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DEMONSTRATION STRAITS PLANTS

U.S. DEPARTMENT OF ENERGY

Division of Coal Conversion

QUARTERLY REPORT

July - September 1977

DOE/ET-0027/3

Publication Date: February 1978

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COAL

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FOREWORD

This document was prepared by the Energy Research and Development Administration (ERDA) prior to the activation of the Department of Energy (DOE) by P.L. 95-91 on October 1, 1977. Therefore, wherever ERDA is mentioned, it should be noted that its functions have been transferred to DOE.

The technical reviews contained in this document were prepared by Cameron Engineers, Inc., Denver, Colorado, based on information supplied by DOE and its various contractors. The reviews, as they appear herein, have been authorized for publication by representatives of DOE. Cameron Engineers, Inc. assumes responsibility for the accuracy of the reviews but not for the accuracy of the information provided by either DOE or its contractors.

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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.

DOE's demonstration plant program was started in 1974 by one of DOE'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.

I. SYNTHESIS GAS FOR AMMONIA PRODUCTION DEMONSTRATION PLANT

W. R. GRACE & CO.

NEW YORK, NEW YORK

Plant Site: Baskett, Kentucky

Contract No.: EF-77-C-01-2577

Total Funding: \$318,358,000

Phase I: \$10,198,000 (100% DOE)

Phase II: \$233,060,000
(50% DOE/50% Grace)

Phase III: \$75,100,000
(50% DOE/50% Grace)

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 80 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 a 50-50 cost sharing with industry and government.

The auxiliary ammonia plant will be funded 100% by W. R. Grace at a cost of \$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 six major tasks which include:

- Conceptual design and evaluation of a commercial plant
- Demonstration plant conceptual design
- Site evaluation and selection
- Demonstration plant environmental analysis
- Demonstration plant construction and operation plan
- Economic reassessment of commercial plant design.

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 I-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 to 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 I-2.

Figure I-1. SCHEDULE

Figure I-2. FUEL GAS INDUSTRIAL "B"

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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 (100% DOE)

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 with 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., Synfuels 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
- 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 the Stage 1.

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 of 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.

PROCESS DESCRIPTION

Technology to be used by the contractor includes the COGAS coal gasification concept, licensed by COGAS Development Company. A partnership comprised of the FMC Corporation; Consolidated Gas Supply Co.; Panhandle Eastern Pipeline 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 (COED Process), a fluid bed gasifier, and a slagging type 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 from the combustor into the gasifier. (See Figure II-3) In the gasifier, as the hot char mixes with the char to be gasified, it provides the heat for the endothermic reaction mentioned above. Char from the gasifier is recycled to the 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 produce 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.

ACTIVITY	FISCAL YEAR								
	77	78	79	80	81	82	83	84	85
PHASE I - COMMERCIAL & DEMO PLANTS CONCEPTUAL DESIGN	△	▽							
PHASE II - DEMO PLANT									
• DETAILED DESIGN		△	→	▽					
• LONG LEAD PROCUREMENT		△	→	→	▽				
• CONSTRUCTION			△	→	→	▽			
PHASE III - SHAKEDOWN & OPERATION					△	→	→	→	▽

Figure II-1. SCHEDULE

Figure II-2. COED PYROLYSIS PROCESS

Figure II-3. HOT CHAR CIRCULATION SYSTEM

Figure II-4. ICGG PROCESS FOR PIPELINE GAS GENERATION

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III. PIPELINE GAS DEMONSTRATION PLANT

CONTINENTAL OIL COMPANY
STAMFORD, CONNECTICUT

Plant Site: Noble County, Ohio

Contract No.: EF-77-C-01-2542

Total Funding: \$371,590,000 (Total Contract)
\$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 Lurgi gasification process and will employ Foster Wheeler Energy Corp. as the architect-engineering firm.

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

demonstration plant detailed 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 Lurgi process. This process (shown in Figure III-2) is a modification of the existing commercial Lurgi process in that it will accept caking coals and operate at higher temperatures. The slagging process

Figure III-1. SCHEDULE

Figure III-2. HIGH BTU PIPELINE GAS "A"

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.

Gases leaving the gasifiers are cooled by quenching with a gas liquid (recycled water) spray. The H_2/CO ratio as required for downstream methanation is adjusted 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 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 produced from carbon monoxide and hydrogen over a fixed-bed nickel catalyst.

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 gasifiers. 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.

PROGRESS DURING JULY-SEPTEMBER 1977

Design and Evaluation of Commercial Plant

This task was initiated in June and effort continued throughout the quarter. Heat and material balances were completed on the gasification section and progress was made on other sections.

Demonstration Plant Process Design

Lurgi completed heat and material balances on the gasification section. Process design on the other sections continued.

Site Selection and Evaluation

The site selection plan was issued and preparations were made for the first meeting of the site selection task force.

Environmental Analysis

The environmental analysis began in July and is currently on schedule. The terrestrial, aquatic and air modifying studies have started. The entire project remains on schedule.

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IV. FUEL GAS DEMONSTRATION PLANT

MEMPHIS LIGHT, GAS AND WATER
MEMPHIS, TENNESSEE

Plant Site: Memphis, Tennessee
Contract No.: ET-77-C-01-2582
Total Funding: Phase I: \$10,200,000
(100% DOE)
Phase II: \$233,000,000
(50% DOE/50%
Memphis Light)
Phase III: \$75 million
(50% DOE/50%
Memphis Light)

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 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 fuel gas produced by the facility would have a heat content of approximately 300 Btu's per cubic foot, converted from 2800 tons-per-day of high sulfur coal. Approximately 50 billion Btu's of medium fuel gas would be produced daily.

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 - Demonstration plant site evaluation.
- Task V - Site environmental analysis.
- Task VI - Planning - final design construction and operation.
- Task VII - Economic assessment.

Phase II - Demonstration plant final design procurement and construction.

Phase III - Demonstration plant operation.

The program schedule is shown in Figure IV-1.

PROCESS DESCRIPTION

The U-Gas gasifier is of vertical cylindrical construction with an internal cyclone for returning the elutriated fines to the bed. A sloped grid at the bottom, containing

one or more inverted cones, serves as the air 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 inch size. The feed may contain up to 10% > 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) must be pretreated by contact with air in a fluidized bed operating at gasifier pressure and 700° to 800° F. An oxidized outer layer forms on the coal particles, and this prevents agglomeration and possible blockage in the gasifier.

Coal fed to the gasifier is gasified with a mixture of air and steam in a single stage fluidized bed. The residence time of the coal is about 15 minutes to an hour. Fluidizing velocity is in the order of 1 to 2.5 feet per second.

The key to operation of the gasifier is the agglomeration and separation of the low carbon content ash from the bed. The U-Gas gasifier accomplishes this and maintains bed of approximately 70% carbon and 30% ash by proper design and operation of the grid and the fines return system in the bottom of the gasifier. The grid is sloped toward one or more inverted cones contained in the grid. Part of the fluidizing steam and air flow through the grid while the remaining fluidizing gas flows upward at high velocity through the throat at the cone apex. The ratio of steam to air 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 temperature of 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.

Figure IV-1. SCHEDULE

Figure IV-2. LOW BTU FUEL GAS INDUSTRIAL "A"

Fines elutriated from the fluid bed are separated from the product gas by two cyclones in series: the first inside the gasifier and the second outside. Fines removed by the first cyclone are returned to the bed by a standleg. Fines removed by the external cyclone are entrained in the inlet

air/stream to the gasifier grid come 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.

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V. DEVELOPMENT OF COAL FEEDERS FOR COAL GASIFICATION OPERATIONS

FOSTER-MILLER ASSOCIATES, INC.

WALTHAM, MASSACHUSETTS

Contract No.: E(49-18)-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 gasification 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, crushed to 1/8-inch and below, from an atmospheric-pressure hopper into a gasifier whose pressure may be as high as 100 atm.

Feed methods currently being used in pilot and demonstration plants depend on the coal size and gasifier 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 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 will be tested in the laboratory. Equipment of four different designs will be constructed, and each laboratory-scale feeder will be 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 will be 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 20 atmospheres. 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. Results from these activities led to the selection of four methods:

- Coal plug feeders
- Centrifugal feeders
- Positive displacement feeders
- Conveyor feeder.

Evaluation of these concepts are currently being carried out during Phase II.

PROGRESS DURING JULY-SEPTEMBER 1977

Pilot-Scale Coal Feeder Development

Centrifugal Feeder

The centrifugal feeder testing continued in July with two more sprue geometries. The feeder operated against

195 pounds per square inch back pressure with a flow rate of 1/2 ton per hour, and a sprue passage of 1.2 inches with a .150 inch opening at 2000 RPM. A 1.2 inch sprue with a .216 inch opening was tested at 175 pounds per square inch with a flow rate of 1-1/4 tons per hour at 2350 RPM. Both tests were successful and feeder performance data correlated with the theoretical model of feeder operation. These tests completed the Phase II feeder development effort.

Positive Displacement Feeder

The piston feeder prototype was operated in July for the purpose of determining the ultimate receiver pressure at which the unit could be operated. At 900 pounds per square inch the feeder output was just over 100 pounds per hour for a unit cycle time of about 7 seconds. Phase II testing of the unit is now essentially complete.

Sealed Conveyor Feeder

Testing of the prototype feeder continued to be delayed due to the delay in delivery of required pressure vessels. The pressure components were finally received on September 22 which represents a 4-month delay in the delivery date. The feeder was disassembled the last week in September for evaluation and inspection before initiating pressure testing in October.

Pilot Plant Feeder Development

Phase III of this contract, which will involve the scale-up of successful Phase II feeder concepts for pilot plant use obtained funding on September 26. Design of a 200 pounds per square inch and a 500 pounds per square inch prototype centrifugal feeder for this program was initiated in September. In addition, the design of an upgraded feeder test loop was also initiated in September and will continue.

VI. DEVELOPMENT OF A CONTINUOUS DRY COAL SCREW FEEDER

INGERSOLL-RAND RESEARCH, INC.
PRINCETON, NEW JERSEY

Contract No.: E(49-18)-1794
Total Funding: \$2,642,445
(100% DOE)

INTRODUCTION

Development of a continuous dry coal screw feeder is being conducted by Ingersoll-Rand Research, Inc. through DOE sponsorship. 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 successful development of a continuous dry coal feeder would have a significant impact on coal processing. The equipment could be used in both high- and low-Btu gasification plants and also in coal liquefaction systems.

