COLLECTED WORK NO. 1

COAL CONVERSION

A presentation to the

UNITED STATES SENATE
COMMITTEE ON INTERIOR AND INSULAR AFFAIRS
SUBCOMMITTEE ON ENERGY RESEARCH AND WATER RESOURCES
WASHINGTON, D.C.

March 3, 1975

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THE RALPH M. PARSONS COMPANY
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U.S. SENATE COMMITTEE HEARINGS

March 3, 1975

Mr. Chairman, Members of the Committee, Fellow Panel Members, and Guests.

We appreciate the opportunity to meet with you and to discuss some of the work that we are doing in support of the national priority effort to develop viable coal conversion technology. I will briefly summarize here our impressions of the incentive for increased use of coal in the U.S. during the coming years, our participation in the program targeted to achieve the desired coal conversion development objectives, and comments regarding program elements considered vital to provide the information required to supply the basis for a decision regarding the role that coal conversion should play in future energy supply plans.

1. THE INCENTIVE FOR INCREASED USE OF COAL

The incentives for expanding the use of coal in the U.S. have been well documented so I will restrict comments to a brief summary as I see it.

The first key point is that government estimates indicate that the U.S. has approximately 450 billion tons of economically mineable coal reserves. This represents approximately 80% of the U.S. known fossil reserves. Even considering that production of coal will be increased, these reserves represent energy supplies for a period measured in terms of hundreds of years, and it's under U.S. control. This represents a most valuable national resource and makes coal, along with nuclear energy, a prime candidate for supplying our future energy requirements from indigenous sources.

We are not so fortunate, however, in the location and composition of our coals. More than half of it is located in sparsely populated and lightly industrialized areas in the western part of the country. Approximately 90% of the remaining coal, located east of the Mississippi River, has a sufficiently high sulfur content to prevent its meeting environmental standards when directly burned in utility boilers.

The incentive for developing coal conversion technology is therefore primarily twofold: first, to use high-sulfur coals in a manner that is environmentally acceptable and, secondly, to convert the coals that are located in isolated regions to physical forms that can be stored, or transported to consuming areas, expeditiously and economically.

Because the cost of coal conversion will be significant, the total incentive package should be demonstrated to be adequate to support the economic and total resource allocations necessary for assurance of a viable technology; prime elements of this incentive package consist of energy supplied from indigenous sources under our control, environmental factors, and logistics.

2. PARSONS ROLE IN THE COAL CONVERSION DEVELOPMENT PROGRAM

Let me tell you of some of the professional services that we are supplying to the Office of Coal Research in support of their coal conversion development program. This can provide background for later discussion.

Our work separates into two categories. The first is development of preliminary designs and economic evaluations of coal conversion processes and complexes. The output of these preliminary designs is intended to serve as further basis for planning, more detailed design, and technology assessment. The second role that we play is under the heading of Technical Evaluation Contractor whereby we supply professional services to monitor pilot plant and smaller scale experimental development activities of the coal liquefaction program. It follows that the results of this development program monitoring activity are usable in our Preliminary Design Services work.

To conserve additional time on this point, I suggest inclusion of a more detailed description of our activities as a part of the record and therefore submit that material for your consideration. This summary has been earlier transmitted to the Office of Coal Research for intended inclusion in their 1974-75 Annual Report.[1]

3. PROGRAM FOR PRELIMINARY DESIGN DEVELOPMENT

The program consists of seven designs that span a major part of the coal conversion technology spectrum. In this respect, consider that knowledge and experience gained from one process usually contribute to the state of knowledge for the total technology; I make a point that we are looking at a number of options for coal conversion that can tie together the specific information developed for the individual processes.

Let's quickly run through the designs that either have been or will be developed within the coming three years.

3.1 COMPLETED DESIGN

A design for conversion of 10,000 tons per day of coal to produce approximately 25,000 barrels per day of low-sulfur liquid fuels has been completed and the results published as OCR R&D Report No. 82, Volumes I and II. This design converts midwestern coal under conditions of elevated temperature and pressure by means of addition of hydrogen to produce the desired liquefaction, and reduce sulfur contamination to a point considered acceptable for environmental standards. It would be classified as a hydroliquefaction process.

3.2 DESIGN ALMOST COMPLETED

The second design is in the latter stages of completion preparatory to publication; this is known as the COED process and produces clean gases and liquids by carbonization or pyrolysis of the coal. This design envisions converting approximately 25,000 tons per day of midwestern coal to produce about 30,000 barrels per day of syncrude plus significant electrical energy.

[1]Ed. Note: The summary, *OCR ANNUAL REPORT - 1974, TECHNICAL EVALUATION SERVICES, CLEAN LIQUID AND/OR SOLID FUELS FROM COAL*, has been placed at the end of this reprint.

3.3 DESIGNS TO BE DEVELOPED DURING THE NEXT THREE YEARS

We are in the planning stage to develop five additional designs in the course of the next three years. The nature of the technology is described briefly below.

3.3.1 MODIFIED SOLVENT REFINED COAL (SRC) WITH SYNTHETIC NATURAL GAS (SNG) PRODUCTION

We now anticipate that this will be a conceptual design for a plant to produce 50,000 barrels per day or more of a fuel oil containing one-half of one percent of sulfur or less. It will use hydroliquefaction technology. It will also produce a significant amount of SNG and can, therefore, be referred to as an "Oil/Gas" plant. The intent is that this design will contain improvements that have been defined after analysis of the earlier described 10,000-ton-per-day design that was completed in late 1973. This design is also intended to allow further comparative studies to permit improvement of the economics.

3.3.2 FISCHER-TROPSCH

This technology is often referred to as indirect liquefaction. The basic technology was developed and practiced in Germany and is currently being practiced in the Union of South Africa. The design to be developed will explore the capability of adapting this technology to large-scale plants to produce both premium liquid fuels and significant amounts of SNG. The fuels can be classified as premium because they contain practically nil sulfur content and nil solid or particulate matter. It therefore should be of premium value when used as a blend stock with sulfur- and solids-containing fuels to meet environmental standards.

3.3.3 COAL-OIL-GAS (COG) COMPLEX

One or more designs of this type will be developed. The concept is a large, integrated multiproduct coal conversion complex. This design should incorporate matched components in a total coal conversion technology, all assembled in such a way as to maximize operating efficiency and minimize costs. It is a vehicle for assembling the best combinations of coal conversion processes with advanced power, steam generation, and environmental capabilities.

3.3.4 SOLVENT REFINED COAL (SRC)

This will again be a hydroliquefaction-type process. The SRC pilot plant located at Tacoma, Washington, is in the early stages of operation and is making progress towards achieving its process development objectives. This $18 million facility hopefully will soon reach a stable operating basis and provide required data for the preliminary commercial plant design that we will develop.

It is appropriate to mention that a smaller SRC pilot plant has been operated at Wilsonville, Alabama, for about a year now and has had extended operating periods of the order of 45 and 75 days of continuous onstream time. The Wilsonville data represent a resource that should contribute to the national program.

3.3.5 MULTIPURPOSE DEMONSTRATION PLANT

A further design will be for a coal conversion complex containing a number of liquefaction, gasification, feed preparation, and product recovery/purification process steps. It should be capable of demonstrating feasibility of a number of coal conversion process combinations; its objectives in this sense are somewhat parallel to COG. Specific selection of equipment and hardware will be a major objective later in this program.

3.4 EQUIPMENT PROBLEM DEFINITION

As the technology moves into the demonstration- and commercial-scale plant, it must have reliable equipment to perform, in many cases, under a hostile environment. Therefore, part of the program is to define, during the pilot plant monitoring and preliminary design stages, types of equipment that must either be developed or improved. Using these definitions, the very significant capabilities of the U.S. equipment development and fabrication industry and technical community must become involved. Our program is designed to contribute to definitions of the problems requiring priority attention.

3.5 ENVIRONMENTAL CONTROL

The objectives of this part of the program parallel those of equipment development. The plants are conceived to be capable of meeting current and envisioned environmental requirements. Part of the program will be to define additional effort required to assure this, and to provide sufficient information to encourage public acceptance of the technology. We think, based on data so far available, that public optimism is in order.

4. COMMERCIAL EXPERIENCE BASE FROM COAL PREPARATION, PETROLEUM, PETROCHEMICAL, AND CHEMICAL INDUSTRIES

Again, we recognize that coal liquefaction and coal gasification have been practiced on an industrial scale. This has been done in Europe and is being done now in the Union of South Africa. It also is true that a number of process steps involved in a coal conversion plant or complex have a significant experience base resulting from U.S. experience in the coal preparation, petroleum, petrochemical, and chemical industries.

This experience base can be summarized briefly by pointing out that a commercial experience record is available for the steps of mining and transportation, coal preparation, hydrocarbon hydrotreating, acid gas removal, shift conversion to produce hydrogen, carbon dioxide removal, and sulfur recovery--all to be used in coal conversion plants. In a number of cases, demonstration and some development remains to be accomplished, but this represents an extension of our current knowledge base. In another area--namely, gasification--there are commercial gasification operations existing, and the challenge is to provide second-generation technology with improved economics that we can live with in the U.S. economy. On still another point--methanation to produce SNG--there is encouraging evidence that this technology can soon reach commercial reliability basis.

5. TECHNICAL EVALUATION (LIQUEFACTION) ACTIVITIES

I will just mention here that the continual monitoring of the pilot plant and supporting program provides the basis for technical communications between the separate parts of the program as it progresses towards the point of commercialization. As the information is developed in the pilot plants, it becomes rapidly available for use in design, value comparisons, and optimization studies. It also provides development people with feedback from the engineering design and construction industry to anticipate what the designer will need to know to complete his work.

6. DEMONSTRATION PLANT PROGRAM

Pilot plant monitoring and preliminary design work described so far must have significant value in preparation for implementing a Demonstration Plant program. There are ranges of projected economics for these technologies based on small-scale and pilot plant results to date. Recognizing that bias can exist, there still remains an honest difference of professional opinion as to the performance and economic viability to be expected from commercial coal conversion plants. This condition can be expected to continue until one or more large demonstration plant facilities are built and operated for a sufficiently long period of time to show what the reliability or onstream time is, to produce enough product to define its acceptance in the market place, and to define any unusual maintenance difficulties. The major point to be demonstrated will be reliable economics for this technology.

This information, when developed, will provide a basis for industrial and government decisions as to what role coal conversion most properly should play in the future. Certainly at this point, it becomes clear that we must, by some technique, decide on the future of coal conversion. The stakes are high enough for our future energy sources that we should proceed to obtain the necessary information to provide a sound basis for decision on whether coal conversion will be a significant contributor to our future energy needs.

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OCR ANNUAL REPORT - 1974

THE RALPH M. PARSONS COMPANY

TECHNICAL EVALUATION SERVICES,
CLEAN LIQUID AND/OR SOLID FUELS FROM COAL

The Ralph M. Parsons Company provides technical assistance services to the OCR in an urgent national program for development and demonstration of viable commercial processes to convert coal to clean liquid and/or solid fuels. Parsons work encompasses the following:

- Development of conceptual designs and economic evaluations for commercial plants.
- Evaluation of pilot-plant performance and other experimental operations.
- Definition of information required for design of commercial plants.
- Evaluation of unit operations and processes for possible applications in coal processing, including design and construction of pilot plants.
- Independent evaluation of proposals for new work and proposals for changes in ongoing work.

To accomplish the described objectives, detailed professional engineering assistance was provided OCR in such fields as coal mining and preparation; coal liquefaction technology; petroleum refining; power plant design; nuclear energy applications; coal gasification; systems engineering; plant economics; environmental analysis and control; materials of construction selections; control systems design; and energy conversion efficiency analysis.

Nineteen seventy-four activities were concentrated upon critical elements of the expanding total OCR program which fall within Parsons' area of responsibility. The principal objective is rapid evaluation of laboratory and pilot-scale coal conversion data and its application to development of commercial plant designs and economics. An intermediate objective is design of demonstration plants which are forerunners of future viable large-scale industrial facilities for production of "clean" fuels from coal energy sources.

COED Commercial Plant Concept

The highest priority work consisted of development of a conceptual process and engineering design, in addition to an economic analysis, for a commercial COED-based coal conversion complex.

Design of the COED complex includes a grass roots installation located near a captive coal mine which is part of the complex. An artist's conceptual drawing is shown in Figure 1. A block flow diagram depicting major plant units is presented in Figure 2. A brief outline of projected characteristics of the facility follows:

The coal mine would have the capacity to produce approximately 13-million tons per year of run-of-mine coal. Planned facilities would prepare coal for processing by crushing, washing, and sizing. Prepared coal is suitable for feed to a pyrolyzing unit at a nominal rate of 25,000 tons per day. Coal would be pyrolyzed in a series of fluidized beds heated to successively higher temperatures. Char produced in the pyrolysis section would be gasified with oxygen and steam to produce a low Btu gas. This gas, combined with intermediate Btu gas produced in the pyrolyzer section, would be purified to meet environmental standards and used to satisfy in-plant power and steam requirements. Exportable power would also be available. Sulfur contaminant present in the feed coal would be largely converted to pure elemental sulfur which can be used as a raw material for fertilizer or process industries.

