aircraft Corporation, is conducting a coal feeder development program under the auspices of DOE. A need exists for this development effort because current lock hopper or slurry concepts for coal feeding are inadequate. The feeder system is a critical component of a coal conversion plant, affecting equipment and maintenance costs, plant efficiency, and down time. An improved coal feeder that is applicable to all processes using dry pulverized coal at reactor pressures up to 1,500 psi must be developed.

PROGRAM DESCRIPTION

Work under this three-phase program was initiated in July 1975. Phase I, which was completed in March 1976, involved the selection of candidate coal feed injector concepts based on a detailed examination of the system requirements imposed by the various coal conversion processes.

The examination included:

- Screening potential candidates
- Investigating existing equipment
- Synthesizing feeder system designs

- Assessing problem areas
- Defining laboratory evaluation techniques
- Preparing a final report

Phase II studies, which were completed in July 1977, involve tests on four coal feeder systems. These include a fluid dynamic lock, kinetic extruder, ball conveyor, and an ejector. To establish a firm basis for the design of the coal feed systems for use in commercial plants, testing efforts for this phase will include:

- Laboratory tests, using simple bench-scale equipment, to answer questions pertinent to equipment design.
- Supporting analysis provided by mathematical models developed for optimizing equipment design, projecting operating efficiency, and updating economic data generated during phase I.
- Design of test equipment.
- Fabrication, including procurement of materials.
- Installation of test equipment followed by testing as outlined in the test plan and data reduction and analysis.
- Documentation.
- Design, procurement, and installation of equipment for the test loop facility.
- Assurance that hardware is manufactured to applicable specifications and that all operations and specifications adhere to safety requirements.

During Phase III, candidate kinetic extruder feeder concepts showing promise for commercial scale use will be designed and operated in current and/or projected pilot plants. Feed rates for these feeders are

expected to be in the range of three to five tons per hour. As part of this phase, Lockheed will also prepare a report that will include design specifications, assembly and detail drawings, assembly procedures, installation and functional test procedures, and operation and maintenance manuals. The data obtained in the pilot plant tests will be analyzed, and a final report including an engineering design of equipment for a demonstration plant will be prepared.

A fourth phase, not part of this contract, will utilize the results of pilot plant testing, and is projected to include the development, design, fabrication, and delivery to DOE of coal feeders compatible with demonstration plant requirements. Feed rates in this phase are anticipated to be 50 tons-per-hour and greater.

PROJECT ACCOMPLISHMENTS

Lockheed completed Phase I of the contract and issued the Phase I report in December 1975. Literature and patent searches were conducted which established fundamental principles used in the design of the feeder. Operating requirements were established via field trips to various coal conversion installations in the U.S. As a result of these efforts, various candidate concepts were selected for further evaluation and were segregated into low pressure and high pressure usage. Cost data were subsequently generated to compare the equipment and operating costs of each of the feed systems. From these studies, four feeder concepts emerged as the most promising for further laboratory testing. The four systems selected for Phase II investigation were:

- Ejector, based on the use of jet pumps.
- Kinetic Extruder, a system based on the use of centrifugal force to reduce the permeability of the compacted coal to prevent net back flow of gases.
- Ball Conveyor, using large metal balls loosely fitting into a standpipe and conveying coal in the interspace, designed to overcome net gas leakage by the downward motion of the column and the static pressure by the weight of the column. The return leg uses a liquid seal to prevent gas flow.
- Fluid Dynamic Lock, a system based on the use of a bladeless, disk type compressor.

Phase II of the contract, was completed in July 1977. The Phase II report preparation was carried out throughout both July and August. Lockheed felt that the Phase II program resulted in design procedures which permit confident evaluation of the four feeder systems considered for coal conversion plant application. Because of the

variety of coal feed stocks, feed rates, and pressure levels being considered and the variety of proposed conversion processes, it is not possible to select one feeder system as superior. A tradeoff must be conducted to select the proper candidate for a specific use.

As a result of the work carried out in Phases I and II, the kinetic extruder was selected for further development during Phase III. In the kinetic extruder, coal at atmospheric pressure is fed to the center of a spinning rotor having multiple radial sprues. Centrifugal force compacts the pulverized coal and forms a low permeability plug. The plug moves with a velocity that prevents backflow of gases from the high-pressure discharge zone.

At the beginning of Phase III, extensive design studies were performed to identify components of the kinetic extruder which had an important impact on performance. In accordance with the development plan, these components were optimized and subject to extensive testing in a coal feeder test loop or to detailed analytical evaluation, as was the case for the bearings and seals.

The improved components were incorporated in the design of kinetic extruder, Model 3. The major accomplishments during the experimental activities include:

- Demonstration of one ton-per-hour delivery rate at 400 psi back pressure (the maximum obtainable within the present test-site capability).
- Total test time exceeding 30 hours while feeding coal against pressure at the one ton-per-hour rate.

Based on these activities, the feasibility of building commercial size equipment for feeding coal at 1,500 psi has been established.

During 1978, emphasis will be on efficient means to vary the output rate of the kinetic extruder. This will include means to cope with variations in feed stock.

PROGRESS DURING JULY-SEPTEMBER 1978

During July, the main activities involved application studies, with emphasis being placed on establishing specifications and cost data for seven and 50 ton-per-hour coal feeder systems.

During the month of August, emphasis was put on hardware procurement. The controllable sprue rotor fabrication is nearing completion, and delivery is scheduled for early September. The Model 3 kinetic

extruder is scheduled for delivery by midOctober. The horizontal shaft housing and drive system will be available by year's end.

Work progressed during September on hardware fabrication and procurement. The controllable sprue

rotor was received. Test facility modifications were underway. Flow requirements were determined from seal and bearing studies on the seven and the 50 ton-per-hour units. It has been determined that coal particle attrition while feeding coal against back pressure through a kinetic extruder is not a significant problem.

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IX. PRELIMINARY DESIGN SERVICES

THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

Contract No.: EX-76-C-01-1775
Total Funding: \$3,280,154
(100% DOE)

INTRODUCTION

The Ralph M. Parsons Company is providing technical assistance services to DOE with the objective of developing and demonstrating practical processes for producing liquid and/or solid fuels from coal. Under this program, initiated in 1972 and updated in 1974, Parsons is:

- Preparing conceptual designs and economic evaluations for commercial plants.
- Evaluating pilot plant performance and other experimental programs.
- Evaluating unit operations and processes for possible applications in coal processing, including design and construction of pilot plants.
- Evaluating proposals for new work and for changes in ongoing work.

The development of commercial design concepts and technical evaluations involve:

- Review of chemical, mechanical, and material problems associated with the design of large plants and equipment.
- Identification of problems in sizing, safety factors, and instrumentation of equipment, which must be resolved before equipment is specified for manufacture.
- Identification of equipment design problem areas, and development of programs for solution of those problems.

- Identification of construction problems, including availability of materials, type of land base, and area required for construction, that must be solved before large equipment can be fabricated in the field.
- Establishment of overall utility requirements. This effort will provide a common economic basis for comparing capital and operating costs of the processes. Ultimately, the commercial design concepts will serve as guides for selecting the best coal processes to be demonstrated in commercial-sized plants.

PROGRAM DESCRIPTION

Parsons has two primary tasks: (1) development of conceptual designs and economic evaluations of commercial plants and (2) technical evaluations.

Conceptual designs and economic evaluations of commercial-scale plants are being developed for the Char-Oil Energy Development (COED) process, an oil-gas process based on the Solvent-Refined Coal (SRC) process, the Fischer-Tropsch process, and a combined POGO (Power, Oil, Gas, and Other Products) process. The conceptual designs and economic evaluations are based on engineering data such as process yields, conversion efficiency, plant economics, and environmental analysis from pilot plant operations.

The overall objectives of the individual tasks are given below. The idea behind the Coal Mining/Coal Preparation task is to design and evaluate, as feed facilities to conversion plants, coal mine and preparation facilities for five geographic areas where conversion facilities are being studied. Plant capacities of up to 100,000 tons per day of coal feed are being considered.