PROGRAM DESCRIPTION

Under the current contract with DOE started in July 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 involves 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. will be used to obtain information on the feeder requirements. Using the information gathered, Ingersoll-Rand is to examine existing equipment and conceptually design new approaches to coal feeders.

In Phase II, critical components of the candidate equipment selected in Phase I will be 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, IMPCO screw feeder will be installed and operated in a pilot plant 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 sizes 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.

PROJECT ACCOMPLISHMENTS

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.

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. A proposal is to be submitted for further evaluation of the piston feeder concepts.

DOE received the Phase I report in March for review and comment.

PROGRESS DURING JULY-SEPTEMBER 1977

Feeder Development

1.5" Diameter Screw Feeder Development

During July, this feeder was operated in the extrusion mode with external heat. Pittsburgh Seam #8 coal and an increasing volume screw were used during the test which was carried out at atmospheric conditions. Approximately one ton of coal was extruded during the 54 hour test which was designed to investigate the overall operational reliability and screw wear.

The feeder operation was found to be satisfactory throughout the test; however, the screw wear rate observed was found to be unsatisfactory. The screw was fabricated from Nitralloy #135 with the screw surfaces nitrided. The screw dimensions were measured before and after the test and it was found that the six flights at the screw discharge end showed significant wear. Expressing the wear rate in pounds of screw metal lost per one million pounds of coal extrudate, the wear rate was measured to be approximately 3.5 parts per million. This screw wear rate was found undesirable and it was determined that it would be necessary to evaluate advance materials and coating to minimize the wear rate.

The standard thermoset screw in extrusion mode with external heat was tested in previous quarters and found to exhibit poor performance qualities. Modifications to the screw were made and tests were conducted on the modified screw in August. Pittsburgh #8 seam coal was used and the barrel temperature profile, screw rotation speed and plug length were selected based on previous experience with other screws. Stable operation for up to one hour was obtained; however, the screw eventually stalled and it was not possible to obtain steady state operation.

5-1/2" Diameter Screw Feeder Development

Tests were conducted with the feeder in extrusion mode with external heat. Two modifications had been previously made to improve operation and were the focal point of the experiments. These modifications included a much heavier vent screen assembly to alleviate the breakage problem and a flat tip adapted that was fabricated and installed at the screw discharge end of the 1-1/2 inch diameter screw. With the improvements and modifications, steady state operations were achieved at atmospheric conditions.

Fully Plasticized Coal Delivery Program

This part of the development program was initiated on July 1, and a literature search was initiated to obtain several references discussing the behavior of coal when heated to its plastic state. In addition, people working in the area of coal plastic properties were contacted. Meetings were held between IRRI and the Jet Propulsion Laboratory to coordinate activities of both groups in these areas. Additionally, the modifications of the NBV-12 machine required for conducting the program were initiated. The design and procurement of required materials will be accomplished in following quarters.

VII. COAL FEEDER DEVELOPMENT PROGRAM

LOCKHEED MISSILES AND SPACE COMPANY,
INC.

SUNNYVALE, CALIFORNIA

Contract No.: E(49-18)-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 100 atm 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 will 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 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 principals 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 snugly fitting into a standpipe and conveying coal in the inter-space, 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

To establish a firm basis for the design of the coal feed systems for use in commercial plants, Phase II 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

PROGRESS DURING JULY-SEPTEMBER 1977

Prototype Feeder Testing

The prototype feeder testing program which was Phase II of the contract, was essentially completed in August. 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 by Lockheed 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.

Based on design studies performed thus far, the Kinetic Extruder was found to have good potential for large throughputs of coal grinds up to 1/8 inch in particle size. Finer coals can be fed at lower throughputs and higher pressures. Multistaging of the Kinetic Extruder has been considered, but further tradeoffs are required before final recommendations can be made on the potential for hybrid systems that might incorporate the Ejector as the final stage, for example. The Kinetic Extruder should be evaluated for high-pressure pilot plant use.

The Ejector appears well suited as a booster or topping stage in high pressure systems. The use of steam as the driving fluid should also be explored if it proves compatible with the process under consideration. Present plans call for the evaluations of Ejectors as a booster stage for pilot plant application.

The Ball Conveyor should be considered for low-pressure, high-throughput requirements. Design tools

and experimental procedures have been developed that permit assessment of the Ball Conveyor as a potential feeder candidate. Feedstock particle-size distribution and the permeability of the coal are important parameters. Several concepts have been considered for coal loading into the column and also for the ball letdown system. These two subsystem functions require development before an all-up Ball Conveyor system can be designed and built.

Based on studies carried out to date, the Fluid Dynamic Lock does not appear to be a strong candidate

for coal feeding. The need for narrow disk spacing limits application to very fine coal grinds and the limited pressure rise per stage forces the use of many stages, increases power consumption and equipment cost. The device should be considered as a recompression unit for recirculating fluidizing gases in fluidized bed reactor. The available design procedures can be used to evaluate the Fluid Dynamic Lock for this type of application.

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VIII. TECHNICAL ASSISTANCE SERVICES

THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

Contract No.: E(49-18)-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 Prepara-

tion 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 defined 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.

PROGRESS DURING JULY-SEPTEMBER 1977

Conceptual Design of Commercial Plants

Power, Oil, Gas and Other Products Plant (POGO)

Phase I of this task was completed and the Phase I report entitled "Project POGO-Total Coal Utilization - COG Refinery Design Criteria" was published and distributed.

Basic process design, flow sheet preparation, material balances, material of construction reviews and final flow sheet drafting continued on the major engineering sections of the plant. Eight major unit designs were completed and include the following:

- Fuel Gas Generation
- Fuel Gas Acid Gas Removal
- Fire Water System
- Potable and Sanitary Water System
- Raw Water System
- Effluent Water Treating
- Sulfur Plant
- Process Water Treating

In addition to the above accomplishments, Parsons initiated work on two alternate case POGO plant locations; the Rocky Mountain Region and the Southern Appalachian Region. Both designs being based on typical local coal analyses.

Multi-Process Demonstration Plant

Design and equipment cost estimates for the coal unloading, storage, and grinding facilities for all three phases of the project were completed.

Process design for a number of units were advanced along with design of water reclamation system and the Phase II and Phase III power generation unit combined cycle design. The preparation of the fixed capital investment estimate was also initiated.

Environmental Considerations

The preliminary designs of the separate units in the Multi-Process Demonstration Plant and the POGO complex were reviewed as they were completed. The environmental acceptability and compliance with specific environmental laws and regulations were assessed.

General

Four papers were prepared and presented during the quarter and include:

- "The Analysis of Finned Catalyst Heat Exchanges" at the AIChE/ASME Heat Transfer Conference in Salt Lake City, Utah, August 16.

- "Environmental Factors for Fischer-Tropsch Coal Conversion Technology" at the Second Pacific Chemical Engineering Congress sponsored by the AIChE in Denver, Colorado, August 29.
- "Potential Markets for Emerging Energy Technologies" at the Second Pacific Chemical Engineering

Congress sponsored by the AIChE in Denver, August 30.

- "Conversion of Coal to Liquids by Fischer-Tropsch and Oil/Gas Technologies" at the Symposium on Comparative Synfuels Economics sponsored by the American Chemical Society in Chicago, Illinois, September 1.

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IX. CONCEPTUAL DESIGN FOR ADVANCED COAL LIQUEFACTION COMMERCIAL PLANT

FLUOR ENGINEERS AND CONSTRUCTORS
IRVINE, CALIFORNIA

Contract No.: EX-77-C-01-2251

Total Funding: \$2,701,024
(100% DOE)

INTRODUCTION

Fluor Engineers and constructors are currently under contract to the Division of Coal Conversion, Department of Energy to prepare a conceptual design package for a commercial facility to produce liquid synthetic fuels by an advanced coal liquefaction scheme. The process currently under study is similar to the hydrogen donor solvent concept.

PROGRAM DESCRIPTION

The contract involves a series of closely related tasks which are expected to require about 18 months for completion. The initial task involves a screening study to select an overall plant configuration and liquid product slate. The objective is to establish a basis for design and selection of both basic and unit processes for the final design. The result of the effort will be an overall plant configuration plus an overall material and energy balance, capital and operating cost estimate. The technology to be used for each key step will have been identified. Following the initial screening study, the process design phase for the plant will commence. Material and energy balances will be developed and process flow diagrams prepared for non-proprietary units. In addition, utility consumptions, effluent streams, and catalyst and chemical requirements will be defined as well as specification of feed, product, and by-product streams.

The third task to be undertaken will involve equipment specifications for the plant. An outline of process duty specifications and dimensional drawings will be prepared for all mechanical equipment and vessels. Duty specifications will be written for conventional pre-engineered package systems such as water treating, instrument air, oxygen plants, and ash or slag handling. The specifications produced will not be complete in all details. However, sufficient information will be included so that a competent engineering contractor could complete the detailed engineering design without recourse to any substantial additional process design.

In addition to development of the basic engineering package, efforts will be expanded in identification of those areas of process and mechanical design where additional development work is required before promising technology can be applied commercially.

After completion of the above tasks, a technical and economic evaluation will be made to determine the production rate and the number of parallel trains for each key unit within the commercial facility. The task also includes an evaluation to arrive at a recommendation for the size of a demonstration plant. In addition, a number of auxiliary studies will be carried out to supplement the plant design. These tasks include:

- Mine and plant site
- Environmental assessment
- Operating and maintenance instructions
- Final economic assessment

The mine and plant design activity cover a number of design functions which include:

- Preliminary engineering of a coal mine to be developed for a hypothetical typical coal deposit in the Appalachian region. Work will include a mining method, a mining plan for long term exploitation of the mine, a reclaiming plan, and a solid waste disposal plan.
- Transportation method from mine to plant.
- Coal storage and coal preparation.
- Plot plan development for mine and plant.
- Narrative specifications covering all support facilities.
- Preliminary single line electrical diagram.
- Scale model of the proposed plant.