Oil produced in the pyrolysis section would be filtered to remove solids and then hydrotreated to make it suitable for sale as synthetic low sulfur crude oil. Synthetic crude oil production would be 28,000-32,000 barrels per day, depending on exact composition of coal and process conditions.

Included within the complex would be all necessary facilities for production of oxygen, hydrogen, and all required utilities as well as treatment and disposition of all waste streams.

It is estimated that the land area required for mining in a typical Eastern Region of the Interior (Coal) Province would be about 45 square miles over a twenty-year project life. In addition, an area of about 500 acres is required for the plant complex.

Coal Mining and Preparation

Since consumer cost of fuels derived from coal is highly sensitive to coal mining and preparation costs, a conceptual design and economic evaluation was developed for facilities to mine approximately 13-million tons per year of Illinois No. 6 seam coal and prepare it in a form suitable for use as feed to the coal-conversion process plants. Initial mine conceptual design/economic evaluation was used for the COED conceptual commercial plant design. Other long range objectives include development of conceptual designs and economic evaluations for mines in the four additional geographic areas--Appalachia, Feather River (western area), Four Corners, and Utah.

Mining plans and costs to supply feed to additional conceptual design plants including the SRC, Cresap-developed processes, COG, and others are to be developed. Results of a study of a mine operation to produce 24-million tons per year of coal in the Feather River area were published.

Demonstration Plant; Economics

An economic analysis was completed for a Demonstration Plant designed to produce approximately 25,000 barrels per day of low sulfur liquid products from 10,000 tons per day of coal from the Eastern Region Interior (Coal) Province. The report describing the design was published last year as OCR R&D Report No. 82, Interim Report No. 1, Volumes I and II; the economic analysis report is Volume III. An artist's conceptual drawing of the plant is shown in Figure 3.

Economics were based on mid-1973 prices. Required selling prices were estimated for several cases including government and private project ownership. An example was a required selling price of \$1.78 per million Btu (\$11.20 per barrel) for a case of private ownership involving 65/35 debt-equity ratio and a 7-1/2% interest rate. In this case run-of-mine coal was purchased at \$5.75 per ton. A 10% discounted cash flow return on equity (DCF) was used. With a 15% DCF, the price would rise to approximately \$2.10 per million Btu (\$13.20 per barrel). As discussed later, projections for larger plants indicate lower required selling prices.

Demonstration Plant; Environmental Factors

Design factors to provide assurance that coal liquefaction facilities, such as the Demonstration Plant, meet environmental standards were summarized in a report published as OCR R&D Report No. 82, Interim Report No. 3. Means of treating defined waste streams were described and a recommendation was made for procurement of additional data on quantity and composition of waste streams from future pilot plant operations.

Project Independence Blueprint

Parsons participated in Project Independence Blueprint. Preliminary definitions of facility design, capital cost, equipment items, personnel requirements, and operating cost factors were developed for plants to produce 100,000 barrels per day of 0.4% sulfur liquid fuels plus large amounts of co-product SNG.

The two processes included were modified SRC coal liquefaction and Fischer-Tropsch. Economic projections, prepared under short deadlines, were based on mid-1973 prices. For the coal liquefaction unit, the projected required selling price was approximately $1.25 per million Btu's--based on a 12% DCF, a debt equity ratio of 75/25, an interest rate of 9%, and $7.25 coal price.

On the same basis, the required selling price for a Fischer-Tropsch unit was approximately $1.40 per million Btu.

Another form of services provided by Parsons was study of required resource allocations including engineering and construction manpower, steel, national fabrication capability, aluminum, and other items. Effects of these on the national economy were considered along with the impact of construction of multiple coal-conversion plants.

SRC Pilot Plant

The construction of the SRC pilot plant at Fort Lewis, Washington, was completed during the last quarter of 1974. Parsons provided design review plus comments and recommendations in the areas of equipment design, safety, instrumentation, environmental control, material testing and operational procedure programs. Operations will be reviewed with emphasis on assuring development of data adequate for commercial plant design.

Process Evaluation/Optimization

A continuing program of process comparison is underway. Comparisons are being made at two levels: first, an initial screening effort of comparative process factors; and secondly, a more detailed preliminary design effort as illustrated by Demonstration Plant and COED designs.

A related effort is the Coal-Oil-Gas (COG) program which combines process units and concepts into large conceptual multi-product coal conversion complexes. This concept promises increased thermal efficiency and improved economy. Elements of this project include monitoring of improved coal mining and preparation pro0cedures; of advanced power cycles; and studies of improved large equipment fabrication procedures in the design effort. Of interest as possible power sources for inclusion in the COG conceptual designs are potassium-steam topping cycle, pressurized fluid-bed boilers as well as coupling nuclear plants with fossil conversion facilities.

Fischer-Tropsch

Two preliminary assessments of Fischer-Tropsch technology have been completed. One was based on use of a single large shop-fabricated suspension-type gasifier to process 3,500 tons per day or coal. The objective was to investigate the place of Fischer-Tropsch technology in future U.S. synthetic fuel production schemes and, if affirmative, to further define its role.

The preliminary design envisioned a plant to produce approximately 2,325 barrels per day of fuel oil and 60-million SCFD of SNG. Estimated fixed capital investment, based on a four-year project schedule starting January 1, 1974 with some allowance for escalation, was $175 million. Profitability estimates were based on arbitrary fuel oil values of $9.50 and $14.00 per barrel for oil in 1980 and 1985. Results indicate a discounted cash flow (DCF) of 6+% for 100% equity financing for this small plant.

Projected economics for a very large Fischer-Tropsch during Project Independence Blueprint were described above in this summary.

Proposal Evaluation

More than 25 proposals sent to OCR by various companies and institutions were reviewed at OCR request and recommendations made regarding their value in achievement of OCR's goals to develop viable coal-conversion technology to produce clean fuels. Review criteria encompassed overall program work duplication avoidance; technical and economical validity; soundness of objectives and ecological compatibility. Alternate and corrective suggestions were made where proposals required clarification of economics, duplication of program work, or technical support to meet or augment general overall technological aspects of the OCR coal conversion program.

Coal Conversion Plant Design Criteria Definition

The program for optimization of large-scale oil/gas coal processing complexes for each geographical region of the U.S. has continued. The compilation of pertinent information consists of coal and water resources and their consumption for various processing schemes. Equipment design, product characterization, product functional performance and economics data are being expanded. Computer-based estimation of fixed capital investment and means of determining potential profitability, specifically as applied to coal conversion plants, have been refined and improved. Analysis of separate design-factor disciplines such as environmental control; construction materials; equipment fabrication factors and process control procedures continue at an accelerated pace. Work is in progress to develop mathematical simulation models to speed design and process comparisons efforts.