Oil/Gas Plant efforts will be preliminary design and economic evaluation for a commercial plant to produce synthetic fuels and SNG from coal, and to define the maximum practical capacity of a single train plant using the selected process. The purpose of the Fischer-Tropsch plant task will be to develop a conceptual commercial plant design and economics for production of pipeline gas, motor fuel, distillates and other hydrocarbon fractions.

The objectives of the POGO (Power, Oil, Gas, and Other) plant design is to develop a preliminary design of a coal processing plant which will produce power, oil, gas, and other products. The chosen process will be based on economic evaluations of the candidate coal processes available. Other areas of effort will include the development of a model capable of calculating material and heat balances for a number of coal conversion processes using computer capability and to estimate the overall utility balance for the complex.

Parsons is also developing a computerized process simulation program capable of estimating fixed capital investment, material and energy (utility) balances, and potential profitability of various coal conversion complexes. The program will be available to this project.

Among the technical evaluation activities is the development of functional and preliminary specifications for equipment and control apparatus required in the candidate conversion processes. All the components of

a plant, from coal handling through production of fuel, are being considered, along with the associated units for power generation and waste treatment. Another technical evaluation activity is the investigation of materials for construction of equipment to determine which are preferred for use in coal conversion processes. Parsons is also defining facilities required to control air, water, and solid waste pollution to assure that plant operations are within applicable state and EPA environmental standards. Finally, Parsons is providing general support activities and preparing reports as appropriate or requested by DOE.

PROJECT ACCOMPLISHMENTS

The final Oil/Gas Plant Design report was completed in February 1977. The Fischer-Tropsch Plant Design Report was published in March. Work was initiated in April 1977 on the design of the Multi-Process Demonstration Plant and on designs of Prestressed Concrete Pressure vessels.

PROGRESS DURING JULY-SEPTEMBER 1978

During this quarter, work was done on modification to the fluidized-bed gasifier design to make possible the elimination of the oxygen pretreatment stages. The draft report on the Multi-Process Demonstration Plant was then completed and submitted to the DOE. Also, copies of the Prestressed Concrete Pressure Vessels Executive Summary draft report were submitted to the DOE for review.

X. LOCK HOPPER VALVE DEVELOPMENT

CONSOLIDATED CONTROLS

EL SEGUNDO, CALIFORNIA

Contract No.: EX-76-C-01-2355

Contract Funding: \$2,574,669

INTRODUCTION

The objective of this lock hopper valve development contract is to design, manufacture, test and evaluate 8 and 12-inch valves that would be compatible with operating conditions found in numerous coal gasification plants. This program was initiated in June, 1976. The development of such valves will be required to assure the efficient, continuous and safe operation of coal conversion processes in future plants.

PROGRAM DESCRIPTION

The specific objectives of the project are threefold:

- To provide reliable data sufficient to permit the confident design of solids handling valves compatible with existing and projected pilot plant operations.
- To produce reliable coal valves suitable for commercialization.
- To provide for the orderly transfer of the demonstrated technology to private industry.

The project will be conducted in three phases. Phase I, preliminary design, will evaluate the proposed design based on engineering analysis. A review of and determination of the availability of special hardware and test procedures will be conducted. Phase II, prototype design and pretest, will involve the fabrication and testing of

8-inch prototype valves. In addition, analysis of test results will be conducted in order to identify areas where modifications may be necessary in the final prototype design. Twelve-inch valves (based on Phase II tests results) will be fabricated and tested in a pilot plant during Phase III. A review and evaluation of the test results will be made and a report published concerning the test data. The overall objective of this program is to design, develop, fabricate, and test scale model prototypes of each of four types of valves to be used in a coal gasification system. The valve types are identified as follows:

- Type I — Valves for Feed System
- Type II — Valves for use Between Injection Hopper and Gasifier
- Type III — Valves for Char and Ash removal System
- Type IV — Valves for Slurry Discharge System

ACCOMPLISHMENTS TO DATE

Of the four types of lock hopper valves in the 8-inch class, the Type III was chosen for preliminary design studies and prototype development since it had the most stringent requirements. This valve will incorporate high alumina ceramic and commercial refractory parts for higher reliability and longer life because of their higher resistance to corrosion and erosion over metal parts.

An extensive material survey and evaluation was conducted by Consolidated Controls to select a refractory

material or materials, other than for their insulating qualities, that would retain a high degree of structural integrity as finished components when used at elevated temperatures and pressures under the highly erosive and corrosive environments. Other prerequisites are permanence in dimensional stability, non-spalling and non-fracturing from temperature fluctuations, low permeability and ease of fabrication.

Though published reports have been completed encompassing the above criteria, the testing and evaluation still continue to date.

High alumina ceramic components are used where strength greater than that offered by any other refractory material is required. These components include such items as the seats, the sealing disc in the gate, stop rings, and most noticeably, the ceramic spring.

The designs were completed for all four valve types, and the manufacture of each of the valves began.

PROGRESS DURING JULY-SEPTEMBER 1978

Developing and testing of scale model prototypes of each of the four types of valves continued during this quarter. Fabrication of a valve test stand was essentially completed.

While there was no major design activity during this quarter, since all designs are complete, some minor effort was expended in exploring variations on valve gate designs. The gate continues to be a problem, and the designs being considered now are mostly one-piece ceramic items instead of composite refractory/ceramic items.

Three reports were published during the quarter. They are:

- FE-2355 (Revision A), "Coal Gasification Valves, Phase I, Component Development Test Report."
- FE-2355 (Revision A), "Coal Gasification Valves, Type III, Development Test Procedure."
- FE-2355 (Revision B), "Coal Gasification Valves, Phase I, Refractory Materials Test and Evaluation Procedure."

Various commercial ceramic bonds were tested in this quarter by bonding test blocks of materials together. Testing is underway to develop an improved method for hard coating cast refractories. Methods are also being investigated to impregnate various ceramic fibrous materials with hard coating to improve cracking resistance.

Activity in this quarter was slowed by hardware problems, particularly in the gates and in the interference in the ceramic spring. The Type I, II, and IV valves are approaching the assembly phase. With the past experience of the Type III valves as a guide, the new valves should be easier to complete.

XI. VALVE DEVELOPMENT FOR COAL GASIFICATION PLANTS

FAIRCHILD STRATOS DIVISION
MANHATTAN BEACH, CALIFORNIA

Contract No.: EX-76-C-01-2356

Contract Funding: \$2,238,023

INTRODUCTION

The goal of this valve development contract, is to design, develop, test, and evaluate 8-inch and 12-inch solid handling valves scaleable to 24-inch that would be compatible with operating conditions found in various coal gasification plants. The project was initiated in June 1976 because reliable valves to handle abrasive solids were not available for pilot plants, and even larger valves will be required to assure the efficient, continuous and safe operation of coal conversion processes in future plants.

Presently available lock hopper valves are not suitable for prolonged troublefree service in the hostile environment encountered in coal gasification service. Through a program of extensive material testing and thermal and structural analysis, a valve design will be developed for this type of service.

PROGRAM DESCRIPTION

Phase I Conceptual Design

During Phase I, different concepts will be evaluated and trade-off studies will be conducted to arrive at the most promising design.

Erosion and corrosion resistant materials will be investigated and tested in order to determine the most promising materials for critical parts such as seats and bearings. Thermal and structural analyses of the valve components will be conducted. The Phase I effort was scheduled for completion by April 1978.

Phase II Prototype Testing

From the experience gained in Phase I, a total of eight 8-inch prototype valves will be designed and manufactured, two each for Type I, II, III and IV service conditions. (Feed System (350°F), Injection Hopper 600°F), Ash Removal (2000°F) and Slurry Discharge (600°F) respectively.)

These valves will be tested at the Morgantown Energy Technology Center (METC). Failures and shortcomings experienced during this testing program will be analyzed. The design will be modified to incorporate any recommended changes. The Phase II effort was scheduled to start in May 1978 with delivery in May 1979.

Phase III Pilot Valve Testing

After demonstration of the performance of the Phase II valves, eight 12-inch valves will be designed and manufactured for Type I, II, III and IV service conditions. These valves will be tested in a pilot plant, and

experience from operating these valves will be incorporated into a Demonstration Plant Size Design. All findings of the testing programs will be incorporated in a final report.