The environmental effort will involve:

- Determination of applicable environmental regulations.
- Identifications of all gaseous, liquid and solid effluents.
- Determination of Procedures of processes for pollution abatement.
- Preparation of descriptive material to demonstrate that the plant can meet the applicable environmental regulations.

A complete plant description will be prepared which will include operating and maintenance instructions, flexibility and performance limits of plant operations, anticipated start up problems and critical areas of design and safety.

Finally, a capital cost estimate for the mine and plant will be developed. It will cover estimation of all fixed and operating costs and determination of product prices using discounted cash flow procedures.

PROJECT ACCOMPLISHMENTS

The process configuration tasks were completed during the sixth month of the contract. The processing scheme chosen by Fluor were determined to be as follows.

Extraction

Fluor developed a procedure for characterizing extract as a function of time and temperature in the extractor. As a result of this effort, extractor conditions were chosen at 700° F, 15 minutes residence time, and a 60 percent depth of extraction. The basic design consists of separate vessels, each with mechanical agitation.

Solids Separation

An extensive study was carried out to evaluate rotary precoat and horizontal leaf filtration, solvent deashing using an anti-solvent, and deashing by means of settling, by one or two stages. The results showed that single stage settling was the preferred route for the type of coal chosen for the project. The reduced capital cost, which is estimated to be several hundred million dollars was the major incentive for selection of the system.

Low Temperature Carbonization (LTC)

The proposed design consists of a single vessel which is operated at 400 psig with oxygen addition. The incentive for this particular high pressure system is that it permits direct transport of char from the LTC to the gasifier which eliminates lock hoppers and other mechanical feeders.

The fluidized-bed, agglomerating ash process was incorporated into the processing scheme. An operating pressure of 400 psig was selected as a practical level since overall thermal efficiency is relatively insensitive to gasification pressure. The gasification of vacuum resid as an auxiliary feedstock to the gasifier was adopted. Fluor stated that gasifying resid rather than burning it provided added assurance that the plant would be environmentally acceptable for sulfur, nitrogen oxide and particulate emissions.

The total plant configuration was studied using a computerized technique developed by Fluor for determining overall and interunit material and energy balances. Conclusions reached by Fluor were listed as follows:

- Maximum gasoline should be produced with no production of either diesel or heavy fuel oil by-products.
- Conventional coal cleaning procedures should be used rather than feeding ROM coal directly to the liquefaction process.
- Depth of extraction has only a minor effect upon overall thermal efficiency.
- The efficiency penalty resulting from the use of settling is small, since the extract contained in the underflow is converted to useful materials, char and gas.
- There is no significant efficiency penalty associated with the use of water slurry evaporation (as a means of feeding LTC char to the gasifier) for producing hydrogen since the water is useful as shift steam. For fuel gas production, however, water slurry vaporization entails a substantial thermal penalty.

- There is no advantage to coking of the vacuum resid. Since resid may be used either as an in-plant fuel or as a gasification feedstock, other streams must be found to replace any resid that is coked.
- Combined cycle gas turbines display the greatest overall efficiency and their use should be maximized.

A summary of the product slate and process features selected to date and discussed previously are given below.

Product Slate:

Gasoline, 10 Reid Vapor Pressure

$89 \frac{R+M}{2}$	66,532	Barrels per Stream Day
SNG	68.5	Million Std. Cubic Ft. Day
Ethane	12.0	
Propane	8,089	
Butane	8,557	
Sulfur	1,193	Long Tons per Stream Day
Ammonia	240	Tons per Stream Day

Process Features:

Depth of Extraction—	60%
Solids Separation	— Single stage settling
Solids Disposition	— Converted to char in 400 psig LTC
Feed to H ₂ Plant	— LTD char plus vacuum resid
Extract Hydrogen- ation Conversion—	73.4%
Gasifier Type	— Fluid Bed, Agglomerating Ash
Power Generation	— Combined Cycle Gas Turbine

PROGRESS DURING JULY-SEPTEMBER 1977

Minor design work and unit flow diagrams were completed during the quarter. The major effort, however, centered on preparation of materials for inclusion in the final report. The first draft of this report is expected to be completed by October 21. The final plant design, economic analysis, and capital cost estimates will be presented here when they become available.

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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 development program was initiated in June, 1976 because 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. It is designed to:

- Provide reliable data sufficient to permit the confident design of solids handling valves compatible with existing and projected pilot plant operations
- Produce reliable coal valves suitable for commercialization
- 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. 12-inch valves (based on Phase II test 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.

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. Because of these requirements, this valve will incorporate high alumina ceramic and commercial refractory parts for higher reliability and longer life because of its 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 its 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 the permanence in dimensional stability, non-spalling and non-fracturing from temperature fluctuations, low permeability and ease of fabricability.

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

High alumina ceramic components are used in areas where strength greater than that offered by any 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. All components have evolved from the preliminary design conception to its final configuration with little design change because of the long manufacturing time by the ceramic industry.

With all material and components on hand, assembly of the first Type III prototype valve has begun with about 50% completion to date.

PROGRESS DURING JULY-SEPTEMBER 1977

Redesign of Lower Seal Housing

The lower seal housing on the Type III valve will have a ceramic insert located at the inner diameter. This is necessary because of the permeability of the lower seal housing which is made of Greencast 94 refractory. In order to obtain a good seal between inlet and outlet sections of the valve, a ceramic insert would assure a minimum amount of leakage due to permeability. The insert will be cast in place at the time the outlet housing is cast.

Permeability Tests

Permeability tests of Greencast 94, Taycor 414 PH, and Plicast 40 were performed. A test fixture was fabricated to allow gaseous nitrogen under pressure to permeate a cylindrical sample, 2 inches in diameter by $1\frac{1}{2}$ inch in length in all three orthogonal axes. The outgoing gas was then measured for a total amount of permeation of the sample. Data from the Plicast 40 and Taycor 414 PH samples indicated the Plicast has about three times the permeability of the Taycor material at 1600 psig. The Greencast samples showed the least amount of permeability. Additional test specimens of Greencast 94, and Plicast 40 refractory were made. All the specimens were placed in the test fixtures. Plotting scfm vs pressure indicates the three Greencast 94 specimens had about the same permeability. Greencast 94 samples number 1 and 2 had a very low permeability when compared to sample number 3, 4 and 5 at 1000 to 1200 psig.

Material Shear Test

Two samples each of Greencast 94, Plicast 40, and Taycor 414 PH were cast, one approximately 0.50 inch

thick and the other 1.5 inch thick. These samples were used to acquire data on the shear strength capability of each. The only conclusion is that Greencast 94 had the same shear strength for two different thicknesses. Data from the rest of the test specimens were inconclusive as far as relative shear strength is concerned.

Coefficient of Linear Expansion Test

Four sample specimens were sent to Interpace Corporation for a linear expansion determination. The samples were Greencast 94, Plicast 40, and Taycor 414 PH refractories and Wesgo 99.5 alumina ceramic. The results show the alumina ceramic and Greencast 94 refractory having about the same coefficient of linear expansion; 4.5×10^{-6} in/in/ $^{\circ}$ F and 4.36×10^{-6} in/in/ $^{\circ}$ F respectively. Taycor 414 PH and Plicast 40 were significantly lower, about 4.0×10^{-6} in/in/ $^{\circ}$ F and 4.2×10^{-6} in/in/ $^{\circ}$ F respectively.

Structural Gate Test

The first gate assembly was fabricated by casting Taycor 414 PH material without the ceramic closure in place. The prototype gate clamp and cover were used as the attachment for the test machine jaws. A spacer, yoke, and stud were fabricated to adapt the other end of the gate to the test machine.

The first two gates cast with Taycor 414 PH refractory failed at 800 and 650 lbs. respectively because cracks had developed in the thin cross section during the process.

The next three gates were cast using Greencast 94 refractory because of the relatively low shrinkage rate when compared to Taycor 414 PH. The third gate did not develop cracks during curing and ultimate failure occurred in the clamped area at 3725 lbs. The fourth did develop cracks but in the clamped area this time with subsequent failure at 1600 lbs. The fifth gate had cracks across the thin section but the ultimate failure occurred in the clamped area at 4275 lbs.

Ceramic Spring Test (Elevated Temperature)

The spring was placed in a 2200 $^{\circ}$ F kiln between flat rigid ceramic plates. A refractory load bar was mounted to a cantilever beam. The beam was pivoted from the wall so that the load could be applied to the spring by addition of weights at the free end of the beam. Upon inspection of the spring after cool down, permanent deformation had occurred. Efforts to determine the maximum stress level at various temperatures will be conducted on

Ceramic Spring No. 2. This will be accomplished by loading the spring with known weights and subjecting it to various high temperatures (1500-2000°F). After cool down, the height of the spring will be measured for permanent deformation.

Lower Seal Housing Structural Test

The purpose of this test is to verify the structural integrity of the lower seal housing from external pressure load due to permeability. A test fixture has been designed

to let out for fabrication. This fixture will duplicate the stress level between the lower seal housing and the insulation. Different materials will be used as the lower seal housing for comparison.

Development Test

A preliminary detailed test procedure was completed during this time. The procedure outlined all the necessary development tests required in document FE-2213-016-04.

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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 valves are not suitable for prolonged trouble-free in the hostile environment encountered in coal gasification service. Through a program of extensive material testing, 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, 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 analysis of the valve components will be conducted.

Phase II Prototype Testing

From the experience gained 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, Injection Hopper, Ash Removal and Slurry Discharge respectively.)

These valves will be tested at MERC. Failures and shortcomings experienced during this testing program will be analyzed. The design will be modified to incorporate any recommended changes.

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.

WORK ACCOMPLISHMENT

A grade-off study was conducted to determine the most promising valve design. Candidate seat and hearing 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 2000 cycles with no visible deterioration.

PROGRESS DURING JULY-SEPTEMBER 1977

The valve was assembled and tested.

Tests performed are:

- Hyrostatic Proof Test
- Seat Leakage Tests
- Cycle Tests

The seat design was modified to incorporate a shrink fit seat. A shrink fit boron carbide seat assembly was manufactured and tested in the ambient seat test fixture with satisfactory results.