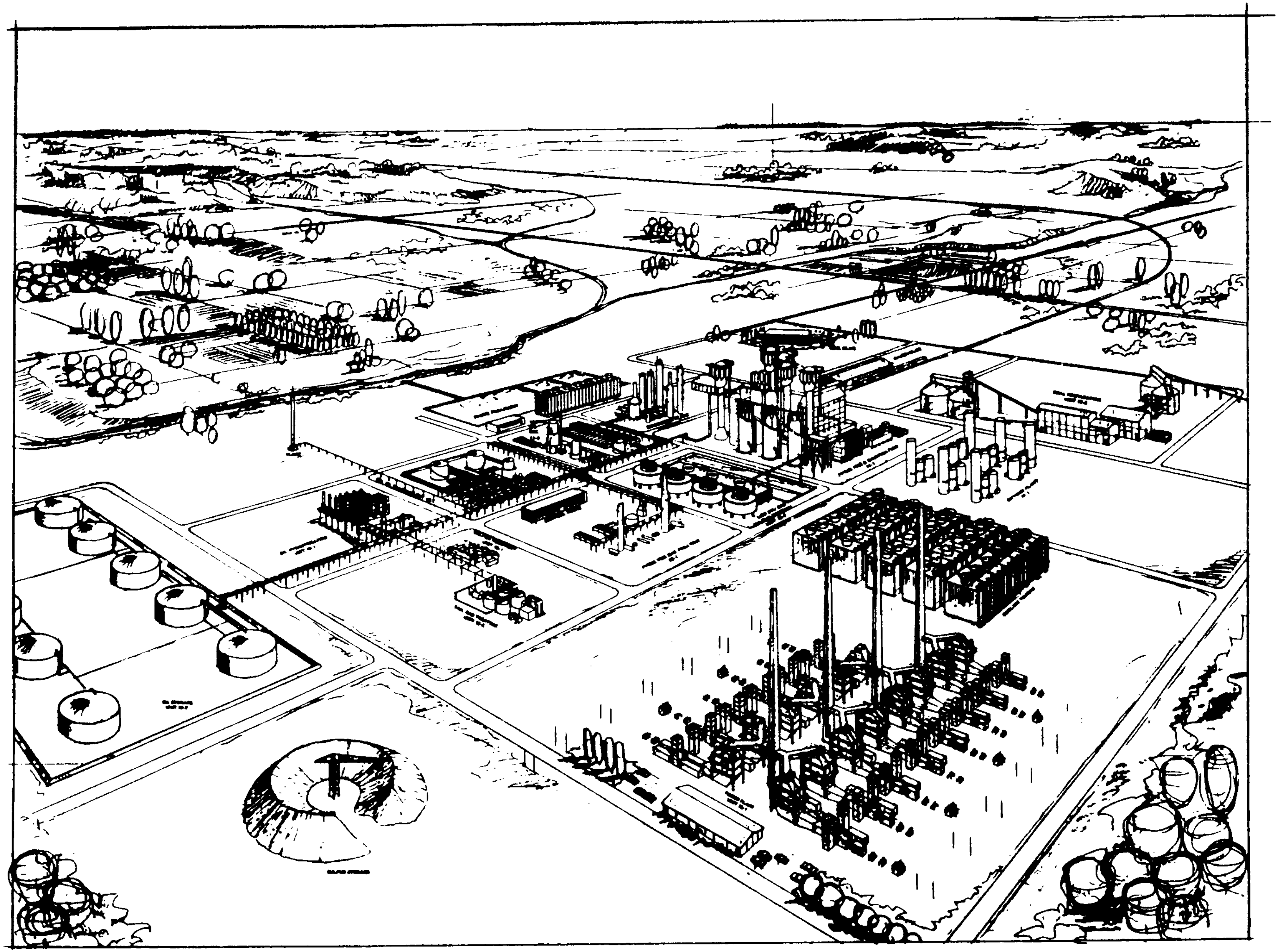

Figure 1. Artist's Concept of Combined Clean Fuel/Power Facility
COED Process

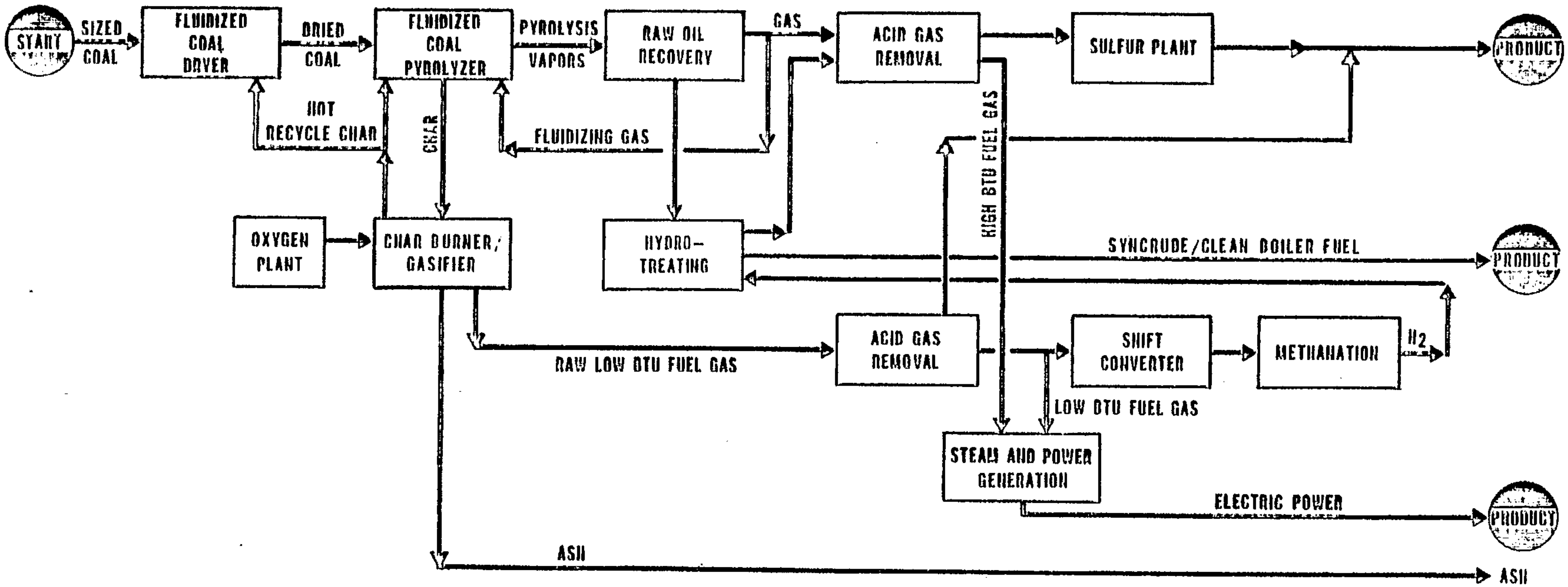

Figure 2. COED Process
Combined Clean Fuel/Power Facility

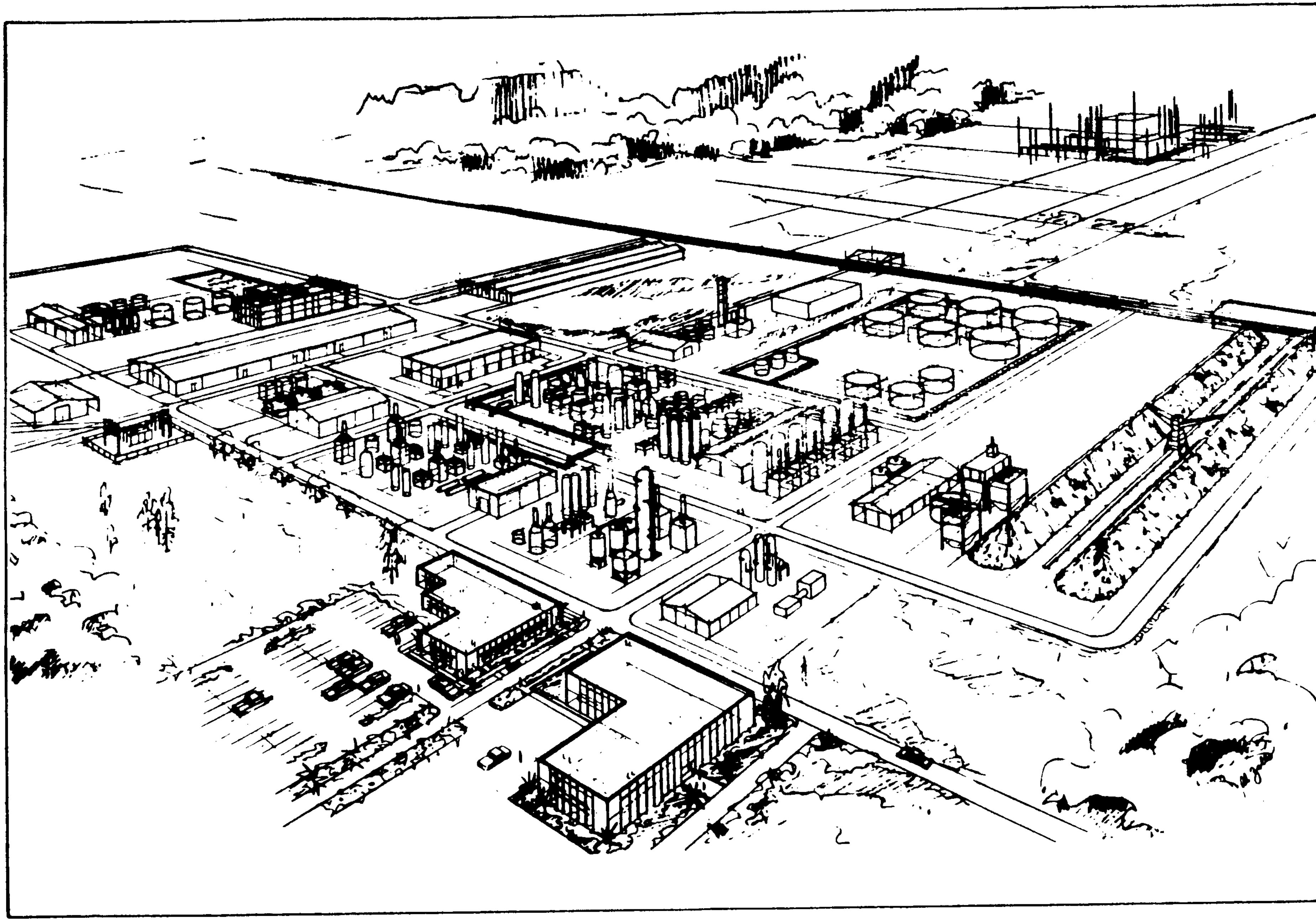

Figure 3. Artist's Concept of Typical
SRC-Based Oil/Gas Plant

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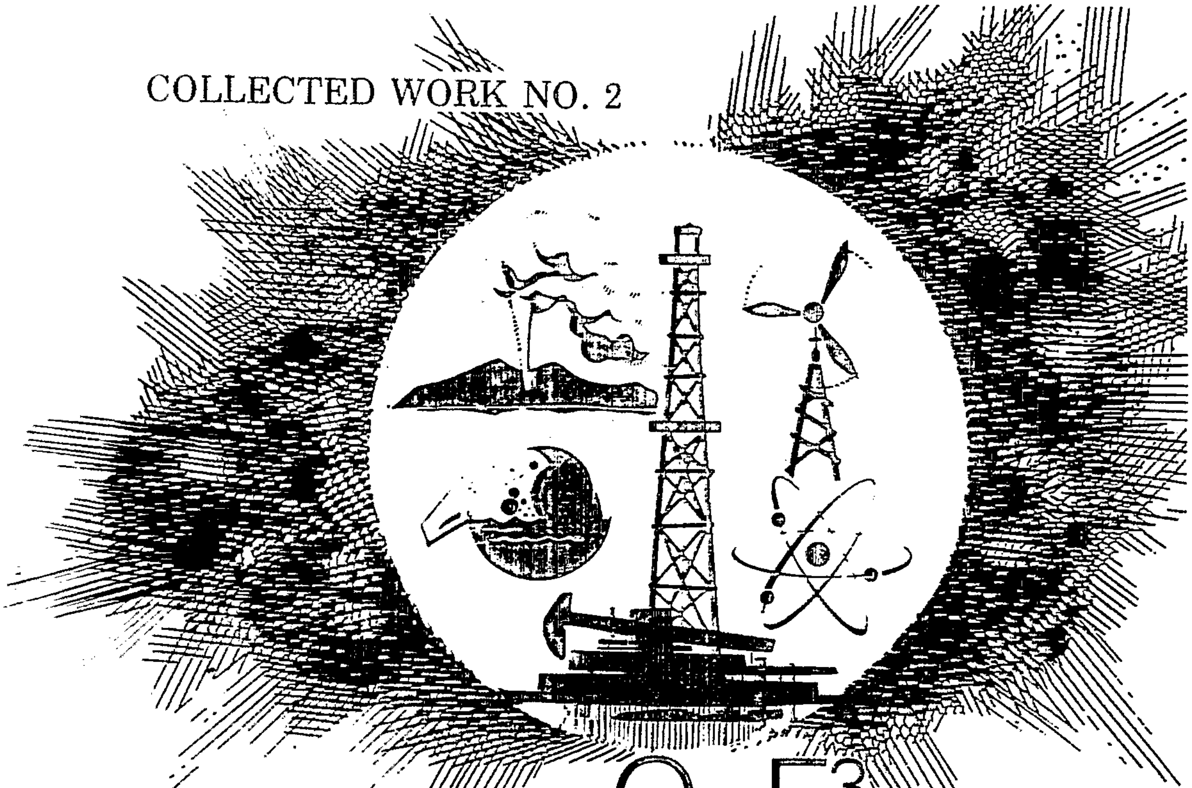

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COAL CONVERSION: AN OVERVIEW OF STATUS AND POTENTIAL

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Abstract

California and the U.S. need new sources of energy to sustain economic viability and future growth. Two of the high-potential means of augmenting existing indigenous supplies are coal and nuclear energy. Historically, coal has supplied less than 1% of California's energy needs because of lack of known commercial coal deposits within the state and environmental reasons. However, coal represents the largest fossil fuel reserve in the United States, and there are vast deposits in the western states. Potentially this coal can be converted to liquids such as synthetic crude oil, fuel oil, and gasoline or to substitute natural gas (SNG) and brought to California. The Ralph M. Parsons Company is active in assisting the Office of Coal Research to develop viable technology for production of environmentally acceptable fuels from coal.

This paper summarizes the characteristics of principal coal conversion technologies and their potential for supply of energy in the form of "clean" liquids and gases. These coal-derived products represent key candidates for future energy supply from indigenous resources; the achievement of the goal of development of a viable commercial industry has become a national objective.

1. INTRODUCTION

The development of additional indigenous sources of environmentally acceptable fuels has become a national priority. This has been caused by long-term trends of increasing U.S. total energy demands, decreasing supply of crude oil and natural gas from domestic wells, and continued pressures to improve the environment. The net result has been increasing reliance on imported energy and projections of adverse economic results if current trends are allowed to continue.

The foregoing national energy trends and implications, in general, apply also to California.

1.1 EXPANDING THE ENERGY SUPPLY

Two primary candidates for expanding our domestic energy supply are coal production and nuclear generation. This paper will discuss the need for additional energy, with particular attention to the California scene, and the potential role that coal and coal conversion including liquefaction and gasification might play in the future energy supply/demand scenario.

The Ralph M. Parsons Company, active in the national coal-conversion development program is charged with responsibility to assist the Office of Coal Research in its program to speed the development of viable, commercial coal-conversion technology. We acknowledge the support and guidance of the Office of Coal Research (now a part of the Energy Research and Development Administration) in our work.

1.2 COAL CONVERSION DEFINED

Coal conversion as used in the context of this presentation means the transformation of coal from its solid form to a liquid, gaseous, or low-ash solid product which will meet environmental standards. In the case of high-sulfur coal, the conversion process will reduce sulfur content of the product to a satisfactory level.

1.3 WHY COAL CONVERSION?

The simplest thing to do to obtain energy from coal is to burn it! However, there are incentives to convert it to "clean" liquid, gas, or solid forms. One is to meet environmental standards and another is to put it in a more convenient form for shipment and storage near the point where it will be consumed. The incentives must be significant enough to justify the conversion because it requires considerable economic input and effort in order to convert the coal to these more desirable forms.

2. CALIFORNIA'S ENERGY NEEDS

Historically, the State of California has been a large energy user, consuming almost 9% of the total U.S. energy consumption. It has a broad growing range of industrial, commercial, and agricultural activities requiring energy to sustain its economic viability and growth. Figure 1 projects California's demand for energy; its supply from indigenous State sources including geothermal, hydroelectric, and other; and forecasts shortfall in energy supply.[1] Figure 1 does not include the effects of the completed pipeline which will carry Alaskan crude to California ports, and is expected to have a major impact on supply. The projections confirm California's requirement for supplemental local energy sources in coming years.

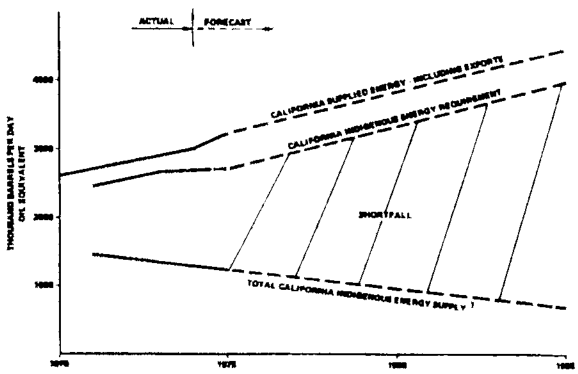

FIGURE 1. CALIFORNIA ENERGY SUPPLY AND DEMAND

A similar view of demand and supply of liquid products from indigenous California sources is shown in Figure 2.[1] Here again there will be a shortfall until the Alaskan product begins to appear in California ports; the amount of Alaskan crude that will stay in California remains to be seen. Without the Alaskan contribution, California faces a continually increasing demand for liquid petroleum products during a period when production from its own fields is expected to continue to decline.