PROJECT ACCOMPLISHMENTS

Phase I

A trade-off study was conducted to determine the most promising valve design. Candidate seat and bearing materials were tested for abrasion and impact resistance.

A valve design layout was completed and a thermal and structural analysis of the valve was conducted. A prototype valve was manufactured and the assembly was tested at ambient temperature and cycled approximately 1000 times to verify the operation of the actuator mechanism.

Test fixtures for evaluating the seats and bearings were manufactured. Boron carbide seats were tested in this fixture and cycled 500 times at room temperature. At this time, the seat showed no signs of wear. A borided 502 steel seat was tested and showed signs of wear and was therefore eliminated as a candidate material.

Tungsten carbide coated shafts, Stellite No. 6 and tungsten carbide bearings were tested in the bearing test fixture at simulated operating conditions.

The tungsten carbide coated shaft with tungsten carbide bearings performed for 30,000 cycles at temperatures of 650°F with no visible deterioration.

PROGRESS DURING JULY-SEPTEMBER 1978

During July, the DOE authorized Fairchild Stratos Division to proceed with the Phase II (Prototype Testing) effort. Phase II work is scheduled to continue until November 1979, and will include some carry-over effort from Phase I (Conceptual Design).

By the end of this quarter, the overall Phase II effort was approximately 15 percent complete. Layouts for all task valves were 90 percent complete. Overall detail drawings were 25 percent complete. The preliminary steady-state thermal analysis report (FSD Document ER 75388-80) was submitted to DOE. Work progressed on plumbing and instrumentation diagrams, electrical design, a Task II valve plastic model, a functional test plan, and on completion of quality assurance operating procedures.

XII. COAL GRINDING EQUIPMENT DEVELOPMENT

KENNEDY VAN SAUN

DANVILLE, PENNSYLVANIA

Contract No.: EX-76-C-01-2475

Contract Funding: \$840,000

INTRODUCTION

Kennedy Van Saun is under contract to DOE to develop and modify coal grinding equipment and procedures to meet the needs of demonstration and commercial coal conversion plants. The efficient conversion of coal to clean synthetic fuels is very dependent on achieving and maintaining a continuous and controllable reaction process which is in turn dependent on uniform and optimum size consist of the coal feedstock. Current practice is to size grinding equipment without regard for excessive amounts of fines and undersized particles. This project is therefore designed to alleviate the above mentioned deficiencies associated with the coal grinding processes. A coal grinding handbook which can be utilized by process engineers for grinding system selection will be published at the end of this project.

PROGRAM DESCRIPTION

It has been anticipated that the project will be carried out in four phases in order to meet the project objectives. These objectives, as formulated by DOE are:

- To produce reliable coal grinding equipment for the controlled grinding and preparation of feed coal for demonstration and commercial size plants.
- To provide a controlled size output with a minimum of undersirable or unusable fines.

The project, initiated in September 1976, is expected to be completed in December 1978. Phase I, the study phase requires approximately eighteen months to complete. This will involve a study on the state-of-the-art of commercial coal grinding equipment. Further, three to five types of coal will be selected for experimentation. The Pennsylvania State University, under subcontract to Kennedy Van Saun, will perform laboratory analysis to determine the mechanical properties of the coal, the kinetic parameters of comminution, and perform rate testing.

Phase II, is the preparation phase where the selection, design, layout and modification of coal grinding equipment to be used in Phase III will be carried out. The actual grinding experiments with the coal will take place during Phase III. Dry and wet grinding tests (in water and oil) will be made. Phase IV will involve documentation and reporting on the findings during the first 3 phases of the contract. A handbook will be prepared which will describe modifications of equipment and selected grinding procedures, required safety items, and will also include economic analysis comparing various grinding procedures and equipment.

PROJECT ACCOMPLISHMENTS

The testing facility layout for the four grinding systems — dry ball mill, ball and race mill, hammer mill and wet ball mill — was completed and the dry ball mill

grinding system installed. Since the feed material handling system is common to all grinding systems and the product material handling system is common to all dry grinding systems, the other grinding systems are also almost completed.

Five coal samples were selected and delivered to the testing site. The types of coal and delivered tonnages, in order of decreasing Hardgrove Index, are washed Lower Freeport bituminous (108), washed Western Kentucky #9 bituminous (99), unprepared Ohio #9 bituminous (86), unwashed Belle Ayre South subbituminous (80) and washed Pennsylvania anthracite (44).

Numerous manufacturers of coal size reduction devices were contacted and a brief literature search conducted. This information was assembled into a report and a draft copy issued.

The main thrust of the laboratory analysis, being performed by the Pennsylvania State University, is the investigation of the breakage characteristics of the coals in order to assist the testwork at KVS. This work has centered on the grinding of the coals in a ball mill (dry and in water) and a ball and race mill (Hardgrove Machine).

XIII. COAL PUMP DEVELOPMENT AND TECHNICAL SUPPORT

JET PROPULSION LABORATORY
PASADENA, CALIFORNIA

Interagency Agreement No.: EF-77-A-01-2616

Total Funding: \$2,176,000

INTRODUCTION

In support of the Department of Energy, Division of Coal Conversion, the Jet Propulsion Laboratory (JPL) has been awarded a contract to assist DOE in the development of coal feeder devices and to lend technical support to DOE in evaluating new feeder technology.

The objectives of the contract are two-fold. One concerns the analysis of general coal feeder and related peripheral equipment and technology. The other objective concerns the assessment of the technical feasibility of developing on a commercial scale, a coal extruder or "coal pump" based on the plastic properties of coal.

The first objective consists of two separate tasks (Task I and III) which are based on engineering analysis and evaluation. Task I, coal feed program support, will provide support to DOE by:

- Analyzing coal-feeding requirements for scale-up coal plants with particular emphasis on pressurized converters.
- Formulating engineering and performance criteria to guide the subsequent selection, development, and commercialization of coal-feeder systems.
- Monitoring the technical progress of the feeder developments: evaluating performance of ongoing coal-feeder programs, comparing development progress against the criteria.
- Formulating and recommending program plans for the development of selected feeder systems.

Task III, facilities development requirements study, will be carried out by:

- Identifying equipment deficiencies for demonstration facilities.
- Recommending equipment development actions to DOE.

The second objective (Task II) will be accomplished by establishment of a base engineering experience in the continuous extrusion of coal in the plastic state through use of a modified thermoplastic extruder, and assessment of the feasibility of developing large commercial size coal feeding systems based on this approach. Also, JPL will attempt to acquire the data required to initiate the design of a commercial-size coal extruder.

PROGRESS DURING JULY-SEPTEMBER 1978

Task I — Coal Feed Program Support

The Pilot Scale Dry Coal Feeder Evaluation and Development Strategy was completed. The objective of this evaluation was to review the progress of the feeder development programs and recommend alternatives which would more effectively emphasize feeders with the highest commercialization potential.

Feasibility tests and design review meetings were conducted for a number of other feeder designs. These included the IRRI Screw Feeder, the FMA Centrifugal Feeder and the Three-inch Bench Scale Piston Feeder.

Task III — Facilities Equipment Development Requirements Study

The Coal/Solids Handling and Feed System Program Plan was completed and distributed. JPL will provide technical support for this program. In addition, a new task to develop an Instrumentation and Control Program Plan was initiated during this reporting period.

Equipment used in the harvesting and processing of peat is being investigated.

Task II — Coal Pump Development Extruder Development

A technical review of the coal pump development task was held on August 17, 1978. Experts in the plastics and coal field from industry, academe, and government participated in the review.

Four tests were conducted on the 2.5 inch coal pump during this quarter.

The fourth run of the quarter was more successful. The coal pump was operated at 100 rpm and 60 to 95 pounds-per-hour for 3.5 hours. Operation was generally smooth, but the run was stopped at 3.5 hours because

of a coal blockage in the feedport as a result of the backstreaming of volatiles.

The Davis Standard 1.5 inch single screw extruder which was obtained on loan from the DOE Pittsburgh Energy Technology Center is currently being installed at the JPL Application Research Laboratory. This extruder will be used as a means of obtaining controlled sprays of coal in pressure vessels.

The behavior of coal in the solids conveying zone was studied in a small screw extruder test apparatus. The behavior of the coal was studied at starved-feed and flood-feed conditions at room temperature and at flood-feed at 400°F. Flowrate and torque were measured for various screw speeds and back-pressures.