XII. COAL GRINDING EQUIPMENT DEVELOPMENT

KENNEDY VAN SAUN

DANVILLE, PENNSYLVANIA

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

Contract Funding: \$808,000

INTRODUCTION

Kennedy Van Saun is under contract to DOE to modify and develop improved coal grinding equipment and procedures for the coal conversion industry 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. Currently, there are no grinding or size reduction equipment available which can prepare feed coal without excessive amounts of fines and undersized particles. This project is therefore designed to alleviate the abovementioned 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 by Kennedy Van Saun 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 undesirable or unusable fines

The project, initiated in September 1976, is expected to be completed in September 1978. Phase I, the study phase will require approximately eighteen months to complete. This will involve categorizing existing equipment by output spectrum, volume rate, and the driving power required. A study on the state-of-the-art on commercial coal grinding equipment will also be performed. Further, three to five types of coal will be selected for later experimentation and classification. Penn State University under subcontract to Kennedy Van Saun, will perform laboratory analysis to determine the mechanical properties of the coal, the Kinetic parameters of communication, and perform rate testing.

Phase II, will be 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

Summary of Past Work

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

wet ball mill—is completed and the dry ball mill grinding system is 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 have been 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 have been 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).

PROGRESS DURING JULY-SEPTEMBER 1977

The testing facility construction is over 95% completed. All major components of the four grinding systems are installed and only several instruments for the wet grinding system remain to be installed. However,

only the dry ball mill grinding system has undergone a shakedown.

Shakedown of the complete dry ball mill grinding system has been completed. This shakedown includes the common feed handling system, air swept system including fan and air heater, classification system, dust system and sampling system.

Testing has been initiated in the dry ball mill grinding system. The initial testing is establishing baseline product size consists for various feed moisture contents, feed size consists, classification settings and air rates.

The draft of the State of the Art report was reviewed by DOE and returned to KVS for additional clarification. The necessary modifications to achieve the clarification were started.

The laboratory analyses continued to focus mainly on developing the breakage characteristics of the coals. It was concluded that the B valve for the ball milling of the coals are independent of the grinding environment (dry or in water) and are normlizable. The S valves for the ball milling of the coals are first order and those for grinding in water are higher than the equivalent value for dry grinding. The S valves increased with increasing Hardgrove Index for ball mill grinding and ball and race mill grinding. Non-first order anamolies were found when dry ball mill grinding very fine coals and for longer ball and race mill grinding times.

The B functions changed in an orderly fashion for the ball and race mill according to Hardgrove Index. The B functions also changed in an orderly fashion for the ball mill according to Work Index. However the coal type orders were not the same for both cases, inferring why the conversion from a Hardgrove Index to a Work Index is not a simple one.

XIII. COAL PUMP DEVELOPMENT AND TECHNICAL SUPPORT

JET PROPULSION LABORATORY

PASADENA, CALIFORNIA

Interagency Agreement No.: EF-77-A01-2616

Total Funding: \$2,176,000

INTRODUCTION

In support of the Department of Energy, Division of Coal Conversion, the Jet Propulsion Laboratory 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, evaluation, feasibility assessment, and selection 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 and is based on engineering analysis and evaluation. Task I, coal feed program support, will provide to DOE by:

- Analyzing coal-feeding requirements for scaled-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 2, facilities development requirements study, will be carried out by:

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

The second objective 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.

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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 temperatures (particularly when rapidly 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 commercial 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

Past Achievements

- 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)
- Visits to pilot plants and identification of specific points in the systems where instrument needs exist and where instrument tests are planned
- Initial lab tests of capacitive density and flow instrument concept

A commercial capacitive oil/water interface monitor was purchased and will be tested in the separator vessel at HYGAS in November. It is believed that this instrument will be capable of solving the oil/water interface location problem without modification.

An industrial subcontract for continued development of an optical particulate monitor was awarded to Spectron Development Laboratories, Inc. The device will have extended capabilities as far as particle size range and changing sample location within the pipe are concerned.

Non-penetrating analysis of process streams was shown to be feasible for a number of major and ash-forming elements in coal via analysis of gamma rays produced by neutron capture. An improved irradiation facility using a Californium 252 source of neutrons was completed during this quarter. The portable neutron generator was operated for the first time and initial data from irradiation of coal is being collected.

Software to be used for quantifying instrumentation requirements for specific coal conversion processes was developed and tested on two simple system models. Work was completed on a methanation process reactor model to be used in further tests of the code.

The first draft of chapters on instrumentation for temperature, level, and flow for the updated State-of-the-Art Report were done. Work continues on chapters on other types of instrumentation. The first draft will be completed in January.

A trailer to be used as a mobile laboratory during field tests of instruments was procured during the quarter.

PROGRESS DURING JULY-SEPTEMBER 1977

The first Symposium of Instrumentation and Control for Fossil Demonstration Plants was held in Chicago on July 13-15. Over 200 representatives of government, industry, national laboratories, and universities participated. An opinion survey of the participants indicated that the symposium was very useful and that another should be held in 1978.

Construction continued on the Solids/Gas Flow Test Facility and the mechanical fabrication was about 90% complete at the end of the quarter. The major holdup has been due to delayed delivery of the second hopper-cyclone-bag filter assembly. The vendor now promises an early October delivery. Work continued on the conceptual design of a high temperature (800°F) S/GFTF.

The theoretical feasibility studies on application of acoustic/ultrasonic techniques to mass flow measurement in coal slurries and solids/gas media were completed. The second technical memorandum on the study, covering solids/gas media is being prepared. Acoustic devices for in plant tests at HYGAS and BI-GAS were designed and built. Initial tests will occur in December or January.

Laboratory models of a capacitive density-velocity device were constructed and tested for a variety of electrode configurations. A ruggedized prototype was designed and constructed for tests on the slurry feed line at HYGAS. These tests will take place at the time of the acoustic tests in December or January.

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 organic wastes and inorganic salts; destroy toxic organic wastes; and render insoluble, recover, and segregate non-destrucible 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. A summary of this effort is given in Table XV-1.

PROGRESS DURING JULY-SEPTEMBER 1977

The composition and flow rates of the influent and effluent water streams for the six plants selected were determined during the quarter.

Based on the interrelationships between the adequacy of water supply, the foul water composition and the site-specific effluent control regulations, block diagrams for the six conceptual water treatment plants have been finalized.

Each treatment plant contains certain treatment units that are critical to the overall performance of the plant. These units have been identified and will be considered in great detail in the design stage. Several alternatives will be considered for these operations to demonstrate the optimal process selection. While other operations, e.g., boiler feed and cooling water treatment, will be included in the integrated plant design, detailed examination will be deferred to other, relevant water treatment plants.

Table XV-1 Process and Site Selection

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 50 × 10 ⁶ scf/day	Demonstration 50 × 10 ⁶ scf/day	Commercial 250 × 10 ⁶ scf/day	Demonstration 2000 tons/day	Demonstration 50 × 10 ⁶ scf/day	Demonstration 50 × 10 ⁶ scf/day
Product Energy 10 ⁹ Btu/day	48.5	49.6	238	63.2	47.5	47.0
Water Source	Lake Sakakawea	Ohio river	San Juan river	Allegheny river	Sewage	Brackish
Water Availability	Adequate	Adequate	Medium stringent	Adequate	Very stringent	Stringent, water treatment expensive
Water Streams (10³ lb/hr)*						
Boiler Feed Water, Total	203	287	1640	4	138	247
Clean Water from Methanation Reaction Returned to Boiler	(40)	(36)	(270)	0	(47)	(26)
Makeup to Boilers	163	251	1370	4	91	221
Other Water Input	0	0	0	35	261	0
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	1220	370	—	220
Probably Wasteful	370	450	(commercial design)	450	—	—
Minimum Water for Ash Disposal	12.3	13.6	187	12.8	10	4
F.G.D.	13	11.5	240	0	22	48
Other Net Requirements for Full Scale Plant	—	—	220	—	—	—

*1 × 10³ lb/hr = 2 gpm = 2,880 gals/day

TREATMENT PROCESSES

Ammonia Separation

A review of the possible processes including stripping, biological nitrification-denitrification and acid treatment has shown the U.S. Steel Corporation Phosam process to be the most suitable. At a meeting between U.S. Steel and WPA, U.S. Steel agreed to provide detailed systems for the proprietary section of these plants. The designs for the ammonia still and raw water stripper have been initiated.

Biological Oxidation

A review of biological treatment of coal conversion condensates was completed and presented at the Third Symposium on Environmental Aspects of Fuel Conversion Technology in Hollywood, Florida held September 13-16, 1977. This information is being used for the detailed design of biological units for the HYGAS plant in North Dakota-Montana. Air activated sludge, high purity oxygen activated sludge, oxygen-air aeration basin, trickling filter/cooling tower and anaerobic treatment (laboratory scale) are being considered.

Boiler Feed Water Treatment

Stone and Webster Engineering Corporation has completed evaluation of six different boiler feed treatment systems for the HYGAS plant in Pennsylvania-Kentucky-W. Virginia. Five different ion exchange systems and one combined reverse osmosis-ion exchange system were analyzed. The established ion exchange system was taken to be a co-current fixed bed system. This was the most expensive system and used the most chemicals added. A counter-current fixed bed ion exchange system and the combined reverse osmosis reduced the cost by about \$1/1000 gallons and, also, reduced the chemicals added. The counter-current fixed bed system would be used in the Western area where the effluent waste would be treated by evaporation and then disposed of in an evaporation pond. The combined reverse osmosis-ion exchange system would be used in the east-central area where the waste effluent would be treated to remove any toxic chemicals and then disposed of into the receiving waters.

Phenol Separation

A literature review of processes, solvent extraction in particular, has been completed. This will provide the necessary background information for the detailed designs which will be included with the Lurgi commercial plant in New Mexico.

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XVI. SURVEY OF INDUSTRIAL COAL CONVERSION EQUIPMENT CAPABILITIES

OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

Contract No.: W-7405-eng 26
Contract Funding: \$700,000

INTRODUCTION

In FY 1977, the Oak Ridge National Laboratory undertook a 2-year survey of industrial coal conversion equipment capabilities for the Major Facilities Project Management Division of the Energy Research and Development Administration. This survey is being continued for the Division of Coal Conversion of the Department of Energy.