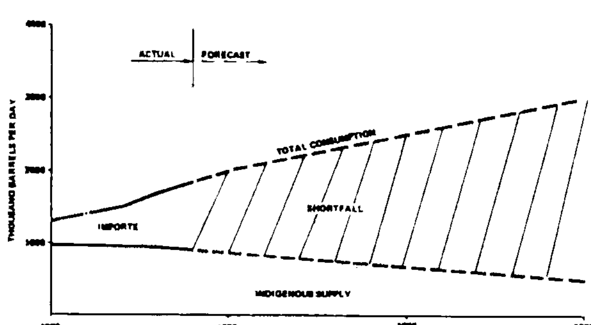

FIGURE 2. CALIFORNIA CRUDE OIL CONSUMPTION VS. INDIGENOUS SUPPLY

Demand-indigenous supply information for natural gas is shown in Figure 3.[1] Since natural gas has been the preferred energy source because of price, convenience, and ecological reasons, demand has been high. However, the indigenous supply has continued to decrease, leaving a significant shortfall in supply which has been supplied by imports from other states and by foreign imports, each of which presents uncertainties for future supply.

The conclusion to be drawn from this brief survey is that California has an incentive to continue to look for reliable supplies of "clean" energy in the forms of liquids and gases at an economically acceptable price. Coal conversion products offer one of several means for supplying this demand.

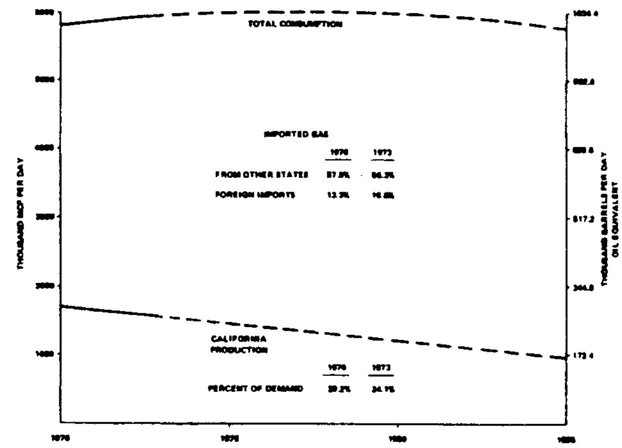

FIGURE 3. CALIFORNIA NATURAL GAS CONSUMPTION VS. INDIGENOUS SUPPLY

Let's now look at the potential for coal to supply an increasing percentage of the energy requirements.

3. COAL: A MAJOR NATIONAL RESOURCE

Coal is our most abundant fossil-fuel resource in the United States. One source[2] indicates that we have approximately 450-billion tons of proven reserves which are economically mineable using current techniques. At the current rate of U.S. coal consumption — approximately 600 million tons per year — these reserves would last for approximately 750 years. From another perspective, these proven reserves would supply the *total* energy requirements of the United States for approximately 150 years.

On this basis, coal must rank with nuclear energy as a prime candidate to supply future incremental energy requirements from domestic sources in the United States.

4. COAL: POTENTIAL AS AN ENERGY SOURCE FOR CALIFORNIA

California has nil proven coal reserves. Historically, coal has supplied less than 1% of California's total energy needs.[3] Nevertheless, more than half the U.S. coal reserves are located in the western United States as illustrated in Figure 4. Coal could make a significant contribution to California's future energy needs but this will require a significant change in logistics, technology, and economics.

Coal liquefaction offers a potential supply of liquid fuels that can replace petroleum crude oil products. Liquids could be produced close to the coal mine site and then efficiently transferred, by pipeline or other means, to the California use point. Coal gasification also offers potential: a possible procedure consists of

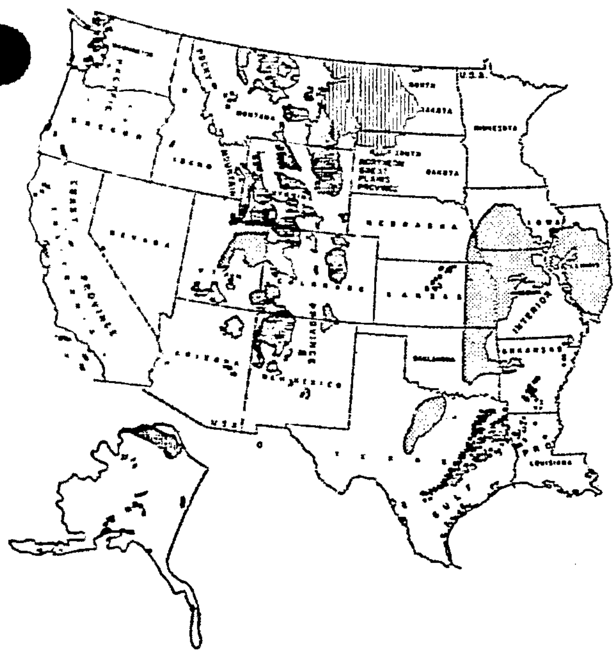

FIGURE 4. COAL FIELDS OF THE WESTERN UNITED STATES

gasification and production of high-Btu or substitute natural gas (SNG) near the coal mine and then transporting the SNG through existing or new pipelines. Still another possibility is the production of low-Btu gas near the coal source and its conversion into electrical energy which, in turn, would be carried by transmission wires to the California market.

5. THE U.S. COAL CONVERSION DEVELOPMENT PROGRAM

5.1 PAST COAL CONVERSION TECHNIQUES

Before discussing the development of second- and third-generation coal conversion technology, we should recognize that both coal liquefaction and coal gasification have been practiced in the past, and continue to be used today, on an industrial scale. During World War II, the Germans produced a major part of their aviation gasoline using liquefaction technology based on hydrogenation of coal. They also produced some liquids by indirect liquefaction using Fischer-Tropsch technology; here coal is first gasified to form an intermediate gas mixture called "synthesis gas" which, in turn, is recombined under selective conditions to produce the desired type of liquid product.

Coal gasification has been widely used throughout the world including the United States. The United States has built and operated literally thousands of producer gas units to convert coal to a gas product which could be treated to be used as a fuel or as an intermediate for production of chemicals such as ammonia and methanol. Major cities in the United States as late as the early 1950s depended on the conversion of coal to gaseous products to feed pipelines distributing gas to commercial, industrial, and residential users.

5.2 CURRENT COAL CONVERSION OBJECTIVES

Recognizing that coal conversion to liquids and gases has been practiced, the objective of the current U.S. coal conversion development program is to improve the economics, efficiency, reliability, and in many cases, the size and capacity of the units. The concept of economic viability has, in fact, recently been a moving target; energy values have risen from the low levels which existed in the United States until recently to the current values with the probability of higher future costs.

A significant program is under way to develop viable commercial processes for coal conversion. In the past, the U.S. Bureau of Mines has expended more than $100 million in developing the technology. The Office of Coal Research which was formed in 1961 with a prime objective of fostering development of viable coal conversion technology has committed more than $500 million to date and authorized work on more than 170 separate development contracts. Staffing has increased approximately ten times since 1970. The program is expanding under the auspices of the Energy Research and Development Administration where the proposed Fiscal 1976 budget for coal R&D is approximately 280-million dollars, up 60% from estimated Fiscal 1975 expenditures.

5.3 SUMMARY

It is generally accepted that coal must make a significant contribution to our expanded energy needs. Achievement of this objective has been given a high priority by the executive and legislative branches of government. Major elements of both U.S. industry and government now are participating in this broad program. The challenge is to find conversion methods that will result in usable products at a competitive price.

6. PARSONS ROLE IN THE COAL CONVERSION DEVELOPMENT PROGRAM

The Ralph M. Parsons Company is active in a role to assist ERDA to develop commercial plants for the conversion of coal to clean fuels. There are two distinct activities involved in this role. They are:

(1) Parsons supplies Preliminary Design Services in which it develops preliminary/conceptual designs and estimated economics for commercial plants. An example of this is illustrated in Figure 5 which shows an artist's sketch of a plant to convert approximately 10,000 tons per day of high-sulfur coal to about 25,000 barrels per day of low-sulfur

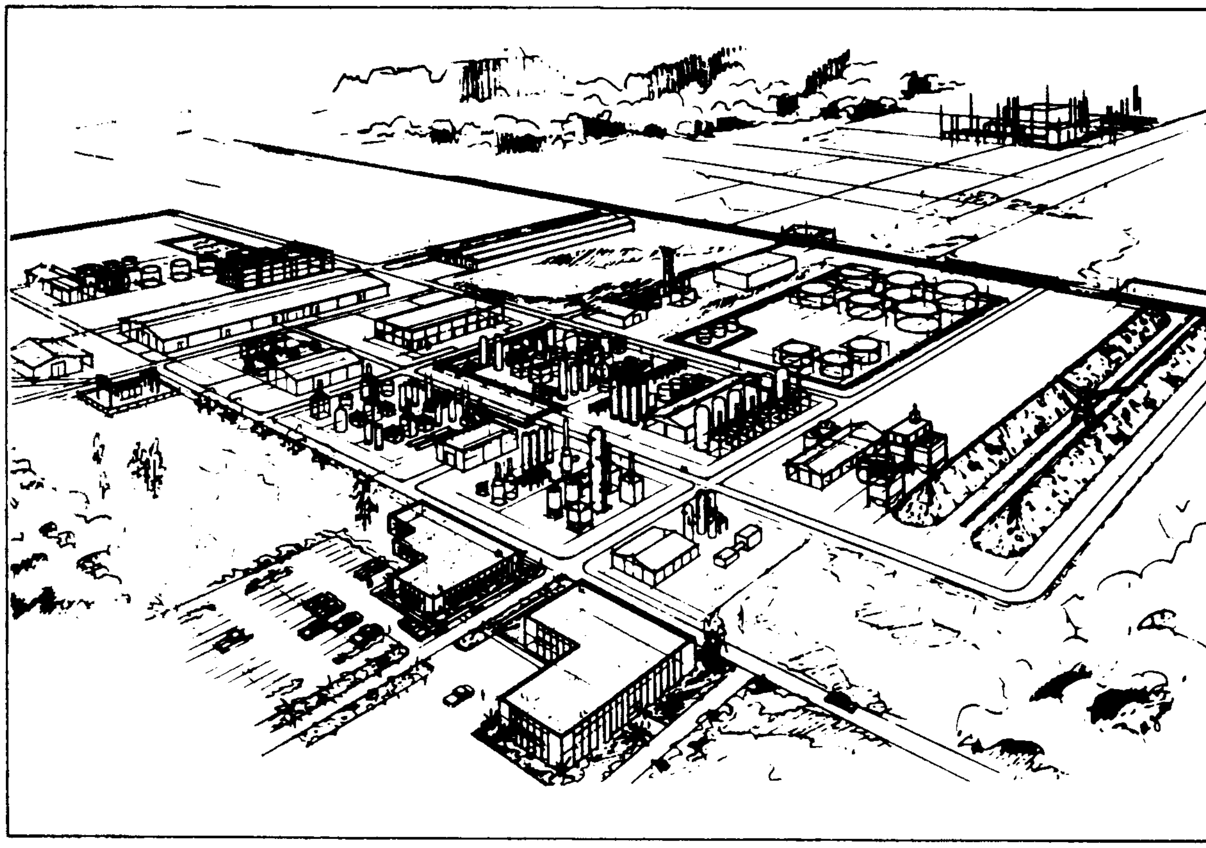

FIGURE 5. ARTIST'S CONCEPT OF A COAL LIQUEFACTION PLANT

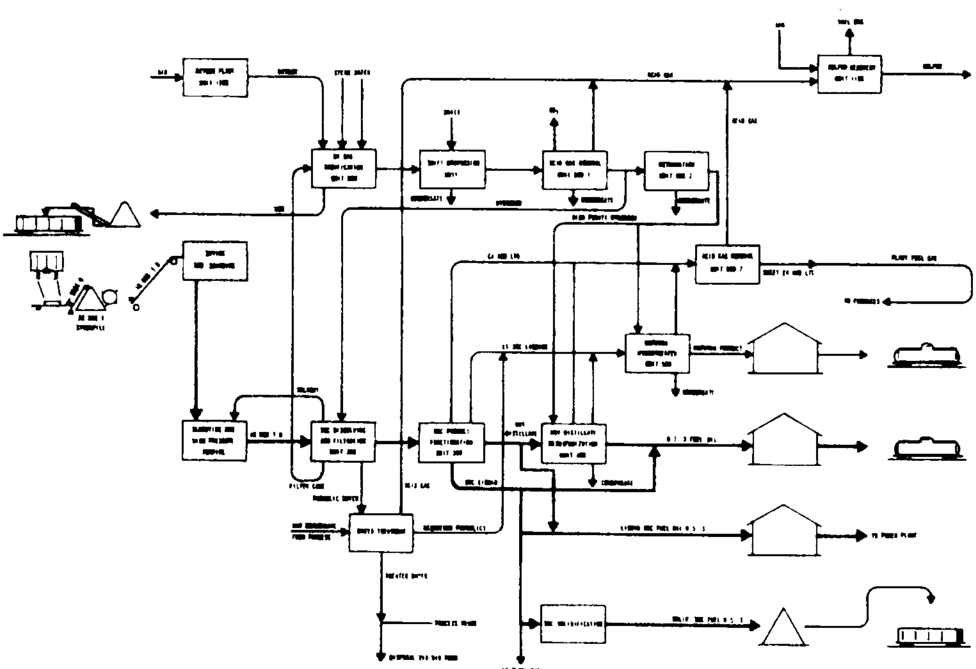

FIGURE 6. LIQUEFACTION PLANT PROCESS SKETCH

liquids consisting of fuel oil and naphtha. Figure 6 indicates schematically the processing steps which would be required in order to achieve this liquefaction result.[4]

(2) Parsons also supplies services to OCR as a Technical Evaluation Contractor for the Clean Liquid and/or Solids Coal Conversion Development Program. In this role, Parsons monitors the major coal liquefaction pilot plants and provides professional services to assist OCR in advancing these programs.