Materials Characterization

The final report of the University of Kentucky Institute of Mining and Minerals Research (IMMR) on a contract from the Coal Pump Development project has been approved for distribution and will be available in late October. The title is "Development of Methods of Characterizing Coal in Its Plastic State," written by William G. Lloyd.

Analytical Support

A review of the many coal conversion processes continued. Of the existing gasification processes the entrained type appears to be the most logical application for the coal pump.

XIV. INSTRUMENTATION AND PROCESS CONTROL FOR FOSSIL DEMONSTRATION PLANTS

ARGONNE NATIONAL LABORATORY
ARGONNE, ILLINOIS

Contract No.: ANL 189a 49622R2

Contract Funding: \$1,000,000 FY-77

INTRODUCTION

The Department of Energy, Division of Coal Conversion, is funding Argonne National Laboratory efforts in the development of instrumentation and process control for large scale gasification, liquefaction, and direct combustion plants. The object of the program is to insure timely availability from commercial sources of process control instruments needed for these facilities.

PROGRAM DESCRIPTION

This program will develop instruments not currently available but ultimately needed for coal conversion and/or combustion demonstration plants. Several general types of instruments are needed to improve safety and to optimize operation: mixed-phase mass-flow, on-line composition, level of fluidized beds, and temperature (particularly when rapid fluctuating) in vessels and on vessel walls. These instrument systems are required for process monitoring and control in each phase of the plant operation: initial startup and operation, operational reliability improvement, and process efficiency optimization.

The development program will involve continuing information exchange and cooperation with commer-

cial instrument suppliers and final plant users through symposium sponsorship, industrial subcontracts, and industrial participants at Argonne National Laboratory (ANL). The program will ultimately transfer the knowledge and designs to instrument suppliers for instrument production. Using unique test facilities constructed during the program, instrument testing and calibration will continue after the development of the instruments.

The program will be carried out under five major tasks. Task I, update the State-of-the-Art Report, will involve incorporating the latest information on process needs and developments in commercial instrumentation into the recent ANL study of instrumentation for fossil demonstration plants and will provide an information base for future efforts. Task II, develop mixed phase mass flow instruments, represents the heart of the overall hardware development program. This task includes development at ANL and in industry of several promising techniques for measuring the flow of solids in fluids. It includes the design and fabrication of mixed solids/fluids loops for instrument development, testing, evaluation, and calibration. Task III, develop other on-line instruments, includes on-line composition analysis, level measurement, and temperature monitoring. Task IV, perform process control analysis, will give guidance on instrument performance requirements in support of the hardware development tasks. Task V, organize instrumentation and control symposia, is an important part of the information exchange aspect of the overall program.

PROGRAM ACCOMPLISHMENTS

- Visits to Pilot Plants and Identification of Specific Points in the Systems where Instrument Needs Exist and where Instrument Tests are Planned.
- Issue Initial State-of-Art Study on Instrumentation Needs for Coal Conversion Plants (ANL-76-4).
- Initiate Construction of Solids/Gas Flow Test Facility (S/GFTF).
- Feasibility-Study for acoustic/ultrasonic flow measurement in solid/liquid streams.

PROGRESS DURING JULY-SEPTEMBER 1978

The first draft of the updated State-of-the-Art Report of instrumentation for process control in coal conversion systems was approximately 95 percent complete. It will be completed during the next quarter.

Operation of the Solids/Gas Flow Test Facility (S/GFTF) in all eight operational states was reached after extensive shakedown tests, including tests of safety and emergency shutdown interlocks. The Spectron particle counter was installed and successfully tested. This test revealed the need to have control of dust particles concentration over a much wider range, particularly at low concentrations. Special attention has been given to flow systems having large variations in the density of materials in different states (solid, liquid, or gas). A slurry-liquid test loop will provide experimental confirmation of such calculations in addition to providing a loop for testing mass-flow instrumentation.

The data from the HYGAS experiment were analyzed and indicate that an acoustic/ultrasonic flowmeter is feasible. The noise background level is small when compared with the transmitted signal through the toluene/coal slurry. The attenuation through the slurry was higher than the predicted theoretical values but within the design requirements. Based on the HYGAS results and additional laboratory experiments, a design concept for a doppler acoustic flowmeter was tested, and the results indicated feasibility. Also, data from HYGAS pertaining to the active acoustic cross-correlation tech-

niques are being analyzed, and preliminary results indicate that a measurement of velocity through this technique can be made.

Analysis of the capacitive mass-flow data from the HYGAS pilot plant experiments was continued. Density signal (averaged capacity) increases approximately linearly with char concentration in percent by weight. Density signals were shown to provide possible warning of incipient plugging and/or plugging of slurry feedlines. A study of capacitor potential mapping in regions of non-homogeneous dielectrics was initiated using an existing neutron diffusion code.

The optical particulate monitor developed by Spectron Development Laboratories under contract to ANL has been delivered. Initial tests on the S/GFTF-I have taken place. The high particulate loading in the entrained particulate test region tended to overload the instrument. It will be modified to decrease the sample volume and make operation in streams with higher particulate loadings feasible.

The 1978 Symposium on Instrumentation and Control for Fossil Demonstration Plants was held June 19-21, 1978 in Newport Beach California. Over 200 representatives from all areas of coal conversion instrumentation and control discussed problems and solutions related to coal conversion. Hardware in developmental and commercial stages were respectively displayed in the Show and Tell ISA Exhibit. A major consensus, resulting from the Symposium, was the acknowledgment that several basic and unique problems exist in coal conversion instrumentation and control. To facilitate the timely exchange of information leading to solutions of these problems, a Symposium is planned for 1979. ANL personnel presented several papers during this quarter; these are:

- A Feasibility Study on Methods of Calculating the Effect of Process Measurement Error in Coal Conversion Systems.
- Energy Calculation for Capture Gamma Measurements With Coal.
- Process Stream compositional Analysis in Advanced Coal Utilization Plants Using Neutron-Induced Gamma Spectrometry.
- Calculating the Effect of Process Measurement Uncertainty in Coal Gasification Systems.

XV. DEVELOPMENT OF CONCEPTUAL DESIGNS FOR WATER TREATMENT IN DEMONSTRATION PLANTS

WATER PURIFICATION ASSOCIATES
CAMBRIDGE, MASSACHUSETTS

Contract No.: EF-77-C-01-2635
Contract Funding: \$263,000 (100% Transfer
Funds From EPA)

INTRODUCTION

The program objective is to produce six conceptual designs for integrated water treatment plants in coal conversion demonstration plants. The water treatment plant designs will be developed so that disposal of all residuals can be made in an environmentally acceptable manner.

The program will be carried out under the following five major tasks:

- *Process and Site Selection.* Selection of six demonstration coal conversion plant site combinations.
- *Conceptual Designs for Water Treatment Technologies.* Develop designs for building an integrated water treatment plant.
- *Ultimate Disposal of Residuals.* Provide designs to accomplish the following: reduce mass and water to relatively harmless soluble and insoluble inorganic wastes and inorganic salts; destroy toxic organic wastes; and render insoluble, recover, and segregate non-destructible toxic metal wastes.
- *Integrated Water Treatment Plants.* Selection and explanation of specific designs to create an integrated water treatment plant for coal conversion plants.
- *Development of Test Program.* Develop a test program which incorporates the following: type and size of equipment to be installed; specific measurements to be made and the necessary measurement techniques and equipment; and specific calculations to

be made to optimize the next generation of the water treatment section.

PROJECT ACCOMPLISHMENTS

The coal conversion process, coal type, site location, and water source for six coal conversion plants were identified by WPA and approved by DOE. The criteria used for selection included a mix of technology and geographic siting of plants in both the east and west.

PROGRESS DURING JULY-SEPTEMBER 1978

During the quarter, designs were completed for the individual treatment units which make up the water treatment systems for the SRC and the BIGAS plants. The write-up for the SRC plant contains a complete discussion of the phenol removal system which includes a resin adsorption plant. The write-up for the BIGAS plant includes a side stream softener for cooling water control and boiler feed water reclaimed from treated sewage water. A complete description of the processes considered in these designs as well as for the HYGAS, Lurgi, and Synthane Processes is presented in Table XV-1.