The objective of this project is to conduct surveys of industrial equipment capabilities that will identify the present capability of industry to supply the equipment needed. The project will also determine research and development needs, including lead time requirements, for producing equipment of advanced design for the various unit operations of critical importance to the Division of Coal Conversion.

PROGRAM DESCRIPTION

This survey was begun in November of 1976 (FY 1977) with four principal areas of interest: (1) rotating components (pumps, compressors, hydraulic turbines and gas expanders), (2) valves, (3) hot gas clean-up and (4) heat recovery. Equipment requirements for each of these four areas were determined from several conceptual designs of commercial scale coal liquefaction and gasification plants. Questionnaires were prepared and sent to equipment manufacturers concerning their capability to supply equipment to meet the requirements which had been determined. These questionnaires also addressed prob-

lem areas affecting equipment availability, research and development needs and lead times for procuring equipment. In addition to using questionnaires, visits were made to a number of leading equipment manufacturers to discuss the various aspects of their capabilities to supply equipment. The results of these four surveys, completed at the end of FY 1977, are given in the next section.

During FY 1978, surveys concerning let-down valves, expansion joints and mechanical connectors, including seals, are to be undertaken. Also, surveys of equipment cost, equipment operating experience in pilot plants and equipment development programs and alternatives are to be conducted.

PROGRAM ACHIEVEMENTS

The FY 1977 surveys on rotating components, valves, hot gas clean-up and heat recovery and utilization resulted in the following conclusions.

Rotating Components

It has been concluded that equipment should be available for essentially all clean stream applications likely to be encountered in coal conversion facilities except for oxygen compressors. Slurry pumps and oxygen compressors need to be developed or very significantly upgraded. Also, fans and blowers for dirty gas streams need development work as do expanders for high temperature service, although this latter equipment is

critical to only a few processes. Hydraulic turbines which were not specified but which might be used for slurry applications in future coal conversion plants are not available.

Valves

Results indicate that the valve and valve actuator industry is capable of manufacturing, in quantity, equipment of the size and for the pressure and temperature range which would be required in the coal conversion industry; valve manufacturers do not have product application experience to predict the continuing functional ability of valves used for lock hopper feeders, and for slag/char let-down service. Developmental and testing efforts to modify existing valve design or develop new valve concepts for these applications were estimated to range from 1 to 6 years. A testing facility to simulate actuation of critical valves under service conditions, such as that planned for lock hopper feeder service at MERC, would be beneficial.

Hot Gas Clean-Up

If existing turbine tolerances (0.0002 gr/scf) were increased by two orders of magnitude and the particulate carryover from either a low Btu gasifier or a pressurized fluidized bed combustor were held to 5 gr/scf, an overall clean-up efficiency of at least 99% would have to be achieved. The use of high temperature-high pressure (HTHP) filtration in gasification applications appears to be limited. Inertial separation devices have most likely achieved their maximum levels of efficiency with existing designs, and research aimed at dramatically improving their performance appears to be unwarranted. Surface filters (either metal or unique high temperature fabrics) have potential in HTHP gas cleaning. Granular bed filters are at the stage where on-line operational testing is needed. Major engineering and operational prob-

lems need to be resolved before electrostatic precipitators become viable HTHP filtration devices. Commercial equipment for the removal of H₂S at high temperatures is unavailable at this time. From an environmental point of view, any HTHP filtration system capable of satisfying turbine particulate allowances will more than likely be able to meet any EPA emissions constraints.

Heat Recovery and Utilization

A large variety of equipment types is available from many applications, including feed/effluent interchange, combustion air preheating, and heat-recovery steam generation. Collective vendor fabrication capability is quite extensive, but proper thermal design of some units poses problems. Needs include better steam characterization, viscosities of heavy oils and slurries, multi-phase heat transfer correlations, and rates of fouling, erosion, and corrosion.

During the first quarter of FY 1978, work plans were prepared and some preliminary work on those surveys mentioned in the section on Program Description has been accomplished. The status of existing pilot plant projects has been reviewed and eight pilot plants have been tentatively selected to be contacted concerning their experience in operating coal conversion equipment. Methods of presenting equipment costs are also being reviewed prior to requesting such information from manufacturers. All tasks planned for FY 1978 are to be initiated by early January.

Also during this period, a presentation of the results of the FY 1977 surveys were made to the Department of Energy in Washington, D.C., and ORNL personnel who worked on the valve survey participated in the "Workshop on Valves for Solids Handling Service in Coal Conversion Processes" held in Morgantown, WV. DOE comments were being incorporated into draft reports of the four FY 1977 surveys at the end of the quarter prior to editing and publication.

XVII. CONCEPTUAL DESIGN FOR AN ATMOSPHERIC FLUIDIZED BED DIRECT COMBUSTION ELECTRIC POWER GENERATING PLANT

STONE & WEBSTER
BOSTON, MASSACHUSETTS

Contract No.: EF-77-C-01-2583
Contract Funding: \$1,354,000
(100% DOE)

INTRODUCTION

Stone & Webster is currently under contract to DOE to provide a conceptual design for an Atmospheric Fluidized Bed Direct Combustion (AFBC) Electric Power Plant that will combust high-sulfur coal in an AFBC boiler and generate electric power in an environmentally acceptable manner. The effort on this project will also focus on improving existing boiler technology to produce a conceptual design of a boiler with sufficient integrity and reliability for integration with power generating equipment which will operate between 560-580 megawatts (MW).

The specific objectives are:

- To project capital, operating and product costs for a central power plant
- To design a technically feasible and efficient combination of unit processes and equipment that will directly combust high sulfur coal and produce electric power in an environmentally acceptable manner

The work to attain the overall objective falls into two overlapping phases. Phase I involves the development of conceptual designs and examination of merit of a contemporary size (560 MS) plant including an atmospheric fluidized bed boiler of designs projected by each of the major boiler manufacturers, specifically Babcock & Wilcox and Foster-Wheeler. The purpose of this phase is to provide convincing evidence to the electric utilities to show that fluidized bed combustion is a better choice for

future coal burning facilities than current conventional methods such as suspension burning of pulverized coal.

Phase II will be based on the development of Phase I, particularly with regard to the examination of risks associated with scale up of design features beyond the extent of their present demonstrated success. The objective of the second phase is the compilation of the conceptual design of an atmospheric fluidized bed combustion demonstration plant of size and extent acceptable from the standpoint of risk and general reasonableness toward attainment of goals to its owner and sponsors.

PROJECT ACCOMPLISHMENTS

The total project input has been planned in terms of nine major tasks designated 1000 through 9000.

Work of Phase I has focused mainly on Tasks 1000, to establish a broad background for the work, and 2000, base plant definition.

Subcontract work by Pope, Evans and Robbins, under Task 3000 has been applied largely to development of a current state-of-the-art report on atmospheric fluidized combustion in anticipation of consultations upcoming with the boiler manufacturers as they firm up the basic concepts from which their individual designs will evolve. Subcontracts with the boiler manufacturers have been initiated under Task 4000, but their work has only been

started as of the close of March 1977. Tasks 5000, 6000, and 7000 relate to the specific AFB plant designs and descriptions which remain to be undertaken in the 2nd Quarter 1977. Task 8000 reports have been limited in issue to the three each preceding monthly technical and financial reports. However, two supplemental reports are substantially complete and will be issued soon. These are Base Plant Report and the FBC State-of-the-Art Report. Finally, Task 9000 relating to the demonstration plant, remains scheduled to start about the first of June.

PROGRESS DURING JULY-SEPTEMBER 1977

A conceptual design has been undertaken for a commercial size (560 Mw) complete power generating station, incorporating an atmospheric fluidized combustion boiler. It is to be developed as a variation of a base which is an established plant design with conventional pulver-

ized coal suspension fired boiler with associated facilities. A detailed representation of the base reference plant was completed in the first quarter of the contract.

The activities of this quarter (second) have concerned the design of the corresponding AFB combustion power plant incorporating the individual AFB designs of the two boiler manufacturers, Babcock & Wilcox and Foster Wheeler. Drawings of the plant incorporating the prospective designs were proposed and are scheduled to be issued early next quarter. The designs will be presented here as they are finalized.

A total of ten electric utility companies have been apprised of the AFB project and engaged to review its progress as it develops. A separately bound document describing the base plant reference was presented to each. The description of the AFB plant will be compiled and forwarded to the utilities next quarter. Comments and suggestions from the utilities will be considered in the final overall design.

XVIII. CONCEPTUAL DESIGN OF A COAL MINE COAL CONVERSION PLANT INTERFACE SYSTEM

BECHTEL CORPORATION
SAN FRANCISCO, CALIFORNIA

Contract No.: EX-76-C-01-2370
Contract Funding: \$601,593
(100% DOE)

INTRODUCTION

Bechtel Corporation is under contract to the Division of Coal Conversion to investigate the coal mine-coal conversion plant interface and develop conceptual designs to identify and correct interface inefficiencies.

The mine-plant interface is a physical installation which, once installed, will serve the life of the plant. Inefficiencies built into the conceptual configuration design will result in financial penalties within the process by increased cost in the feedstocks. Further, it is expected that the volumes of coal required by commercial coal conversion plants will exceed that of existing plants and it is anticipated that a complex of mines will be required. This increase in volume introduces complications in the concepts of mine-plant interface, materials handling, coal preparation, and stockpiling.

The specific objectives of the contract are:

- To provide a conceptual design of coal mine-coal conversion plant interface.
- To demonstrate the technical and economic viability of coal mine-coal conversion plant interface processes.
- To produce new or modify existing equipment and techniques to meet the requirements of the project.
- To provide for the orderly transfer of the demonstrated technology to private industry.

PROGRAM DESCRIPTION

The project will be carried out in two phases. Phase I will involve a interface overview investigation. This will entail the identifications of specific coal mine-coal conversion plant interface concept for which a conceptual design will be developed during Phase II. Activities will include identifications of viable mine configurations and conversion plants; analysis of transportation, mine delivery, and feed materials system concepts, and evaluation of alternative mine conversion plant interface concepts.