To summarize, Parsons is active in the experimental program, development of the preliminary/conceptual design of commercial facilities, and development of economic estimates for these plants.

7. CLASSIFICATION OF COAL CONVERSION PROCESSES

For the sake of convenience, coal conversion processes may be classified as shown in Figure 7. The major classifications include gasification, liquefaction, and pyrolysis.

I. GASIFICATION
   - A. HIGH BTU
   - B. LOW BTU

II. LIQUEFACTION
   - A. HYDROLIQUEFACTION
   - B. INDIRECT (EXAMPLE = FISCHER-TROPSCH)
   - C. EXTRACTION
   - D. PYROLYSIS
   - E. DIRECT

FIGURE 7. COAL CONVERSION PROCESSES CLASSIFIED

7.1 GASIFICATION

The gasification of coal, raw materials, and product gas/components are shown in Figure 8. Gasification processes may be further subdivided into high-Btu, which produces a product that may be used as a replacement for natural gas and can be referred to as substitute natural gas (SNG), and low-Btu. The latter classification includes intermediate-Btu gas in the range of 500 Btu per cubic foot (about half the heating value of SNG) and utility-type gas, with Btu content in the range of 100-350 Btu which can be used locally as an energy source for close-coupled electrical power generation.

The production of liquids can be achieved in a number of ways. The key to liquefaction is illustrated in Figure 9; hydrogen is added to the coal in order to increase the ratio of hydrogen to carbon.

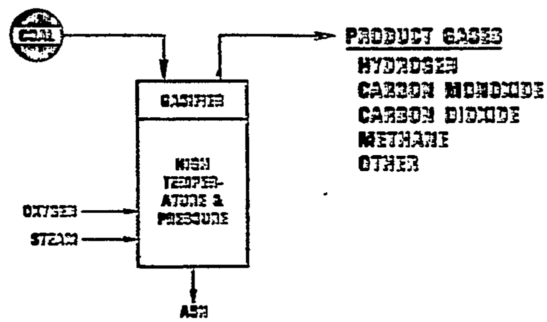

FIGURE 8. GASIFICATION: GENERAL SKETCH

The ultimate source of the hydrogen is water. One way to produce the hydrogen is by gasification of coal or a coal residue. The liquefaction can be accomplished in several ways. In hydroliquefaction, a finely divided coal is fed in the form of a slurry in a coal-derived liquid to conversion equipment, with or without catalyst, where it is contacted with hydrogen at elevated temperature and pressure; examples of the latter may be 850°F and 1,500 pounds per square inch. The addition of hydrogen to the coal results in production of a liquid or near-liquid product.

A second category of liquefaction is known as indirect liquefaction; an example is the Fischer-Tropsch technology which is currently being practiced in the Union of South Africa. In this procedure, the coal is converted by an initial gasification step into building blocks known as synthesis gas which contains primarily carbon monoxide and hydrogen.

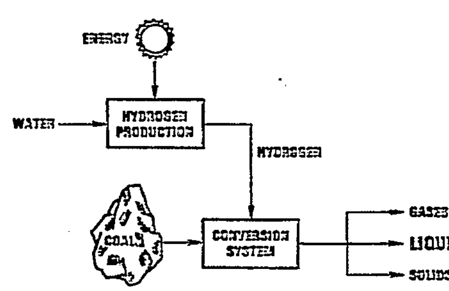

FIGURE 9. LIQUEFACTION: SIMPLIFIED SKETCH OF OBJECTIVE.

Following removal of contaminants such as sulfur, these building blocks are then rebuilt into liquid products in a conversion system. This technology has a great deal of flexibility. It can produce a liquid where the heavy fuel oil components dominate or, alternately, it can emphasize products in the gasoline range. The liquid products have nil sulfur content.

A third method of liquefaction involves direct hydrogenation of coal. Experimental evidence indicates that this can be achieved by proper selection of conditions and equipment. Existing experience is on a relatively small scale.

As mentioned earlier, initial hydroliquefaction is accomplished with or without an added catalyst. To speed up the reaction and add more hydrogen, catalysts used for hydrotreating operations in the petroleum industry have been used; they accelerate the reaction rate of the coal with hydrogen and, in general, result in greater hydrogenation; saying it in another way, the catalytic processes tend to produce a lower boiling liquid product. Research is underway to develop improved catalysts.

7.3 PYROLYSIS

The last classification is pyrolysis. Here the feed coal is heated to remove the volatiles and produce a gas, a liquid, and a residual char. The pyrolysis can be carried out in the presence of a hydrogen-rich gas stream in order to increase the yield of oil. The coal is most often suspended in a gas stream by a fluidization technique; either dense or dilute phase fluidization procedures can be used.

8. GASIFICATION

Let's now look at gasification and consider what it accomplishes, and a few of the types of processes that have been used commercially or are under development. Incentives for converting coal to gas are to make it environmentally acceptable and to change it into a physical form that is preferable for distribution and use. On the first point, coal contains a significant amount of ash which is inorganic material and when burned, may create a fly ash which, if not removed from the combustion gases, can affect the local environment as it leaves the stack, and complicate the combustion process. Coal also has a high sulfur content which upon combustion is converted to sulfur dioxide, sometimes an environmental negative. The gasification of coal eliminates these negatives.

The typical transformation of coal from a solid product to a gaseous product is accomplished by the chemical transformation illustrated by the several equations shown in Figure 10. Here we see that the carbon in the coal will react with steam to form carbon monoxide plus hydrogen. This reaction absorbs heat; therefore, oxygen, either in the form of air or as an enriched oxygen stream, is added to the reactor to react with carbon to produce carbon dioxide and the heat required to sustain the reaction temperature.

$$C + H_2O = CO + H_2 - HEAT$$

(CARBON) (STEAM) (CARBON MONOXIDE) HYDROGEN

$$C + O_2 = CO_2 + HEAT$$

(CARBON) (OXYGEN OR AIR) CARBON DIOXIDE

FIGURE 10. GASIFICATION REACTIONS, SIMPLIFIED

9. CLASSES OF GASIFICATION PROCESSES

For our discussion, the gasification processes can be divided into two classes; those that have been used commercially, and the so-called second generation processes that are under development in the U.S.

9.1 COMMERCIAL PROCESSES

Examples of the commercial processes follow. (No inference regarding relative merit is intended in this discussion.)

9.1.1 COMMERCIAL MOVING BED GASIFIERS

Commercial moving bed gasifiers have been used; an example is the Lurgi Gasifier. It operates at a pressure of approximately 400 pounds per square inch and a temperature in the range of 850 to 950°F. The coal is fed to the gasifier by means of lock hoppers in which the feed coal is alternately pressurized and depressurized by the movement of valves at the top and bottom of the lock hopper; coordination of these pressure changes feeds the coal to the gasifier intermittently at an appropriate average rate. The unreacted ash is removed through a grate at the bottom and is ejected from the gasifier through lock hoppers. The coal is stirred by mechanical motion in the gasifier.

Most commercial experience has dealt with noncaking coals with fines removed. Recent work has been directed to develop procedures for use of caking coals. The gas from the gasifier unit may have a Btu content in the range of 180 to 300 Btu per cubic foot depending on the concentration of oxygen fed; it contains primarily carbon monoxide, carbon dioxide, hydrogen, methane, and nitrogen if air-fed. The raw gas also contains unreacted steam, oils, tars, phenols, ammonia, sulfur compounds, and dust from the coal and ash which must be removed.

Raw gas from the gasifier may be cleaned up and used as a low-Btu gas to fire boilers or close-coupled to a combined gas turbine-steam turbine electrical generation system. It may also be purified, subjected to a methanation step, and dried to produce SNG.

9.1.2 COMMERCIAL ENTRAINED GASIFIERS

Commercial *entrained*, slagging-type gasifiers are also in operation outside of the U.S. An example is the Koppers-Totzek process. This technology entrains finely ground coal with the oxygen and steam feed streams. It can satisfactorily process highly caking coals and produces an intermediate-Btu gas having a heating value of approximately 300 Btu per standard cubic foot. Early development work was done by the U.S. Bureau of Mines at Louisiana, Missouri in 1949; sixteen plants have been operated abroad.

This type gasifier operates at a bottom temperature greater than 3,000°F and the ash is removed in the molten, or liquid state. The gas exits from the gasifier at approximately 2,700°F, a temperature significantly higher than used in the moving bed gasifier. Units operated commercially have processed approximately 850 tons of coal per day and the output of 17 gasifiers would produce 1,000 megawatts of electrical power.

The product gases are processed to remove heat and scrubbed to remove sulfur compounds and solid particulates; they can be further treated to produce SNG by methanation.

9.2 U.S. GASIFICATION DEVELOPMENTS

Examples of second-generation gasification processes under development in the ERDA program are the Hy-Gas, Bi-Gas, CO_2 Acceptor, Synthane, and Battelle Memorial Institute ash agglomerating processes; there are at least five other processes in various stages of development. Brief descriptions of the first three will be given. Again, no judgment regarding relative merits of the processes is to be inferred from those mentioned or described.

9.2.1 Hy-Gas

The *Hy-Gas* process is under development supported by a combined ERDA/AGA (American Gas Association) program. The pilot plant is located at Chicago; it uses fluidization techniques to contact the coal with reactant gases in several discrete stages. It operates in the pressure of approximately 1,000 pounds per square inch.

A sketch of the gasifier is shown in Figure 11.[5] In the top, or slurry drier stage, the pulverized feed coal is fed as a slurry in a light oil and is contacted with a hot synthesis gas; here the slurry oil is vaporized, the coal is devolatilized and reacts with the fluidizing gases to form methane, the prime constituent of SNG, plus other gas components. The gasifier effluent can be processed by quenching, purifying, and methanating to convert it to SNG.

Proceeding down the gasifier, the partially reacted coal is next further reacted with synthesis gas in a "lift pipe" type first-stage hydrogasifier conversion section. Here the coal is suspended in the hydrogen-containing synthesis gas to provide high reaction rates.

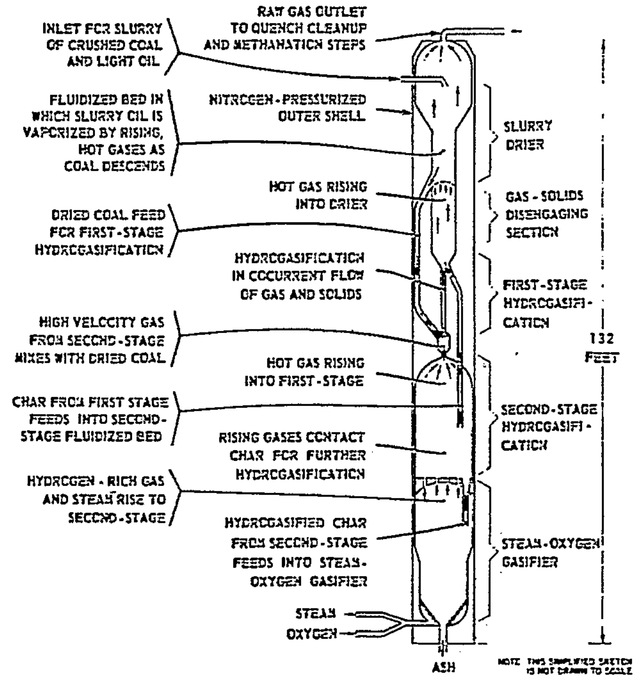

FIGURE 11. HY-GAS PILOT PLANT GASIFIER SKETCH

The solid product from the first-stage hydrogasifier section next passes downward to the second-stage hydrogasifier fluidized bed where is again is contacted with hydrogen-containing gases; the unreacted coal, known at this point as char, is removed and used as a raw material for syngas production.