Design work to combine the individual treatment units into integrated water treatment trains has been initiated for both the HYGAS plants and the Lurgi plant. This

Table XV-1. PROCESS DESIGN SUMMARY

PROCESS	HYGAS	HYGAS	LURGI	SRC	BIGAS	SYNTHANE
Site	North Dakota Montana	Western Penn Eastern Kentucky West Virginia	New Mexico	Western Penn., Eastern Kentucky West Virginia	Montana Wyoming	Illinois
Size	Demonstration <u>50 × 10⁶ SCF Day</u>	Demonstration <u>50 × 10⁶ SCF Day</u>	Commercial <u>250 × 10⁶ SCF Day</u>	Demonstration <u>2,000 × 10⁶ SCF Day</u>	Demonstration <u>50 × 10⁶ SCF Day</u>	Demonstration <u>50 × 10⁶ SCF Day</u>
<u>Water Streams</u> (10 ⁶ lb/hr)*						
Output Waters						
Worst Quality	59	0	130	8	0	119
Next Worst	0	107	950	0	0	0
Not So Bad	0	0	0	16	254	23
Cooling Waters						
Minimum	180	210		290	140	120
Reasonable	290	340	1,220	370		220
Probably Wasteful	370	450	(Commercial Design)	450		
<u>Processes Considered</u> in the Design						
	Oxygen Activated Sludge	Oxygen & Air Activated Sludge	Solvent Extraction Resin Adsorption	Phenol Removal Solvent Extraction	Side Stream Softener	Sodium Ion Exchange Softening
	Cooling Tower/ Trickling Filter	Lime Softening Ammonia Strip- ping	Ammonia Separation Phosam W Process Ammonium Sulfate Process Ammonia Distillation	Resin Adsorption Ammonia Stripping	Clarification Ultrafiltration Actual Carbon Adsorption Ion Exchange Ammonia Strip- ping	Normal Ion Exchange Reverse Osmosis Vapor Compres- sion Evapora- tion Ammonia Strip- ping
<u>Design Status</u>						
Processing Unit Designs	Completed	Completed	Completed	Completed	Completed	Completed
Integrated Plant Design	Completed	Initiated	Initiated	—	—	—

*1 × 10⁶ lb hr = 2 gpm ≈ 2.880 gals day.

work will include a reliability assessment of the train, estimation of plot sizes, inter-unit energy conservation wherever possible, as well as provisions of holding and equalization tanks, by-passes, pipe-sizing, etc. During September the integrated plant design for the HYGAS Plant was completed. This design will be submitted early next quarter.

The final report has been reorganized to add important design procedures to the appendix. These were the design procedures used for more than one plant design and will facilitate easy reference when studying individual plant designs. A final draft of the appendix and a complete table of contents have been submitted to the DOE.

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XVI. CONCEPTUAL DESIGN OF A COAL TO METHANOL COMMERCIAL PLANT

BADGER PLANTS

CAMBRIDGE, MASSACHUSETTS

Contract No.: EX-76-C-01-2416

Contract Funding: \$2,585,610
(100% DOE)

INTRODUCTION

The goal of this project is to prepare a conceptual design for a coal-to-methanol commercial plant, and to make recommendations for a demonstration plant to produce methanol fuel and other synthetic liquids and their precursors by advanced coal conversion techniques. This effort will include a study of various gasifiers and synthesis processes in order to arrive at optimum process selections and configurations. In addition, it is anticipated that cost estimates and economic evaluations to be derived will aid in technical and economic feasibility analysis.

PROGRAM DESCRIPTION

Badger Plants, under the current contract to DOE which began in July 1976, is conducting a three phase program to define and engineer a conceptual coal-to-methanol plant. The three phases will consist of a preliminary engineering stage, the development of a conceptual design, and analysis and evaluation of the overall design. The Phase I preliminary engineering will involve an evaluation of a full scale commercial production plant process design. This will include identification of the characteristics and requirements for an initial plant of a size suitable for demonstrating the economic utility

of future commercial plants. This effort will also include process selection and configuration.

Phase II, development of a conceptual design, will center on preparation of structural specifications and drawings that are fixed to process requirements, process flow diagrams describing the overall material and energy balance, operating conditions and descriptions for each unit process selected.

Phase III is planned to be used for analysis and evaluation of the completed conceptual design. This will include economy of scale evaluation and process trade-off studies.

PROGRAM ACHIEVEMENTS

Design of the coal-to-methanol plant was completed in 1977.

The overall coal conversions schemes of the methanol to gasoline plant were developed based on integrating the Mobil M-Gasoline Process into the Methanol-to-Gasoline Complex. Process design work also commenced in 1977 on a second plant configuration which is based on the production of gasoline, by-product LPG, and high-Btu gas.

PROGRESS DURING JULY-SEPTEMBER 1978

The coal-to-gasoline flow diagrams, material balances and equipment specifications were completed for case A (gasoline and LPG), Case B (gasoline, LPD and high-BTU gas) and Case C (maximum gasoline). These have been revised and updated to achieve completely integrated coal-to-gasoline plant designs. Descriptive texts for each process are being developed for the draft of the final report.

The equipment and plot layouts for each case have been completed using information obtained from the equipment vendors. The finalization of these area layouts is still continuing. Capital cost estimates for the installation of the complete coal-to-gasoline plant were completed for all three cases.

Process flow diagrams, equipment specifications and process descriptions for each case were also revised to include systems to meet the latest EPA standards. These systems include waste water stripping, biological treatment, and flue gas desulfurization. Compilation of air pollutant emissions data has been initiated. This information will eventually be used in a computer model to predict air pollutant concentrations.

Steam, cooling water and fuel gas balances were developed for each design of the facility. These were revised to incorporate the findings of a recent heat recovery study, and were used to develop overall block flow diagrams for each utility. Equipment lists for all utility support facilities have been issued as well as a one line electrical diagram for the complete coal-to-gasoline plant.

XVII. HIGH BTU PIPELINE GAS, HYGAS CONCEPTUAL BASIS

PROCON, INC.

DES PLAINES, ILLINOIS

Contract No.: EF-77-C-01-2618

Total Funding: \$7,540,000 (Design Phase
Authorization Only)

INTRODUCTION

Procon, Inc. was selected to design a coal gasification plant to demonstrate the HYGAS process, developed by the Institute of Gas Technology (IGT) and DOE. The contract calls for preparation of a conceptual design of a 250 MMSCFD commercial plant and based on that design, a demonstration plant design, and the associated economic evaluations. The principal design basis, will be based on Illinois #6 coal.

Unlike the other demonstration contracts, this project is funded only for Phase I, with detailed design, construction, and operation phases to be determined at a later date. A project schedule is given in Figure XVII-1, which illustrates possible activities for the HYGAS demonstration program should it be pursued on a high priority basis.

PROCESS DESCRIPTION

The process flow diagram for an agglomerating coal (Illinois 6) is shown in Figure XVII-2. In the process, crushed coal from the feed hopper is screened to remove (+) 14 mesh and fed to a pretreater where its agglomerating tendency is reduced by heat from the reaction with a limited amount of air. The resultant char is slurried with the light byproduct oil. A positive displacement

pump meters this slurry into the high pressure (500-1200 psi) fluidized hydrogasifier. It enters the upper, drying bed of a stacked series of three in the gasifier. As the solids move by gravity down through the reactor's beds, heat is carried up with the gases originating in the lowest bed where oxygen and steam react with the residual carbon at about 1,800°F. The temperature of the successive beds is set to maximize the formation of methane in the reactor through reaction of the coal with the hydrogen formed in the lower beds. In theory sixty-five to seventy percent of the methane produced is formed in the reactor by the direct reaction: $\text{Coal} + 2\text{H}_2 \rightarrow \text{CH}_4$.

Ash and residual carbon are removed dry from the bottom bed. It is discharged through a control valve to the waste treatment section.

The raw gas including the vaporized slurry oil leaves the top of the reactor and passes through a quench section where coal fines, slurry oil, and excess steam are removed. A shift converter adjusts the hydrogen to carbon monoxide ratio for proper methanation feed. The acid gas removal system removes hydrogen sulfide and bulk of the carbon dioxide present. The methanation section reacts the hydrogen and carbon monoxide to methane and water and the drying section removes the water from the pipeline quality gas.