The Phase II effort will center on interface conceptual engineering and cost estimating. This will involve preparation of designs for mine handling, and transportation, preparation of process flow diagrams, operating costs and descriptions of each unit. Additionally, a detailed economic evaluation of the conceptual system will be made.

PROGRESS DURING JULY-SEPTEMBER 1977

During this quarter, the project was completed and the final report was submitted to DOE for review. It is expected that the report will be available to the public in late November.

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XIX. 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 subject 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.

PROGRESS DURING JULY-SEPTEMBER 1977

Badger engineers continued to advance the design of the coal to methanol commercial plant. Progress was made on each major engineering section of the plant with no major delays reported. The status of each section of the plant as of the end of the quarter is listed below.

Coal and Lime Preparation

High Pressure Feeding Systems

Badger personnel visited the Jet Propulsion Laboratory in Pasadena, California, to review developments of high pressure feeding systems. The concepts currently being developed by JPL were investigated for possible use in the coal to methanol plant. It was indicated that injection extruders could be developed within the next two years to feed dry coal up to system pressures of 1,000

pounds per square inch. Feeder capacities of 100 tons per hour were thought to be within practical limits.

Gasification

Material balances and utility requirements were calculated for alternate slurry feeding combinations: namely, coal-water slurry and coal-methanol slurry. Comparative economic evaluations of the two systems were initiated. Contact was established with Royal Dutch Shell in Amsterdam regarding the Shell-Koppers gasifier as it may relate to the coal-to-methanol project. Feed specifications and operating conditions were sent to Shell for evaluation.

Shift and Acid Gas Removal

The Rectisol process was chosen as the acid gas cleanup system. A "black box" flow diagram for the unit was submitted by the process licensor.

The technical and economic evaluation of various processes for removal of carbon monoxide from the Rectisol units CO_2 vent stream was completed. Initial results indicated that DuPont's "Torvex Process" for the catalytic incineration of the CO was the most attractive from both an economic and technical standpoint. However, later information from the process licensor claimed that the Rectisol units could be designed to meet expected emission standards of carbon monoxide (500 ppm maximum).

The incremental increase in investment and/or utility costs for the Rectisol Unit is expected to be lower than the cost of a CO removal unit. Therefore, the base case conceptual design will be modified to eliminate the CO removal unit. However, economic assessment data will be obtained for the DuPont TORVEX process in the event more stringent emission standards are established, thereby necessitating the use of the TORVEX Process to remove the carbon monoxide from the Rectisol Unit vent streams.

Methanol Synthesis

Reactor size optimization studies based on the Lurgi tubular type reactor were completed. The results indicated that, from a mechanical standpoint, reactor size is limited by the total shop fabricated vessel weight that can

be accommodated by major vessel vendors, both domestic and foreign. Based on this size limitation, 3 methanol synthesis reactors will be required per gasifier train, with a total of 18 required for the plant. It is assumed that no process problems would be encountered with such reactors even though they are larger than those currently being used.

During this period, a complete economic assessment data package was received from Mitsubishi Gas Chemicals pertaining to their low pressure methanol synthesis process. The MGCC investment costs are appreciably lower than the costs for the Lurgi Process; however, the lower operating costs for the Lurgi Process more than offset the MGCC investment advantage. The difference in operating costs between the two processes is attributable to the incremental credit taken for the larger quantity of excess (export) medium pressure steam generated by the Lurgi Process.

By-Product Inert Gases

The proposed commercial Coal-to-Methanol plant produces about 1.4 billion standard cubic feet per day of nitrogen and about 1.7 billion standard cubic feet per day of carbon dioxide. The sale of these streams as by-products is desirable as a means of reducing the production cost of the principle product, methanol.

Potential outlets for such large quantities of gas are oil well pressure maintenance for the nitrogen and secondary oil recovery for the carbon dioxide.

Preliminary studies indicate that nitrogen from the Coal-to-Methanol plant can be delivered to a well-head 500 miles distant at 1000 psig for about \$9 per ton. Indications are that this is not competitive with nitrogen produced from air separation plants erected in the oil field.

Studies on the utilization of by-product carbon dioxide indicate an income potential based on a delivered price in the range of 50 cents to \$1.00 per 1000 standard cubic feet of CO_2 . These prices are based on delivering the carbon dioxide a distance of 1000 miles at 2500 psig. Related to the production cost of methanol, these prices equate to a reduction in the range of 2 to 7 cents per gallon.

Badger concluded that these preliminary results warranted investigation into the economics of waste gas sales.

XX. CONCEPTUAL DESIGN FOR ATMOSPHERIC FLUIDIZED BED DIRECT COMBUSTION ELECTRIC POWER GENERATING PLANT

BURNS AND ROE, INC.
ORADELL, NEW JERSEY

Contract No.: EF-77-C-01-2455

Contract Funding: \$1,321,000
(100% DOE)

INTRODUCTION

The overall goal of this project, initiated in January 1977, is to prepare a conceptual design for an electric power generating plant that will directly combust high sulfur coal in an atmospheric fluidized bed boiler and generate electric power in an environmentally acceptable manner.

A key aspect of this effort will be the development of a generic design of a boiler. The concept and design features including the shape and size of the boiler will be new. Also, recent studies and research indicate that polluting substances can be eliminated at the combustion source by rising a fluidized bed in the coal reactor and this project is being initiated to produce a design that will allow determination of the feasibility of the direct combustion process.

The specific objectives of the contract are to:

- Produce a conceptual design for an atmospheric fluidized-bed direct combustion (AFBC) electric power plant.
- Validate and provide a generic concept and design of an atmospheric fluidized-bed boiler and peripheral equipment that will directly combust non-compliance western coal in an environmentally acceptable manner.

- Project the capital, operating and product costs for a central station electric power generating plant.

The project will be conducted through a number of tasks over a 13-month period. These tasks include:

- definition of initial plant criteria
- definition of design alternatives
- fuel preparation
- atmospheric fluidized bed boiler and accessories
- sorbent systems
- definition of major equipment and system design parameters
- specifications and equipment costs
- commercial plant design
- environmental impact
- economic analysis
- demonstration plant design
- final report and recommendation

PROGRESS DURING JULY-SEPTEMBER 1977

To date, 5 tasks of the 10 task project has been completed. These five tasks include:

1. Initial Plant Criteria
2. Definition of Alternatives
3. Fuel Preparation
4. Sorbent Systems

5. Definition of major equipment and system design parameters

Two reports were issued as a result of the work completed on Tasks 5 and 6. These were entitled "Sorbent Systems" and "System Design Analysis."

The effort continued on the other 5 tasks leaving the overall project completion at 72 percent at the end of the quarter.

The engineering and conceptual design of the Atmospheric Fluidized Bed Combustion steam generator was completed by the subcontractor, Combustion Engineering, (CE) and approved by DOE.

Based on CE's evaluation of several alternative AFBC designs of both stacked bed arrangements and single elevation of beds arrangements, a "ranch style" design was selected. This design has a single elevation of bottom-supported beds, a vertical-surface top-supported convection pass, and a separate watercooled carbon burn-up cell (CBC) section.

CE has also determined that the B&R unit will have 29 independent modules, each 9' x 36' module incorporated in the "ranch" style boiler. The operating superficial velocity is 12 ft/sec with an expanded bed height of 4 feet. Each module in the main beds contain submerged surface in the bed to maintain an overall bed temperature of 1550°F.

The 20 modules in the main beds are divided as follows: 8 beds for superheater duty, 8 beds for evaporator duty, and 4 beds for reheater duty. The low temperature superheater and reheater duty will be done in the beds while the remaining high temperature duty will be done in the boiler convection pass.

A separate carbon burn-up cell (CBC) located near the primary cyclone will be used to recycle elutriated carbon from the main beds, collected by the primary cyclone and economizer hopper. The CBC is used to reduce the overall carbon loss to 1.9 percent. There will be 4 CBC modules, completely separate from the main beds. Each 9' x 30' module maintains a bed temperature of 2000°F while running at a superficial velocity of 9 ft/sec. It was determined that some bed tubes would be required to operate the CBC beds at 2000°F. Each CBC module has an economizer section above the freeboard region which cools the exit gas to 800°F.

The bed modules will be independent fluid bed combustion units. The modules are encased in horizontal waterfalls around all beds. The bed cooling tubes which run along the length of the module act as an internal buckstay system, removing the need for outer buckstays on the waterwalls of the beds.

The relatively small size of the main beds and CBC bed modules leaves them well within the range of being all shippable, if required.

XXI. CRITICAL COMPONENT TEST FACILITY ADVANCE PLANNING FOR TEST MODULES

OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE

Contract Funding: \$280,000

INTRODUCTION

The design of plants for the production of synthetic gas and oil is currently being sponsored by DOE under an agreement for joint government and private construction funding of promising designs. The time scales for these plants require dependence on existing and near-term equipment technology, much of which has not been proved for the intended applications. The economic and environmental risks associated with dependence on available and newly developed equipment in unprecedented service applications have stimulated interest within DOE and the equipment design communities in performance, reliability, and safety testing. DOE has taken the main role in this testing because of its involvement in all areas of coal technology. In this regard, ORNL was authorized by DOE to pursue, in an accelerated time frame, an advanced planning study for the conceptual design of a test facility for evaluating demonstration-plant-scale coal conversion equipment.

The major goals of the study were to survey the range of performance criteria for several classes of coal conversion equipment in pending demonstration plants, to develop preliminary engineering concepts and cost estimates for test modules having these capabilities, and to consider the effects of an integrated test facility on site-dependent resources.

The scope of the design study did not include consideration of all components which might be deemed critical to the coal-conversion demonstration plants. For the purpose of this analysis, those components which directly affect successful operation of the process system were selected. In this category are lock hoppers valves, slurry

pumps, continuous dry-coal screw feeders, and gas-cleanup systems which were selected to define test module requirements. Testing requirements for components yielding increased process efficiency or for improved equipment currently visualized, but not yet in the market, were given less priority and were not covered in the study.

PROJECT PROGRESS

This effort was completed during the quarter and the results of the study are presented below.