Synthesis gas can be produced from char by several alternate procedures. One is reaction with steam and oxygen in a fluidized bed. This procedure is under development in the pilot plant stage.

9.2.2 Bi-Gas

The *Bi-Gas* process is to be tested in a pilot plant under construction at Homer City, Pennsylvania; it is a part of the ERDA/AGA development program. The gasifier, illustrated in Figure 12,[6] is a two-stage entrainment type unit designed to be operated at pressures up to 1,500 pounds per square inch and at bottom temperatures greater than 3,000°F to provide slagging conditions.

Coal is fed to the top or first stage where it is entrained and gasified by synthesis gas produced in the lower or first stage. The first stage, at slagging temperature, reacts char, recovered from the first stage gas stream, with steam and oxygen and supplies the synthesis gas that is produced to the first stage. The gas produced in the gasifier should have a heating value of approximately 380 Btu per standard cubic foot when using oxygen and is characterized by a desirable high methane content. This type gasifier offers promise of highest unit capacity based on the tons of coal to be processed per day per ton of gasifier equipment

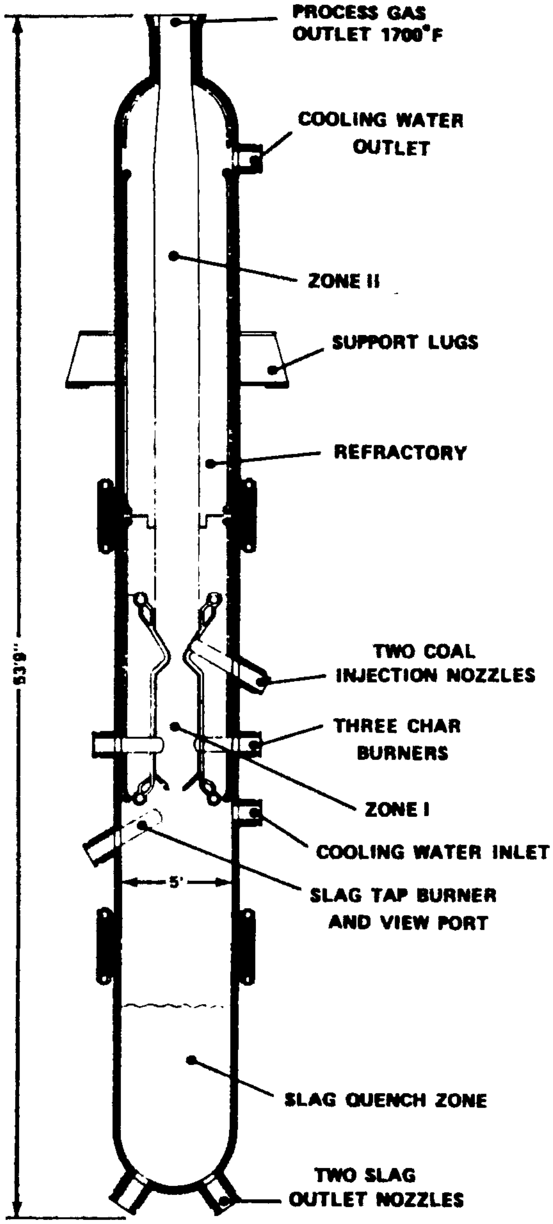

FIGURE 12. BI-GAS REACTOR SKETCH

required. The gasifier product can be purified and converted to SNG.

9.2.3 CO_2 Acceptor Process

A 40-ton-per-day coal feed pilot plant to develop the *CO_2-Acceptor* process, the third of the new generation processes to be described here, is in operation at Rapid City, South Dakota; it also is under the ERDA/AGA program. Its characteristics are described in Figure 13.[7] Recent test results have been obtained at a pressure level of 150 pounds per square inch and a gasifier temperature of the order of 1,500°F.

As mentioned earlier, the reaction of steam with carbon to form hydrogen and carbon monoxide (synthesis gas) requires heat. In the Hy-Gas and Bi-Gas processes, this heat is supplied by burning a portion of the carbon. In the CO_2 Acceptor process, the heat is supplied to the gasifier section by liberating heat when either calcium oxide from lime or a mixture of magnesium and calcium oxides from dolomite are reacted with carbon dioxide to form carbonates. The reaction gives off the heat required to counterbalance the heat requirement of the synthesis gas reaction shown earlier. The process offers the potential for producing a gasifier effluent gas composition which can be sent directly to the methanation step after removal of solid carryover.

The carbonates produced in the gasifier are reconverted to the oxide form in the regenerator by burning char produced in the gasifier. By this procedure, air instead of oxygen can be used and still not contaminate the product gas with nitrogen from the air.

10. LIQUEFACTION

The proposed ERDA fiscal year 1976 budget calls for an expenditure of almost 100 million dollars on liquefaction development. There are several process candidates and operating pilot plants in the field. Examples of technology candidates including SRC, modified SRC,H-Coal, CSF, and COED are described in the following sections.

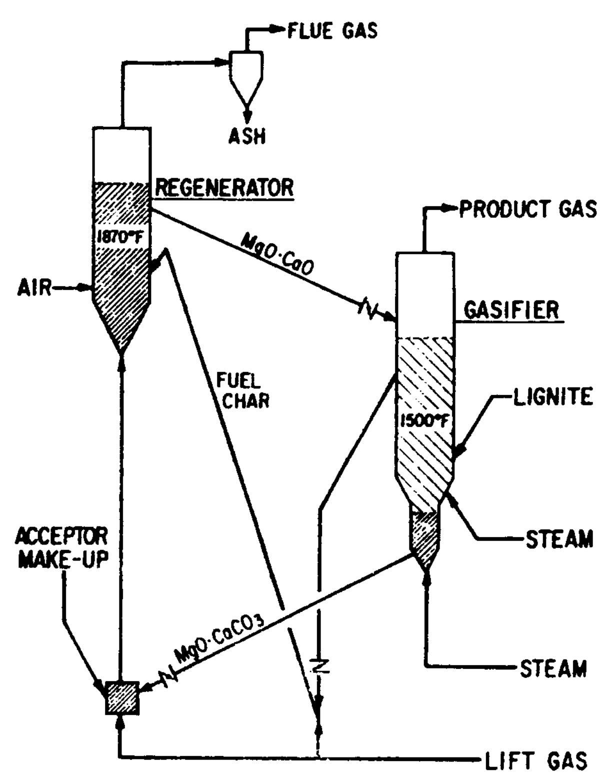

FIGURE 13. CO_2 ACCEPTOR PROCESS SKETCH

10.1 SOLVENT REFINED COAL (SRC)

The SRC process is an example of a noncatalyzed hydroliquefaction process. SRC is a low-sulfur deashed solid product with the physical appearance of coal. It can be produced from essentially all types of coal and the product fairly uniformly has a heating value of approximately 16,000 Btu per pound, which is significantly higher than the parent coals which may typically have heating values in the range of 10,000-12,000. SRC also has a very low solids content as well as a sulfur content typically in the range of 0.5 to 0.9 weight percent.

The SRC process is illustrated in Figure 14. Key steps consist of slurrying ground coal in a recycle coal-derived liquid, pumping the

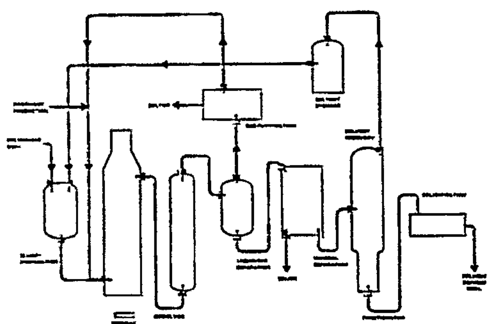

FIGURE 14. SRC PROCESS SKETCH

slurry at pressures in the range of 1,000-2,000 pounds per square inch, mixing it with hydrogen, and passing it through a preheater to raise the slurry temperature to the range of approximately 800°F. It then is fed to a dissolver in order to "liquefy" the coal at a typical operating temperature range of 800-900°F. The mixture passes through a pressure reduction-flashing operation to remove the gases and most volatile material and the solid material is removed by a process such as filtration. The solids-free liquid is then separated into fractions including the lower boiling solvent to be used for recycle and the higher boiling SRC product.

There are two pilot plants in operation. A 48-ton-per-day (coal feed), $18-million unit is located at Tacoma, Washington; it is funded by ERDA. It is in the early days of operation. A smaller 6-ton-per-day unit is located at Wilsonville, Alabama, and funded jointly by Southern Services, Inc, and Electric Power Research Institute. It has operated for extended tests and has produced product which has met the target values for solids and sulfur contents. Studies are underway for potential demonstration-scale plants.

10.2 MODIFIED SRC

This is also a hydroliquefaction process; it shows process results equivalent to a pseudo-catalytic process.

A preliminary design for a 10,000-ton-per-day plant using a modified-SRC design has been completed.[3] A schematic depiction of the process is shown in Figure 15. The modification concept consists of recycle of unfiltered dissolver product as the feed slurry medium, resulting in a higher consumption of hydrogen and production of a product that is a liquid rather than a solid (as in the case for SRC). The dissolver product is further hydrotreated to produce low-sulfur liquid products.

10.3 H-COAL

The H-Coal process is an example of a catalytic hydroliquefaction process. Pulverized coal is slurried with a coal-derived recycle oil, mixed with hydrogen, and fed to a reactor operated at elevated pressure and containing an ebullated bed of catalyst. The coal is converted to liquids and gases. The use of the catalyst can speed the reaction between hydrogen and coal, convert that coal to lower boiling materials, and reduce the sulfur content of the oils to less than 0.5%.

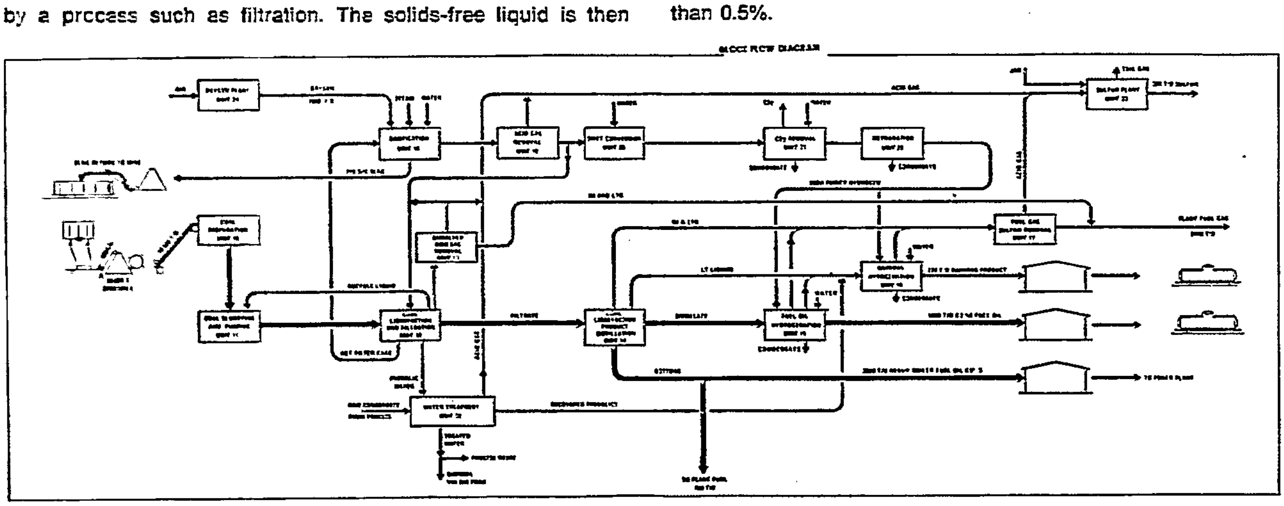

FIGURE 15. MODIFIED SRC PROCESS

10.4 CSF

The CSF process is an example of an extraction process. It has been tested in a pilot plant located at Cresap, West Virginia.

A sketch of the process is shown in Figure 16. Finely ground coal is slurried in a recycle solvent that has been hydrotreated and which performs as a hydrogen transfer agent. The slurry mixture is heated and fed to an extractor which typically operates at approximately 400 pounds per square inch. The coal is liquefied in the extractor, the solids removed by a technique such as filtration, the liquid from the solids separation section is fractionated with a portion of it being recycled to the coal slurry vessel while the heavy material is subjected to a hydrotreating step to create the hydrogen transfer recycle solvent, a light distillate, and a low-sulfur fuel oil. The required hydrogen can be produced by steam-oxygen gasification of char.