By-product recovery will include provisions for the production of H_2SO_4 or elemental sulfur, anhydrous ammonia, phenol, and light oils. The usual utilities such

ACTIVITY	FISCAL YEAR							
	77	78	79	80	81	82	83	84
PHASE I CONCEPTUAL DESIGN		△	▽					
PHASE II ● DETAILED DESIGN ● LONG LEAD PROCUREMENT ● CONSTRUCTION			△	▽			▽	
PHASE III SHAKEDOWN & OPERATION				△			▽	
						△		▽

Figure XVII-1. HIGH BTU PIPELINE GAS, HYGAS CONCEPTUAL DESIGN PROJECT SCHEDULE

Figure XVII-2. HIGH-BTU PIPELINE GAS, HYGAS PROCESS FLOW DIAGRAM

as air, service water, cooling water, refrigeration, steam, and power will be provided as required. Waste treatment sections to permit the maximum recycle of water, acceptable disposal of solids, and optimum treatment of gaseous vents will be included.

The Commercial Plant will provide a nominal 250 million standard cubic feet per day (MM SCFD) of substitute natural gas with a heating value of approximately 980 BTU-SCF. Typically, there might be three gasification trains with an output of about 84 MM SCFD each. This will require 6525 tons per day of coal

feed per train or about 19,600 tons per day for the entire plant exclusive of any fuel required for steam and/or power generation. In addition, about 1210 tons per day of 98% pure oxygen and 6350 tons per day of steam (about 529,400 pounds per hour) are required for each reactor. This amounts to about 3640 tons per day of oxygen and 19,050 tons per day of steam (about x121,588,000 pounds per hour) for all reactors in the entire plant. Also, about 1450 tons per day of spent char (75% by weight ash) per reactor will need to be disposed of properly. Other products will include approximately 138 tons per day of ammonia and 350 long tons-per-day of sulfur on a total plant basis.

PROGRESS DURING JULY-SEPTEMBER 1978

Work began on the Demonstration Plant design in May. The overall block flow diagram, the overall heat and material balances, and the overall process description for both the high and low pressure bituminous cases were issued. Process flow diagrams, piping and instrumentation diagrams and a number of design studies have been issued for each case. Inquiry specifications

for mechanical equipment, pressure vessels, and heat exchangers have been sent to vendors. These are currently being revised for the 1,200 psig case process units to reflect the final Demonstration Plant design.

The preliminary overall site plan has been issued. Electrical wiring drawings, civil and structural design drawings and piping layout drawings are in progress. Work is progressing toward reaching agreements concerning proprietary processes. A revised project schedule has been issued, but the major milestones still appear realistic.

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GLOSSARY

absorption—an imprecise term suggesting the taking up of one substance by another by either a physical process or a chemical combination.

acceptor—calcined carbonate that absorbs carbon dioxide evolved during gasification, liberating heat.

acid gas removal—the process of selectively removing hydrogen sulfide and carbon dioxide from a gas stream.

activated carbon—carbon obtained by carbonization in the absence of air, preferably in a vacuum; has the property of absorbing large quantities of gases, solvent vapors; used also for clarifying liquids.

adiabatic—any process where heat is neither given off nor absorbed.

adsorption—the process by which the surface of a solid or liquid attracts and holds any atom, molecule, or ion from a solution or gas with which it is in contact.

agglomerate—assemblage of ash particles rigidly joined together, as by partial fusion (sintering).

anthracite coal—hard coal containing 86 to 98 percent fixed carbon and small percentages of volatile material and ash.

API—American Petroleum Institute.

API gravity—a scale adopted by the API for measuring the density of oils; ° API = $\frac{141.5}{\text{Specific gravity, } 60^\circ\text{F}/60^\circ\text{F}} - 131.5$

aromatic hydrocarbon—a cyclic hydrocarbon containing one or more six-carbon (benzene) rings.

ash—solid residue remaining after the combustion of coal.

ASTM—American Society for Testing Materials.

autoclave—a vessel, constructed of thick-walled steel, for carrying out chemical reactions under high pressures and temperatures.

bench-scale unit—a small-scale laboratory unit for testing process concepts and operating parameters as a first step in the evaluation of a process.

binder—carbon products, tars, etc., used to impart cohesion to the body to be formed; a coal-extract binder may be used to prepare formed-coke pellets from non-coking coals.

bituminous coal—a broad class of coals containing 46 to 86 percent fixed carbon and 20 to 40 percent volatile matter.

blow down—periodic or continuous removal of water from a boiler to prevent accumulation of solids.

bottoming cycle—the lower temperature thermodynamic power cycle of a combined-cycle system.

Btu—British thermal unit, the quantity of energy required to raise the temperature of one pound of water one degree Fahrenheit.

BTX—benzene, toluene, xylene; aromatic hydrocarbons.

caking—the softening and agglomeration of coal as a result of the application of heat.

calcination—the process of heating a solid to a high temperature to cause the decomposition of hydrates and carbonates.

calorific value—the quantity of heat obtained by the complete combustion of a unit mass of a fuel under prescribed conditions.

carbon fiber—fine filaments of carbon about eight microns in diameter which are used in composite materials, being bound with resins.

carbonization—destructive heating of carbonaceous substances with the production of a solid, porous residue, or coke, and the evolution of a number of volatile products. For coal, there are two principal classes of carbonization, high-temperature coking (about 900°C) and low-temperature carbonization (about 700°C).

catalyst—a substance that accelerates the rate of a chemical reaction without itself undergoing a permanent chemical change.

centrifuge—an apparatus rotating at high speed which utilizes the centrifugal force generated to separate materials of different densities, e.g., undissolved residue from coal solution in the SRC process.

char—the solid residue remaining after the removal of moisture and volatile matter from coal.

Claus process—industrial method of obtaining elemental sulfur through the partial oxidation of gaseous hydrogen sulfide in air followed by catalytic conversion to molten sulfur.

coal—a readily combustible rock containing more than 50 weight percent and more than 70 volume percent of carbonaceous material including inherent moisture, formed from compaction and induration of variously altered plant remains similar to those in peat.

coalification—metamorphosis of vegetable debris into coal.

coke—strong porous residue consisting of carbon and mineral ash formed when bituminous coal is heated in a limited air supply or in the absence of air. Coke may also be formed by thermal decomposition of petroleum residues.

coke breeze—the fine screenings from crushed coke usually passing a 1/2 inch or 3/4 inch screen opening.

combined cycle—two sequential thermodynamic power conversion systems operating at different temperatures.

combustion gas—gas formed by the combustion of coal, e.g., burning.

combustor—a vessel in which combustion takes place.

coupon—a polished metal strip used to measure the rate of corrosion of the metal in a specific gaseous or liquid environment.

cracking—the partial decomposition of high-molecular-weight organic compounds into lower-molecular-weight compounds, generally as a result of high temperatures.

crude gas—impure gas produced in a gasifier.

culm—the waste or slack from anthracite mines or preparation plants consisting of fine coal, coal dust, and dirt.

cyclone separator—essentially a settling chamber to separate solid particles from a gas, in which gravitational acceleration is replaced by centrifugal acceleration.

degasification—a process for removing naturally occurring methane from coal seams.

delayed coking—a process wherein coal is subjected to a long period of carbonization at moderate temperatures to form coke.

demineralization—removal of mineral matter (ash) from coal by solvent extraction, usually under hydrogen atmosphere.

depolymerization—the change of a large molecule into simpler molecules usually accompanied by the substitution of hydrogen for oxygen in the molecular structure.

destructive distillation—the distillation of coal accompanied by its thermal decomposition.

desulfurization—the removal of sulfur from hydrocarbonaceous substances by chemical reactions.

devolatilization—the removal of a portion of the volatile matter from medium- and high-volatile coals.

diatomaceous earth—a yellow, white, or light-gray, siliceous porous deposit made up of opaline shells of diatoms; used as a filter aid, paint filler, adsorbent, abrasive, and thermal insulator. Also known as kieselguhr.

diatomite—See Diatomaceous Earth.

dissolution—the taking up of a substance by a liquid with the formation of a homogeneous solution.

distillation—a process of vaporizing a liquid and condensing the vapor by cooling; used for separating liquids into various fractions according to their boiling points or boiling ranges.

dolomite—a carbonate of calcium and magnesium having the chemical formula $\text{CaMg}(\text{CO}_3)_2$.