Hopper Valves

The most commonly proposed method of solids feeding and removal systems for use in coal-conversion processes is the lock hopper system. Most of the pilot plants have used 4- to 8-inch pipe size valves at low flow rates relative to the anticipated conditions of demonstration- and commercial-scale plants. Typical flow rates for a single feeder in a 250-MM Btu/day gasification plant with three parallel trains would be in the range of 50 to 150 tons per hr (TPH). First-generation demonstration plants would be expected to be designed for the lower end of this range, with second-generation plants designed for the upper end. Valve sizes up to 24 inch are anticipated for commercial plants.

Coal-conversion pilot plants have experienced numerous valve problems due to erosion, corrosion, and seal leakage; the erosion problems have been particularly noticeable on valve seats and stem seals because of the

coal fines that serve as a grinding medium during valve cycle in the normal lock hopper operation. The major difficulties are associated with developing a suitable valve seat, reliable seal systems, and adequate materials to withstand the severe operating conditions. These difficulties are compounded by the back-pressure pulsing that the lock hopper valves are subjected to during each cycle. Lock hopper feed systems in the steel and chemical industry are operated at lower flow rate, temperatures, and pressures and do not appear to present the complex design problems encountered in coal-processing feed systems. The Lurgi coal-conversion plants, which have been in production for many years, use the lock hopper method of introducing coal into the gasifier; however, these systems are generally smaller, operate at only intermediate pressure levels, and restrict operating conditions, such as coal preheat temperature, to give acceptable valve life. Certain of these restrictions could be introduced into projected demonstration plants, but optimum system design and performance would not be achieved. Therefore, there is an economic incentive to develop maximum valve performance capabilities.

Most hopper valves that will be used for solids feeding and let down applications in the immediate future will be modified industrial valves. Valve manufacturers have standard recommended combinations of materials, disk assemblies, guides, and packing arrangements applicable to various process requirements. Each combination and modification responds differently in service depending upon the materials, temperature, pressure, valve orientation, loadings applied to the valve, induced vibration in the valve assemblage, and speed of operation. The lock hopper valve is in use on many commercial blast furnace systems, such as those at Port Pirie, South Australia; and lock hopper feeders have been used on pilot-plant size gasifiers, such as Synthane. Several of the coal-conversion pilot plants and process development units have used in-house-designed lock hopper systems. Most of these systems, however, have experienced many problems with valve seating and external leakage. Also, these systems are designed for lower flow rates than those required for commercial-scale coal-conversion plants. Consequently, valve improvements are needed, especially if large size valves are to operate reliably for thousands of hours.

A program is in progress at Morgantown Energy Research Center (MERC) for development of valves of the size needed in pilot and demonstration plants, and the valve designs are to be capable of scaleup to the sizes anticipated for commercial plants. The effect on various valve configurations can best be determined by establishing a highly flexible, controlled-conditions test facility to simulate coal-conversion operating conditions and installation restraints.

However, until improved valves are developed, the suitability of and constraints to the coal-conversion process imposed by the valve industry must be considered. Until the process conditions have been ascertained, a known market has been established, and valve manufacturers can be assured of a return on their investment in money, manpower, and equipment, special valves developed specifically for coal-conversion process applications will not be available in production quantities.

Valve Test Module

The hopper valve test module designed by ORNL was designed to test the following range of conditions and characteristics for valves which control the flow of solids.

- Flow materials - The test unit is planned to test valves which control the flow of pulverized coal (1/4-inch and smaller) provisions were made to include dolomite, char, ash, and etc.
- Flow rate up to 170 tons-per-hour (TPH) during a 2.6 minute open-close cycle
- Module has capability of testing valves to 24-inch size, however, a 12-inch valve will be utilized
- Pressure differential will be as high as 600 psig.
- The system temperature maximum is designed at 500°F

The scope of the tests will be to determine whether the valves can function properly under typical heads of pulverized solids, properly seal against streams of solids, accommodate large letdown pressure gradients, and seal against typical gas pressure after exposure to wear and abrasion.

The cost estimates prepared for the preliminary conceptual modules amounted to \$7,349,000. This included a 30 percent contingency factor because of the conceptual nature of the design. This cost included buildings and structures, process equipment fees, and engineering costs.

Slurry Pumps

Several of the many different proposed methods of converting coal into gaseous or liquid fuels require transfer of slurries by pumping. Slurries may be composed of various combinations of coal, char, or ash in water, oil, or solvent.

The primary reasons for testing slurry pumps is to demonstrate whether they are durable and reliable enough to withstand extended periods of operation in continuous service applications in coal-conversion processing plants. Slurry pumps can fail for the conventional

reasons that ordinary pumps do or may fail due to excessive erosion and corrosion of internal parts. For this reason, endurance testing is especially important in qualifying a new slurry pump design or in requalifying an existing design for pumping a new and different type of slurry.

There are more than 50 companies in the United States that manufacture and supply slurry pumps for moving a large variety of slurries. In practice, slurry pumping has been accomplished with varying degrees of success because of the unpredictable effects of slurry constituents and characteristics on pump components. The expansion of a coal-based energy industry will introduce more severe service requirements than are normally encountered by slurry pumps in current industrial applications. Pipeline transport of coal as a slurry is already practiced. On a recent pipeline installation in the United States, the Black Mesa pipeline in Arizona, coal is transported at a rate of 550 TPH (3800 gpm) through an 18-inch diam line over a distance of 273 miles. Slurry pumps in this type of service (i.e., coal in water at 50 percent concentration) are performing well, with a reasonably high degree of reliability. Standby pumps are provided, however, so that routine maintenance can be performed while pipeline operation continues.

Also, slurry pipelines are used in several locations in the United States and in other countries for bulk transport of limestone and concentrated iron and copper ores. These pipelines range in length from 6 to 240 miles, and diameters range from 4 to 20 inches.

In addition to long-distance pipeline transport, slurries of a wide variety are pumped in many manufacturing plants. These applications range from relatively dilute slurries to those with a consistency of paste. The slurries also vary widely with respect to abrasion and corrosion properties and to viscosity of the carrier fluid. Slurries often must be pumped at temperatures up to several hundred degrees Fahrenheit due to the need for reasonable viscosities or due to other manufacturing limitations.

The pumping of coal-water slurries at ambient temperatures might be acceptable in the present state-of-the-art except that variations in ash content and the degree of beneficiation performed can affect the abrasive nature of the coal and can also affect the slurries in which coal is used. The various coal-conversion processes involve the pumping of slurries composed of various combinations of coal, char, or ash in water, oil, or solvent.

Slurry Pump Test Module

The slurry pump test module will be capable of testing either centrifugal or reciprocating pumps. The pumping

rate may be varied within the range of 500 to 2500 gpm. The module will accept discharge pressures up to 4000 psia. For centrifugal pump tests, the suction pressure may be varied from atmospheric pressure to 2000 psia. For reciprocating pump tests, the suction pressure will be fixed at 50 psig because the reciprocating pump will be supplied with a forced circulation suction. Experience with reciprocating pumps in similar slurry services indicates the necessity of having circulation through the inlet valve area.

Slurries were considered to involve coal, char, mineral residue, or ash with either water or heavy oil. Heavy-oil slurries may be used to test pumps up to 650° F. Equipment is included to remove the solids for reuse of either the oil or the water.

It was assumed that presized dry solids could be purchased; therefore, equipment for sizing and drying is not included. Solids were assumed to be in the range of 300 mesh to 1/4 inch. An elutriator is included in the unit to allow a slight variation in the average particle size of fresh slurry.

The basis for the foregoing design capabilities was a tabulation of "at hand" knowledge of present or forecast service requirements for commercial or demonstration-size synthetic fuel coal plants. Certain adjustments to the operating ranges were necessary to keep the concept of the module reasonable. Four principal adjustments are listed below:

- High flow rates at low discharge pressure were considered a common service that did not require testing
- Flows of 4000 gpm and high discharge pressure were considered a reasonable and necessary test. However, it was felt that these rates would be produced by two or more pumps operating in parallel and that a test facility having a 2500-gpm capability would be adequate
- A service involving very low suction pressure (less than 1.0 psia) was omitted because it also involves low flow rate and discharge pressure (325 gpm and 50 psig). The assumption is that in practice, one pump will be used to remove slurry from a vacuum vessel and a second will be used to inject the slurry into another process system. It seems unlikely that complete service would be provided by one pump
- A service requiring 850° F operating temperature was also omitted because this is an extreme for a single case. Since the module involves recirculation of the slurry, this temperature would cause oil-coking problems

The estimated cost for the system is \$23,000,000. The estimate includes allowances for the special nature of piping, thermal insulation, and electrical requirements. A contingency of 30 percent was included.

Gas Clean-Up Systems

Several coal-gasification processes and pressurized fluidized bed boilers that require some form of hot gas cleanup are being developed. These processes generally operate at high temperature and pressure and include one or more power generation cycles to improve overall thermal efficiency. Power-recovery gas turbines, coupled to gasifiers or pressurized fluidized beds, are usually desired to recover some work before the off-gas stream enters a steam-power cycle or waste heat recovery process. Gas stream temperatures from several proposed high-temperature-high-pressure gasifiers range from 1200° to 2100°F which is sufficiently high to recover power using a gas turbine before entering a more conventional process. This power recovery approach is designed into several systems for some of the major gasification processes now under development or near commercialization. However, these systems require development of advanced methods of hot gas cleanup to be workable. Other high-temperature-high-pressure gasification processes now under development would probably use hot-gas cleanup methods if they were commercially available.

Gas turbine power technology is well developed for use in clean gas streams at temperatures up to around 1750°F. This technology is expected to be expanded within a few years with the development of air-cooled turbine blades. Gas turbines available today and in the foreseeable future that operate at this temperature encountered severe erosion when exposed to particulate-loaded streams. The highest temperature successfully used to date with power recovery gas turbines in dirty streams is around 1275°F. This is typically used with single-stage power recovery turbines on catalytic cracking units in the petroleum industry using two to three stages of cyclone particulate removal. The state-of-the-art for these single-stage expanders is a temperature of approximately 1275°F and a pressure ratio of 2.8. Some proposed coal conversion processes operate at pressures which would require multistage units at temperatures above 1275°F are not as tolerant of particulates and encounter more severe erosion. Thus, the temperatures for which advanced hot-gas cleanup method is needed for essentially all the processes which recover power from the gasifier off-gas stream.