This process differs from the preceding liquefaction processes by virtue of carrying out the critical coal liquefaction step at a lower pressure and in the absence of a significant hydrogen gas phase. The hydrogen is added to the coal-derived liquids after removal of the contaminating ash and solids.

10.5 PYROLYSIS

The COED process is an example of a pyrolysis process. It has been successfully operated at a 36-ton-per-day pilot plant located at Princeton, New Jersey, under OCR sponsorship.

A schematic representation of the COED process is shown in Figure 17. Here the feed coal is dried and then subjected to heating to successively higher temperatures as it passes through multiple pyrolysis vessels in series. Typically, the temperatures may be successively raised from ambient conditions to the 1,000-1,100°F range at essentially atmospheric pressure. The coal is heated by contact with hot gases produced by gasification of char plus appropriate recycle of char between the pyrolysis vessels. The vapor phases from the pyrolyzers can be combined and the pitch removed by condensation or quenching. There is sufficient fire char carryover that the hot pitch stream is filtered to remove the solids and then hydrotreated to produce on the order of 1.0-1.5 barrels of synthetic crude per ton of coal consumed. Typical characteristics of the syncrude are °API about 30 and sulfur content about 0.1 weight percent.

The weight of char produced in the pyrolyzers amounts to approximately half the weight of the feed coal. This char can be gasified to supply energy to sustain the pyrolyzers and also to produce additional synthesis gas which can be used for such purposes as to produce SNG or electrical power. Also, tests are underway to demonstrate the practicality of direct combustions in clean plants. The concept shown in Figure 17 depicts the power production option.

11. SUMMARY

A major national effort to develop viable coal conversion technologies usable in the U.S. economy is now well underway. A number of specific gasification and liquefaction processes under development have been described. However, the preferred process for a given specific application may well prove to be a *composite* of the strengths of a number of individual processes.

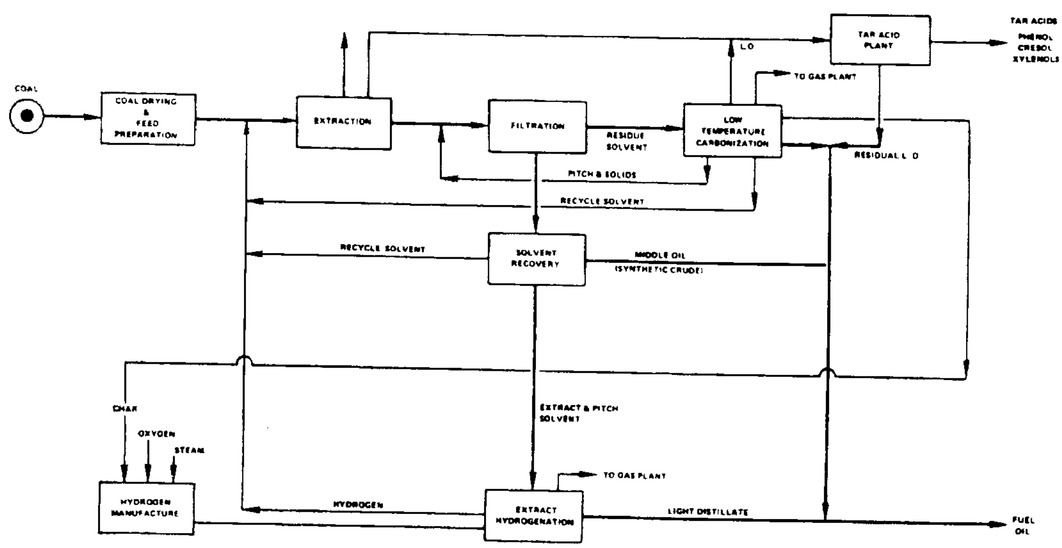

FIGURE 16. EXTRACTION PROCESS SKETCH

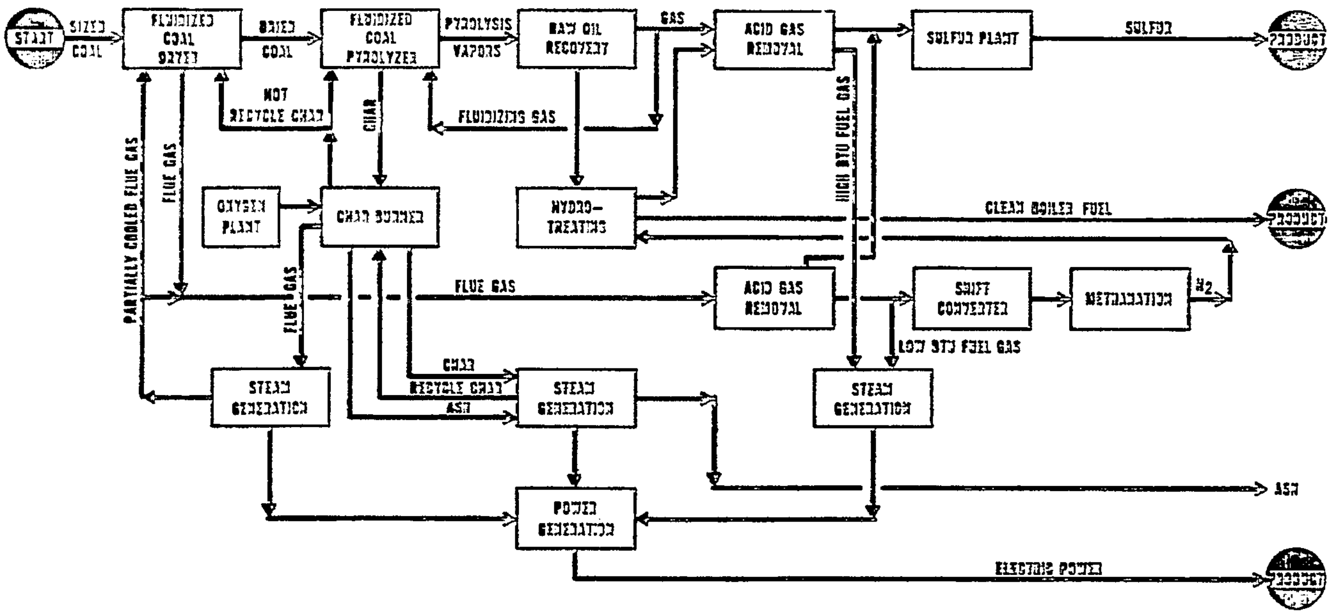

FIGURE 17. COED PROCESS SKETCH

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SECTION 2
PLANT DESIGN/ECONOMIC ANALYSIS

COLLECTED WORK NO. 3

State-of-the-art

Coal liquefaction

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Pasadena, California

Based on an Article published in
Hydrocarbon Processing - November 1976

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State-of-the-art

Coal liquefaction

It's available.
It's done.
Its time will come for general use!

J. B. O'Hara,
The Ralph M. Parsons Co., Pasadena, Calif.

COAL LIQUEFACTION works! The technology available is complex, highly capital intensive and causes major questions regarding its ability to compete economically with alternative fuel and energy sources. But liquefaction is a candidate to supply energy from coal in such forms as boiler fuels, gasoline and SNG.

Development programs now under way seek to define coal liquefaction facilities that are large, simple, reliable and economically competitive. Key elements of U.S. development consists of three pilot plants and three process development units (PDUs) with more on the way. A next [illegible] includes demonstration scale plants to process several thousand tons per day of coal with a constructed value in the probable range of $200 million-$500 million. Commercial plants may process 10,000 to 40,000 mtpd of coal with constructed values in the billion-dollar class.

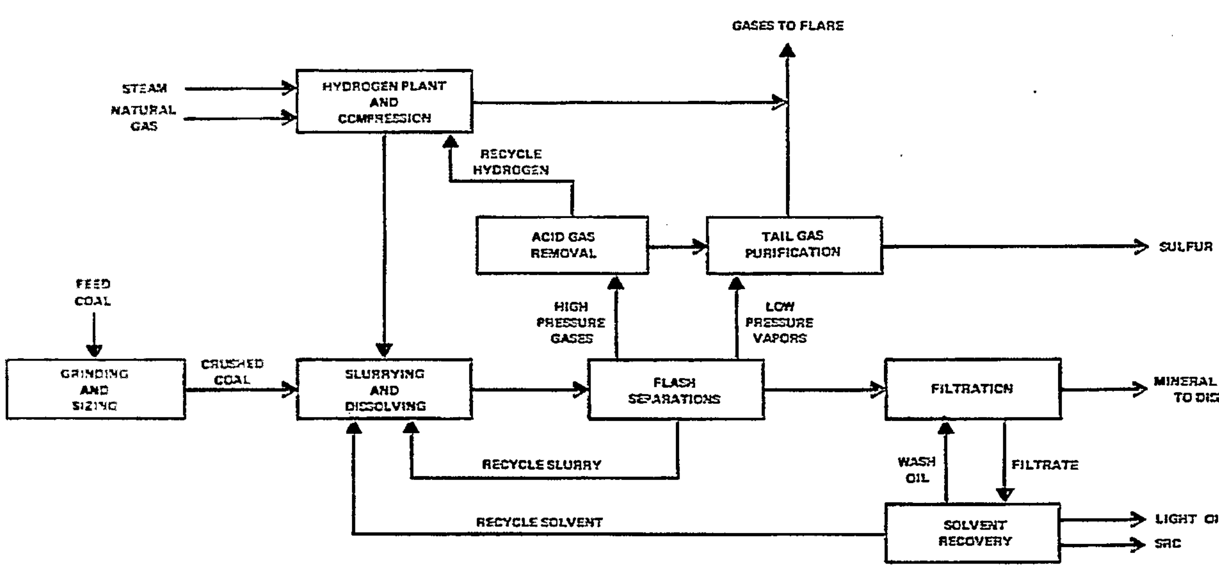
Results of several conceptual designs and predicted economics show a need for selling prices of $1.40 to $3.10 per MM Btu for a zero profit case. For the case of 12 percent discounted cash flow (DCF) return, 9 percent cost of money and a 65/35 debt equity ratio, projected selling prices of $2.35 to $4.85 per MM Btu are seen.

Increasingly more economically attractive plants are expected to be defined as a result of intensive development work underway world-wide and coal liquefaction will make a significant contribution to production of environmentally clean fossil fuels in the future.

HOW IS COAL LIQUEFIED?

Coal liquefaction is a broad-based technology. Processes may be divided into the four classifications (Table 1).

Hydroliquefaction. Ground feed coal is slurried in a recycle coal-derived solvent, mixed with a hydrogen-containing gas and reacted at elevated temperatures and



. 1—SRC pilot plant.

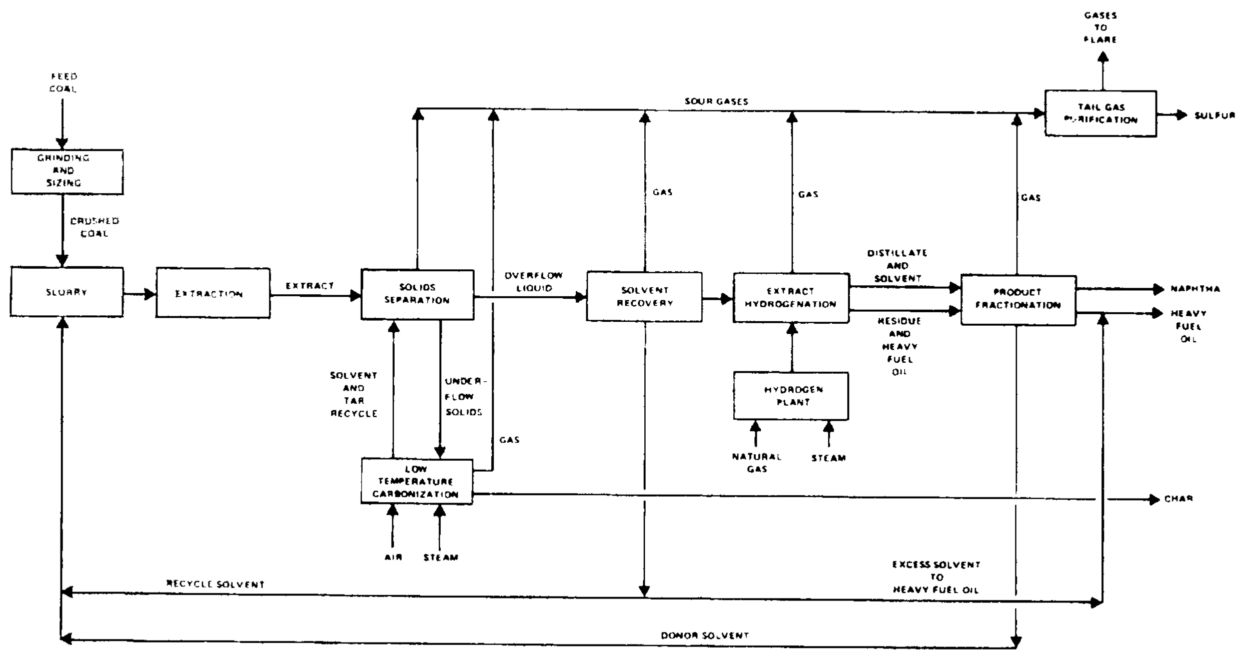


Fig. 2—CSF donor solvent extraction pilot plant process flow.

pressures. The reaction is either non-catalytic, pseudocatalytic or catalytic. In non-catalytic conversions, no external catalyst is added, although certain coals react more readily with hydrogen than others, apparently because of the constituents in the coal ash. In pseudocatalytic conversions, a portion of the reaction product is recycled to the feed slurry to increase ash content in the converter. A catalyst is used in the catalytic process to speed the reaction. Depending on the conversion conditions used, primary reaction products may be solid or liquid at room temperature. Reaction products are separated by flashing to low pressure, removal of unconverted coal and ash by a suitable solid-liquid separation such as filtration and fractionation. Waste streams in hydroliquefaction and all coal liquefaction processes are treated before discard. Sulfur removed from the coal during conversion is recovered as salable elemental sulfur.