Dowtherm—trademark for a series of eutectic mixtures of diphenyl oxide and diphenyl used as high-temperature heat-transfer fluids.

ebullated bed—gas containing a relatively small proportion of suspended solids, bubbles through a higher density fluidized phase with the result that the system takes on the appearance of a boiling liquid.

economizer—heat exchanging mechanism for recovering heat from flue gases.

effluent gas—gas given off from a process vessel.

elutriation—the preferential removal of the small constituents of a mixture of solid particles by a stream of high-velocity gas.

endothermic reaction—a process in which heat is absorbed.

enthalpy change—the increase or decrease in heat content of a substance or system which accompanies its change from one state to another under constant pressure.

entrained bed (flow)—a bed in which solid particles are suspended in a moving fluid and are continuously carried over in the effluent stream.

eutectic—that combination of two or more components which produces the lowest melting temperature.

exothermic reaction—a process in which heat is liberated.

extraction—a method of separation in which a solid or solution is contacted with a liquid solvent (the two being essentially mutually insoluble) to transfer components into the solvent.

extractive coking—similar to delayed coking process, with the emphasis on high tar yields to produce liquids.

filter aid—finely divided solids used to increase efficiency of filtering.

filter cake—the moist residue remaining from the filtration of a slurry to produce a clean filtrate.

filtrate—a liquid free of solid matter after having passed through a filter.

filtration—the separation of solids from liquids by passing the mixture through a suitable medium, e.g., cloth, paper, diatomaceous earth.

Fischer assay—method for determining the tar and light oil yields from coal or oil shale; conducted in a retort under an inert atmosphere with a prescribed increase in temperature to 500°C.

Fischer-Tropsch catalyst—catalysts developed for the catalytic synthesis of liquid fuels from coal-derived synthesis gas; catalysts contain principally iron, cobalt, nickel, or ruthenium.

Fischer-Tropsch process—method of hydrogenating mixtures of

carbon monoxide and hydrogen produced from coal, lignite, or natural gas by means of steam, at 1-10 atmospheres and 360-410°F to yield liquid and gaseous fuels, and a wide spectrum of industrial chemicals.

fixed-bed—stationary solid particles in intimate contact with fluid passing through them.

fixed carbon—the solid residue, other than ash, obtained by destructive distillation; determined by definite prescribed methods.

flash carbonization—a carbonization process characterized by short residence times of coal in the reactor to optimize tar yields.

flue gas—gaseous combustion products.

fluidization (dense phase)—the turbulent motion of solid particles in a fluid stream; the particles are close enough as to interact and give the appearance of a boiling liquid.

fluidization (entrained)—gas-solid contacting process in which a bed of finely divided solid particles is lifted and agitated by a rising stream of gas.

fluidized-bed—assemblage of small solid particles maintained in balanced suspension against gravity by the upward motion of a gas.

fly ash—a fine ash from the pulverized coal burned in power station boilers, or entrained ash carried over from a gasifier.

fractionation—distillation process for the separation of the various components of liquid mixtures.

freeboard—the space in a fluidized-bed reactor between the top of the bed and the top of the reactor.

free swelling index—a standard test that indicates the caking characteristics of coal when burned as a fuel.

Friedel-Crafts reaction—a substitution reaction, catalyzed by aluminum chloride in which an alkyl (R-) or acyl (RCO-) group replaces a hydrogen atom of an aromatic nucleus to produce a hydrocarbon or a ketone.

fuel cell—a galvanic cell in which the chemical energy of a conventional fuel is utilized to produce electricity.

fuel gas—low heating value (150-350 BTU/scf) product generally utilized on site for power generation or industrial use.

gasification of coal—the conversion of solid coal into a gaseous form by various chemical reactions with steam.

gasifier—a vessel in which gasification occurs, usually utilizing fluidized-bed, fixed-bed, or entrained-bed units.

heat capacity—quantity of heat required to raise the temperature of one pound of a substance one degree Fahrenheit.

high-Btu gas—a gas having a heating value of 900 to 1,000 Btu per standard cubic foot, which approaches the value for natural gas.

higher-heating value (HHV)—the heat liberated during a combustion process in which the product water vapor is condensed to a liquid and the heat of condensation is recovered.

hydroclone—a small cyclone extractor for removal of suspended solids from a flowing liquid by means of the centrifugal forces set up when the liquid is made to flow through a tight conical vortex.

hydrocoking—coking of tars, SRC, etc., under hydrogenating conditions to form liquid products.

hydrocracking—the combination of cracking and hydrogenation of organic compounds.

hydrogasification—gasification that involves the direct reaction of fuels with hydrogen to optimize formation of methane.

hydrogenation—chemical reactions involving the addition of gaseous hydrogen to a substance in the presence of a catalyst under high temperatures and pressures.

hydrogen donor solvent—solvent, such as anthracene oil, tetralin (tetrahydronaphthalene), decalin, etc., which transfers hydro-

gen to coal constituents causing depolymerization and consequent conversion to liquid products of lower boiling range which are then dissolved by the solvent.

hydrotreating—a process to catalytically stabilize petroleum or other liquid hydrocarbon products and/or remove objectionable elements from products or feedstocks by reacting them with hydrogen.

Ideal gas—any gas whose equation of state is expressed by the ideal gas law, namely $PV = nRT$ where P is the pressure, V is the volume, R is the gas constant, T is the absolute temperature, and n = number of moles.

Ignition temperature—the minimum temperature necessary to initiate self-sustained combustion of a substance.

Industrial gas—see fuel gas.

Inerts—constituents of a coal which decrease its efficiency in use, e.g., mineral matter (ash) and moisture in fuel for combustion.

In situ—in its original place, e.g., underground gasification of a coal seam.

Intermediate-Btu gas—synthesis gas product with a higher heating value between 350 and 500 Btu per standard cubic foot.

Ignite—brownish-black coal containing 65-72 percent carbon on a mineral-matter-free basis, with a rank between peat and subbituminous coal.

limestone—sedimentary rock containing 50 percent carbonate (CO_3) of lime or magnesia. Chemical formula (for calcite limestone) is CaCO_3 .

liquefaction—conversion of a solid to a liquid; with coal, this appears to involve the thermal fracture of carbon-carbon and carbon-oxygen bonds, forming free radicals. These radicals abstract hydrogen atoms yielding low molecular weight gaseous and condensed aromatic liquids.

liquefied petroleum gas (LPG)—those hydrocarbons that have a vapor pressure (at 70°F) slightly above atmospheric (such as propane and butane); kept in liquid form under a pressure higher than 1 atm.

lock hopper—a mechanical device that permits the introduction of a solid into an environment of different pressure.

low-Btu gas—a gas having a heating value up to 350 Btu per standard cubic foot.

lower heating value—the heat liberated by a combustion process assuming that none of the water vapor resulting from the process is condensed, so that its latent heat is not available.