Presently there is no high-efficiency equipment commercially available for application at high pressure and in the temperature range of 1200° to 1800°F. Cyclones have

been used, but they are not efficient enough for inlet streams to multistage gas turbines. The separation efficiency of cyclones decreases sharply for particles less than 5 micron (μ); particles on the order of 1 micron (μ) are essentially unaffected. Cyclones have been used for the first stage of cleanup in demonstration plants and should be tested in this facility as well as higher performance gas cleanup methods.

Coal gasification and pressurized fluidized bed process designers are faced with severe design restraints due to the unavailability of hot-gas cleanup equipment for high-pressure operations.

Among currently available equipment items, cyclones are very common particulate removal devices but have not been employed on a commercial scale for the projected combination of elevated temperatures and pressures. The most stringent common application for cyclones to date has been on fluidized catalytic cracking units in the petroleum industry at temperatures up to 1275°F.

Many kinds of filters have been designed for various ranges of conditions. The ordinary fabric filter materials, however, cannot withstand the high temperatures. Several companies are now trying to develop filters for high-temperature operations. Silica fiber and metal-felted fabric are some of the materials being investigated. Porous ceramic tubes have also been proposed. Bed filters offer another possibility of particulate removal for high-temperature service. Electrostatic precipitation is a very efficient particulate removal process at low temperatures and atmospheric pressures. In research studies the temperature limit has been raised in one case and the pressure limit in another. To date, an electrostatic precipitator that will withstand high temperature and high pressure simultaneously has not been designed but such a device is being developed.

Gas Clean-Up Test Module

The purpose of the module is to test devices which are likely to be proposed or installed to remove particulate matter from major gas streams that will be inherent in large energy plants. These devices include electrostatic precipitators (ESP), bag filters, cyclones, multicyclones, and sand filters. The core of the gas cleanup module consists of several interrelated systems. There is a 60 inch OD piping loop for gas supply to the test device with a bypass to reduce the test device flow rate. There is a gas cleaning and compression loop to provide motive power for the eductor, a solids withdrawal system and a nitrogen lock gas system, and a combustion air and LPG fuel supply system to the loop in-line burner to provide temperature control for the test gas.

The total cost for the test loop has been estimated at \$40,000,000.

Solids Feeders

Several of the more promising coal liquefaction and gasification systems depend on a feed of dry coal crushed or pulverized to a size not exceeding 1/4 inch. Depending on the process, the coal is fed progressively into a pretreater, preheater, and a gasifier or other type of reactor. These systems operate at inlet pressures up to 1500 psig, and for some systems coal preheated to temperature exceeding 250°F is desirable. The anticipated feed rate of individual feeders for future coal processing plants is 150 TPH. However, for some near-term plants the required feed rate may be only 50 TPH if multiple units are used for each coal-conversion reactor.

At present there are no commercially available, continuous dry-coal feeders for the above applications. Basically the problems are development and subsequent testing of feeder systems at existing technology levels. Because there are numerous coal processes, a variety of feed conditions must be met by commercial equipment to supply the plants of the future. For this reason several feeder concepts should be developed and tested. Table XXI-1 lists the more promising feeder concepts recommended for testing with a coal feeder module.

Present-day equipment uses the batch-feed approach to feed dry particulate material into process equipment at high pressures. To feed coal into a processing plant at 150 TPH would require enormous high-pressure lock hoppers. The manufacture and use of these would entail very high capital and operating costs. Lock hopper valve performance and reliability also present serious problems for this type of feed system because the required feed rate must be considered to be beyond the present state-of-

the-art. The valve test module is expected to resolve the valve problems, but the economic penalties make it imperative that a different approach be taken to feed commercial-size coal-processing plants of the future.

Slurry pumps represent an alternative means of providing a continuous high-pressure feed stream. There are also significant problems associated with using a slurry pump for this application, but the slurry pump test module should resolve these. However, the cost of separating the slurrying fluid and drying the coal represents a substantial economic penalty for use of this method.

At this time, continuous dry coal feeders for the application described above are of laboratory-scale size or exist only as concepts. Numerous concepts have been reviewed and the more promising ones recommended for further testing and evaluation. Extensive development and testing are required before industry will be in a position to furnish this equipment for a commercial coal plant of the size anticipated for the foreseeable future.

Laboratory-scale equipment testing is now under way through programs sponsored by DOE. The three companies participating in these programs are Lockheed Missile and Space Corporation, Foster-Miller Associates, and Ingersoll-Rand Research Corporation. These programs are covered in this publication. The results of these programs should enable pilot-plant-size equipment to be designed and tested in existing pilot plants. Demonstration and commercial plant feeders designed from extrapolated pilot-plant data should be proof-tested for performance and reliability.

ORNL defines the "module" as the operating systems within a 250-foot-high structure. From the feed bins, the solids enter the test device by gravity. They leave the test device by gravity, if necessary through the grinder, passing by gravity to the discharge lock hoppers. From the discharge lock hoppers, the solids flow by gravity to the discharge bins and then to the discharge conveyor.

Table XXI-1. Feeders Recommended For Testing

Feeder Type	Testing Proposed by	Operating Principle
Gas-solid injector	Lockheed	Jet pump
Kinetic extruder	Lockheed	Bladeless centrifugal
Fluid dynamic lock	Lockheed	Bladeless compressor
Screw type extruder	Ingersoll-Rand	Plastic extruder
Centrifugal (closed passages)	Foster-Miller	Two 180° spaced tubular passages
Positive displacement	Foster-Miller	Closed plunger, fluidized coal
Plug feeder	Foster-Miller	Reciprocating ram or screw
Pocket flight conveyor	Foster-Miller	Pockets on a chain

The design of this module is controlled by the selection of a lock hopper to discharge solids from the high-pressure outlet of the feed device. Recycling of solids to size classification and reheat is considered possible with some feed devices. To retain this capability, it is necessary to discard letdown devices based on throttling slurries. A lock hopper appears to be the only remaining option. By very preliminary examination, a 15-min. lock-hopper cycle is about the shortest that can be achieved. This cycle time sets the operating sequence and batch capacities of the feed and withdrawal equipment. The achievable cycle time for equipment as supplied sets the maximum feed rate for the test device.

The lock hoppers discharge their total load in about 5 minutes. The discharge bins accept this load and deliver it to the discharge conveyor at the steady 150-TPH rate, thus permitting consideration of the largest standard size Redler conveyor. To keep the feed bin size as low as

reasonable, the feed bins also have been put on a 15-min feed and 15-min discharge cycle.

Vessel cycles should be on automatic sequence controls. The feed rate to the test module is measured by weigh cells on the feed bins. Feed solids properties are measured by examining samples taken from the outlets of the bins. The current design does not define the means of maintaining the discharge pressure on the test device. In some cases, such a control will be inherent in the device; in others, it will probably be advisable to superimpose an inert-gas supply system onto the test-device discharge itself, with an allowance for a fairly high leak rate. The design calls for a differential pressure control between the test device and the lock hoppers during the lock hopper charging step.

Costs for the module were estimated at \$52,000,000.

XXII. HIGH BTU PIPELINE GAS, HYGAS CONCEPTUAL DESIGN

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 from that design, a conceptual design, detailed process design, and economic evaluations for a demonstration plant.

Unlike the other demonstration contracts, this project is funded only for Phase I, with construction and operation contracts to be awarded at a later date. A project schedule is given in Figure XXII-1, which illustrates the planned activities for the entire HYGAS demonstration program.

PROCESS DESCRIPTION

The process flow diagram is shown in Figure XXII-2. In the process, crushed coal from the feed hopper is screened, weighed and fed to an agitated tank, where it is mixed with light oil. A centrifugal pump feeds slurry to the suction of a positive displacement pump which discharges at high pressure into the drying bed at the top of the hydrogasifier reactor vessel. The reactor vessel has four internally connected fluidized-bed contact stages. It operates at 1000 psig and different temperature zones in the fluidized beds. The dried coal flows by gravity into a vertical lift line which is the first stage of hydrogasification. Here, coal particles are heated to 1100°F by hot

gases from the lower stage, and hydrogen contained in the gases reacts with about 20% of the coal to produce methane.

The partially reacted coal (now char) flows to the second-stage gasifier where it is heated in a fluidized bed to about 1700°F and is further gasified by the steam and hydrogen-rich gas rising from the steam-oxygen gasification stage below.

In this second stage of the reactor, temperature control is maintained by the balance exothermic producing methane and the endothermic reaction producing carbon monoxide and hydrogen. About 25% of the original coal is converted in this reaction stage, with the total conversion about 45% in the first and second stages of hydrogasification. The residual char from this stage is the feed to the final reactor stage where steam and oxygen are introduced. This stage operates at 1850°F and converts char into hydrogen and carbon oxides. Fluidizing gas velocity is sufficiently high in this stage to prevent slagging of the ash which is discharged through the bottom of the gasifier.

Ash from the base of the reaction system vessel is discharged through a solids control valve and transferred by carrier steam flow into a quench vessel at system pressure. The hot ash is cooled by contact water sprays and the carrier steam is condensed. A circulating pump provides ash-water slurry mixing and maintains even slurry consistency. Slurry concentrations of up to 30 weight percent solids can be readily handled. The coal high pressure water-ash slurry is reduced in pressure using a special tungsten-carbide coated valve and filtered

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 SHUTDOWN & OPERATION						△	▽	

Figure XXII-1. SCHEDULE

at low pressure. The filtrate is recycled to the quench vessel.

PROGRESS DURING JULY-SEPTEMBER 1977

Since the contract was not initiated until July 20, 1977, the main effort during this period has involved set up of

management teams and preparation of the Management Plan, Milestone Plan, and Manpower Plans. Initial coordination meetings were held with DOE major facilities project management and its support task force members, Institute of Gas Technology, and UOP Process Division. The project organizational period is well underway and on schedule.

Figure XXII-2. HIGH BTU PIPELINE GAS, HYGAS (PILOT PLANT CONFIGURATION)

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; $^{\circ}\text{API} = \frac{141.5}{\text{Specific gravity, } 60^{\circ}\text{F}/60^{\circ}\text{F}} - 131.5$

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.

deminerallization—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.

lignite—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.

syncrude—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.