MAF—moisture and ash-free; a term that relates to the organic fraction in coal.

mesh—measure of fineness of a screen, e.g., a 400-mesh sieve has 400 openings per linear inch.

methanation—the production of methane (CH_4) from carbon monoxide or dioxide and hydrogen.

methane— CH_4 , a colorless, odorless, and tasteless gas, lighter than air; the chief component of natural gas.

methanol—methyl alcohol, CH_3OH .

micron—a unit of length equal to one millionth of a meter; 10^{-6} meter.

moving bed—particled solids in a process vessel that are circulated (moved) either mechanically or by gravity flow.

natural gas—naturally occurring gas extracted from sedimentary structures consisting mainly of methane and having a higher heating value of approximately 1,050 Btu per standard cubic foot.

noncoking coal—a coal that does not form coke under normal coking conditions.

olefinic hydrocarbon—a class of unsaturated hydrocarbons containing one or more double bonds and having the general chemical formula C_nH_{2n} .

open cycle—a thermodynamic power cycle in which the working fluid passes through the system only once and is then exhausted to the atmosphere.

peat—an unconsolidated, hydrophilic, yellowish-brown to brownish-black, carbonaceous sediment, formed by accumulation of partially fragmented and decomposed plant remains in swamps and marshes which retains more than 75 percent inherent moisture and less than 12 percent mineral matter in saturated natural deposits.

petrochemicals—those derived from crude oil or natural gas, or their coal-derived substitutes; they include light hydrocarbons such as butylene, ethylene and propylene, the raw materials for the production of plastics by polymerization.

phenols—a group of aromatic compounds having the hydroxyl (OH) group directly attached to the benzene ring.

pilot plant—a chemical process plant containing all the processes of a commercial unit, but on a smaller scale, for the purpose of studying the technical and economic feasibility of the process.

pipeline gas—a methane-rich gas that conforms to certain standards and has a higher heating value between 950 and 1,050 Btu per standard cubic foot.

plenum chamber—an enclosed space through which air is forced for slow distribution through ducts.

precoat—layer of suitable filtering medium, e.g., diatomaceous earth, laid down on a rotary filter cloth prior to operation.

prilling tower—a tower that produces small solid agglomerates by spraying a liquid solution in the top and blowing air up from the bottom.

process development unit—a system used to study the effects of process variables on performance; sized between a bench-scale unit and a pilot plant.

proximate analysis—analysis of coal based on the percentages of moisture, volatile matter, fixed carbon (by difference), and ash, using prescribed methods. Reported on different bases, such as as-received (or as-fired), dry, mineral-matter-free (mmf), and dry mineral-matter-free (dmmf).

purification—removal of a wide range of impurities present in gases from coal gasification.

pyrolysis—thermal decomposition of organic compounds in the absence of oxygen.

quenching—cooling by immersion in oil, water bath, or water spray.

Raney nickel catalyst—specially prepared nickel catalyst used in the hydrogenation of organic materials and the methanation of synthesis gas to methane.

raw gas—see crude gas.

reactivity—susceptibility to chemical change; for example, in coal liquefaction, the reactivity of the coal for conversion to liquid products is a function of the coal rank, among other things.

reactor—vessel in which coal-conversion reactions take place.

Rectisol process—a process for the purification of coal-gasification gas based on the capability of cold methanol to absorb all gas impurities in a single step; gas naphtha, unsaturated hydrocarbons, sulfur compounds, hydrogen cyanide, and carbon dioxide are removed from the gas stream by the methanol at temperatures below 0°C.

reducing gas—a gas which, at high temperatures, lowers the state of oxidation of other chemicals.

reforming processes—a group of proprietary processes in which low-grade or low molecular weight hydrocarbons are catalytically converted to higher grade or higher molecular weight materials; also applies to the endothermic reforming of methane, for the production of hydrogen, by the reaction of methane and steam in the presence of nickel catalysts.

refractory—a material capable of withstanding extremely high temperatures and having a relatively low thermal conductivity.

residence time—time spent by a typical particle in a particular zone.

saturated hydrocarbon—a carbon-hydrogen compound with all carbon bonds filled; that is, there are no double or triple bonds as in olefins and acetylenes.

scrubber—apparatus in which a gas stream is freed of tar, ammonia, and hydrogen sulfide.

seam coal—coal which is intermediate in rank between bituminous coal and anthracite; contains 8 to 22 percent volatile matter and from 91 to 93 percent carbon.

semi-water gas—a mixture of carbon monoxide, carbon dioxide, hydrogen, and nitrogen, obtained by passing an air-stream mixture through a hot bed of coke, having a higher heating value of about 120 Btu per standard cubic foot.

sensible heat—that heat which results in only the elevation of the temperature of a substance with no phase changes.

shift conversion—process for the production of gas with a desired carbon monoxide content from crude gases derived from coal gasification; carbon monoxide-rich gas is saturated with steam and passed through a catalytic reactor where the carbon monoxide reacts with steam to produce hydrogen and carbon dioxide, the latter being subsequently removed in a scrubber employing a suitable sorbent.

sintering—the agglomeration of solids at temperatures below their melting point, usually as a consequence of heat and pressure.

slag—molten coal ash composed primarily of silica, alumina, iron oxides, and calcium and magnesium oxides.

slurry—a suspension of pulverized solid in a liquid.

solvation—the association or combination of molecules of solvent with solute ions or molecules.

solvent—that component of a solution which is present in excess; liquid used to dissolve a substance.

solvent extraction—selective solution of coal constituents from finely divided coal particles into a suitable solvent after intimate mixing, usually at high temperatures and pressures in the presence of hydrogen, with or without a catalyst, followed by phase separation.

solvent refined coal (SRC)—a coal extract derived by solvent extraction; a brittle, vitreous solid (m.p. 300°F to 400°F) containing about 0.1 percent ash and about 10 percent of the sulfur in the original coal feedstock; calorific value is about 16,000 Btu per pound; may be used as a clean fuel for power generation by combustion; utilized for the production of high-grade metallurgical coke, anode carbon, and activated carbon by coking, or hydrogenated to produce synthetic crude oil.

space velocity—volume of a gas (measured at standard temperature and pressure) or liquid passing through a given volume of catalyst in a unit time.

specific gravity—ratio of the weight of any volume of a substance to the weight of an equal volume of water at 4°C.

specific heat—heat capacity of a substance as compared with the heat capacity of an equal weight of water.

standard cubic foot (SCF)—the volume of a gas at standard conditions of temperature and pressure. The American Gas Association

uses moisture-free gas at 60°F and 30 inches of mercury (1.0037 atm) as its standard conditions. The pressure standard is not universal in the gas industry: 14.7 psia (1.000 atm) and 14.4 psia (0.980 atm) are also used. The scientific community uses 32°F and 1 atm as standard conditions.

stoichiometry—the definite proportions in which molecules react chemically to form new molecules.

stripping—the removal of the more volatile components from a liquid mixture of compounds.

subbituminous coal—the rank of coal between bituminous and lignite, classified by ASTM as having a range of heating values between 8,300 and 11,000 Btu per pound on a moist mineral-matter-free basis.

substitute natural gas (SNG)—a gas produced from coal, oil sands, or oil shale conforming to natural gas standards.

superficial velocity—the linear velocity of a fluid flowing through a bed of solid particles calculated as though the particles were not present.

superheater—a heat exchanger which adds heat to the saturated steam leaving a boiler.

syn crude—synthetic crude oil; oil produced by the hydrogenation of coal, coal extracts, oil sands, or oil shale, which is similar to petroleum crude.

synthesis gas—a mixture of hydrogen and carbon monoxide which can be reacted to yield a hydrocarbon.

tall gas—a gas issuing from a gas-treatment unit which may be recycled to the process or exhausted.

tar (coal)—a dark brown or black, viscous, combustible liquid formed by the destructive distillation of coal.

therm—a unit of heat used as a basis for the sale of natural gas; equal to 100,000 Btu.

topping cycle—the higher temperature thermodynamic power cycle of a combined-cycle system.

turndown ratio—the minimum ratio of actual flowrate to design flowrate at which a process unit can be operated.

ultimate analysis—the determination by prescribed method of carbon and hydrogen in the material as found in the gaseous products of its complete combustion, the determination of sulfur, nitrogen, and ash in the material as a whole and the estimation of oxygen by difference; may be reported on different bases, such as as-received (or as-fired), dry, mineral-matter-free (mmf), and dry mineral-matter-free (dmmf).

Venturi scrubber—a gas cleaning device which involves the injection of water into a stream of dust-laden gas flowing at a high velocity through a contracted portion of a duct, thus transferring the dust particles to the water droplets which are subsequently removed.

volatile matter—those constituents of coal, exclusive of moisture, that are liberated from a sample when heated to 1750°F for seven minutes in the absence of oxygen.

water gas—gas produced by the reaction of carbon (in coal or coke) and steam to yield mixtures of carbon monoxide and hydrogen; similar to synthesis gas.

water gas shift—the reaction between water vapor and carbon monoxide to produce hydrogen and carbon dioxide or the reverse: $\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{H}_2 + \text{CO}_2$.

working fluid—a gas stream which directly does work, e.g., powering a gas turbine.