More economically attractive plants are expected to be defined as a result of intensive development work underway world-wide

Extraction: donor solvent process. This method uses a number of steps common to hydroliquefaction. It differs in that hydrogen used to convert coal to liquids is added as a hydrogenerated recycle coal-derived liquid that serves as hydrogen donor.

Feed coal is slurried in donor solvent, reacted at elevated temperature and moderate pressure, such as 25 atmospheres, and the reaction products separated, including removal of unconverted coal and ash by a suitable solids-liquids separation technique. Liquids produced in the extraction are separated by fractionation and a suitable portion is catalytically hydrotreated at elevated temperature and pressure to produce the donor solvent for recycle and product liquids.

Pyrolysis. In pyrolysis, feed coal is heated to an elevated temperature to produce gas, tar which can be hydrotreated to produce low sulfur liquids and char which can be gasified using steam and either oxygen or air to produce a synthesis gas (syngas) consisting primarily of hydrogen and carbon monoxide. This syngas can be treated to remove contaminants such as hydrogen sulfide and used to produce electrical power, SNG, liquids by Fischer-Tropsch technology, methanol or ammonia.

Indirect liquefaction. Fischer-Tropsch and methyl fuels are examples of indirect liquefaction technology. Key steps include gasification of feed coal to produce a syngas, purification of the syngas and conversion to liquids in a catalytic converter. In current Fischer-Tropsch technology, key steps operate at moderate pressure such as 25-30 atmospheres. Liquid products are separated by fractiona-

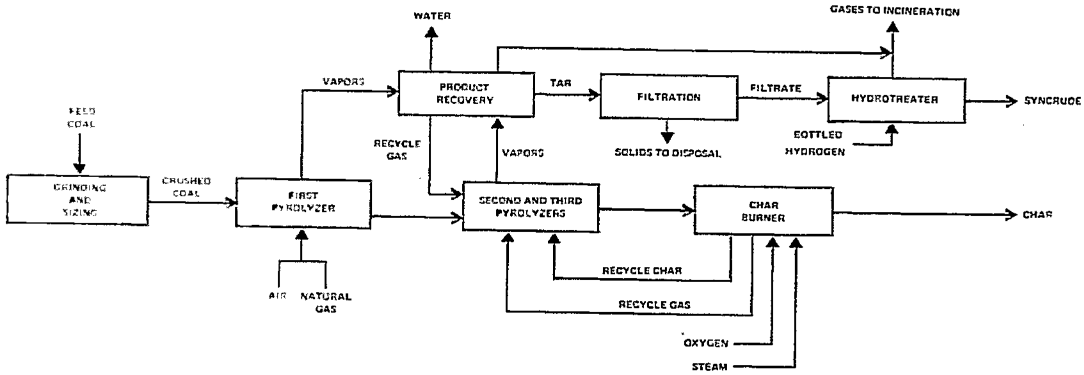


Fig. 3—COED pilot plant.

tion and a significant amount of intermediate or high Btu gas can be produced.

INDUSTRIAL EXPERIENCE

Germany and the Republic of South Africa, and to a lesser extent the United States, the United Kingdom, France and Japan, have built and operated liquid-producing facilities.[1] Basic pioneering work in the field was done in Germany by Bergius on pressure hydrogenation in 1911.[2] F. Fischer and H. Tropsch reported on synthesis of aliphatic hydrocarbons from carbon monoxide-hydrogen mixtures in 1925.[3] Development work continued in Germany and work began by ICI in England in 1927.[4]

Work progressed on related developments in other areas to mutually speed and limit the cost of the development of coal liquefaction by pressure hydrogenation; the International Hydrogenation Patents Co., formed in 1931 to pool patents and know-how in the field, included I. G. Farbenindustrie, ICI, Standard Oil Co. (New Jersey) and the Royal Dutch Shell Group.[5] Continued development of procedures and industrial machinery resulted in seven operating hydroliquefaction plants in Germany in 1939 with a capacity of approximately 1,350,000 metric tons per year (mtpy) of liquid products equivalent to a nominal 27,000 bpd of liquids.[6]

By 1945, the number of German hydroliquefaction plants had grown to 18 with a capacity of more than 4 million mtpy. Production peaked at about 3.6 million mtpy, equivalent to a nominal 70,000 bpd. Parallel development of Fischer-Tropsch technology led to construction of the first commercial plant in 1936. In 1939, nine plants existed in Germany with a total rated capacity of about 750,000 mtpy of liquids.[7]

In England, development work by ICI led to construction of a plant in 1935 designed to produce 150,000 mtpy of liquids—100,000 tons of this from coal and the remainder from low temperature char and creosote oil.[8]

From an economic standpoint, a British survey team translated German production cost to a 1947 U.K.-cost basis and concluded that coal liquefaction, using either the German liquefaction or Fischer-Tropsch technologies, was uneconomical in the United Kingdom at that time.[9]

The SASOL story of production of liquids and fuel gases from coal in the Republic of South Africa is well known.[10] SASOL I is a Fischer-Tropsch plant that is reported to have produced and processed in excess of 8.5 million standard cubic meters per day (scmpd) of syngas and has been in operation since 1955. A program is now under way to design and construct SASOL II which will be on the order of 4 to 5 times larger and is scheduled to begin operation in 1980.

A key point regarding early coal liquefaction plants is that their thermal efficiencies in converting coal to liquid fuels have been in the range of 40-50 percent.[11,12] Future plants promise significantly better thermal efficiencies.

France's experience in coal conversion included operation of a semi-commercial coal hydrogenation plant by Compagnie Francaise des Essence Synthetiques, beginning in 1935. It operated at 300 atmospheres and had an annual capacity of 15,000 mtpy of coal.[13]

Two semi-commercial plants were constructed in Asia around 1939. Both were subsidized by the Japanese government.[14] In the United States, Union Carbide operated

TABLE 1—Coal Liquefaction Process Classification

Classification	Example
Hydroliquefaction	
Non-catalytic	Solvent-refined coal (SRC I), Clean Coke
Pseudocatalytic	SRC II
Catalytic	Synthoil, H-coal
Extraction: Donor solvent	CSF (CRESAP), Exxon
Pyrolysis	
Direct	COED, Garrett
Hydropyrolysis	Coalcon, Clean Coke
Indirect Liquefaction	Fischer-Tropsch

TABLE 2—Projected economics clean boiler fuels from coal

Feed Rate (mtpd)	9,090
	$ Millions
Fixed capital	$390*
Other including startup and working capital	44
Total capital	$434

Example Required Product Selling Prices

DCF	Financing	$/MMBtu
0%	None	$2.00
12%	65/35 Debt/Equity at 9% Interest	$3.30

* Excludes coal mine

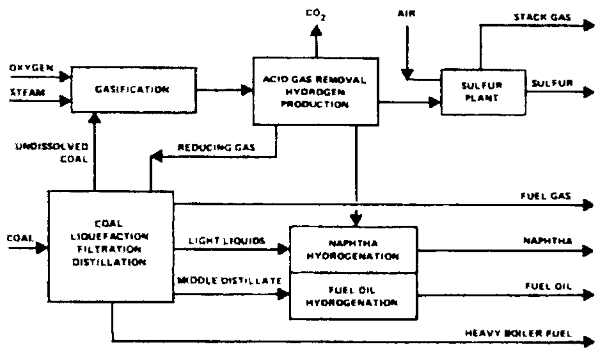


Fig. 4—Clean boiler fuel-liquefaction plant.

a semi-commercial coal conversion unit at Institute, W. Va., and the U.S. Bureau of Mines operated one at Louisiana, Mo., from 1949 to 1954.[14]

All the history tells us that coal can be liquefied on an industrial scale—the big question is whether future projects can be economically competitive with alternative liquid fossil fuel sources. Objectives of current development programs are, therefore, to define coal liquefaction plants that can be large, simple, reliable and economically competitive. A factor that must be considered is the advantage in use of multiproduct complexes that produce significant amounts of fuel gases, including SNG, as co-products of liquids.

CURRENT DEVELOPMENTS

A number of active coal liquefaction development programs are underway throughout the world including the United States, Germany, the United Kingdom, the Republic of South Africa, Australia and Poland. Some key elements of the U.S. coal liquefaction program illustrate what is being done.

Three major liquefaction pilot plants and three PDUs are currently in the ERDA program. Other experimental units and a demonstration plant are in the design phase. These units are being used in development of hydroliquefaction, extraction and pyrolysis processes. The catalytic, pseudo-catalytic and non-catalytic hydroliquefaction processes are being studied.

Units are being used in development of hydroliquefaction, extraction and pyrolysis processes

Solvent-refined coal (SRC). The SRC pilot plant (Fig. 1), located at Fort Lewis (Tacoma), Wash., is designed to process 45 mtpd of coal and produce a solid de-ashed low-sulfur product known as solvent-refined coal. The unit is operated by the Pittsburg and Midway Coal Mining Co., a division of Gulf Oil Corp. The pilot plant, in operation since October 1974, has shown ability to produce specification-grade product. It is currently being operated to produce about 2,750 metric tons of SRC to be used for functional product testing in a 22 MW boiler. The SRC process concept involves hydroliquefaction procedures.

A modification of the SRC process sometimes referred to as SRC II uses a technique whereby a portion of the product slurry containing ash is recycled as feed to the dissolver. This is the pseudocatalytic effect described earlier. Preliminary tests of this procedure have been completed with additional tests planned for the future. A conceptual design using this procedure has been published[15] and a second one is near completion.

A smaller SRC pilot plant, with a design capacity of 5.5 metric tons of feed coal per day, is being operated by ERDA, Electric Power Research Institute (EPRI) and Southern Services Corp. in Wilsonville, Ala. This unit has been operated successfully.

In a related PDU program, Project Lignite is applying SRC-type technology to lignite feeds. This PDU is operated by the University of North Dakota at Grand Forks. The PDU is designed to process approximately one-half mtpd of lignite. It is in the early stages of operation.

Non-catalytic hydroliquefaction is also being developed on a PDU scale by U.S. Steel Corp. as part of their Clean Coke process at Monroeville, Pa. Also, catalytic hydroliquefaction, the Synthoil process, is being tested on a PDU scale at ERDA's Pittsburgh Energy Research Center (PERC) located at Bruceton, Pa.

Extraction. The CSF Donor Solvent Extraction pilot plant, Cresap, W. Va., (Fig. 2) was designed to process approximately 25 mtpd of coal. It was operated from 1966 to 1970. Information was obtained on the basic extraction process. A number of mechanical and materials-of-construction problems were defined during operations. The pilot plant is now being reactivated.

COED. The COED process (Fig. 3) is a multistep pyrolysis pilot plant operated successfully at FMC Corp., Princeton, N.J., from 1970 through May 1975. It was designed to process 33 mtpd of coal. A conceptual design of a commercial plant that would employ this technology to produce a syncrude plus electrical power has been published.[16]

There are other pyrolysis-type processes under development by ERDA. The Clean Coke PDU program includes a carbonization, or pyrolysis step, under an elevated pressure of approximately 10 atmospheres in the presence of hydrogen-containing fluidization gases. The Coalcon process, now in the design stage, also involves hydropyrolysis of coal.

The Garrett flash pyrolysis process is being developed and additional experimental work is also under way at ERDA's Pittsburgh Energy Research Center (PERC), Bruceton, Pa., and at Brookhaven Labs in New York.

Current work on Fischer-Tropsch processing consists of work on the use of flame-sprayed catalyst systems at

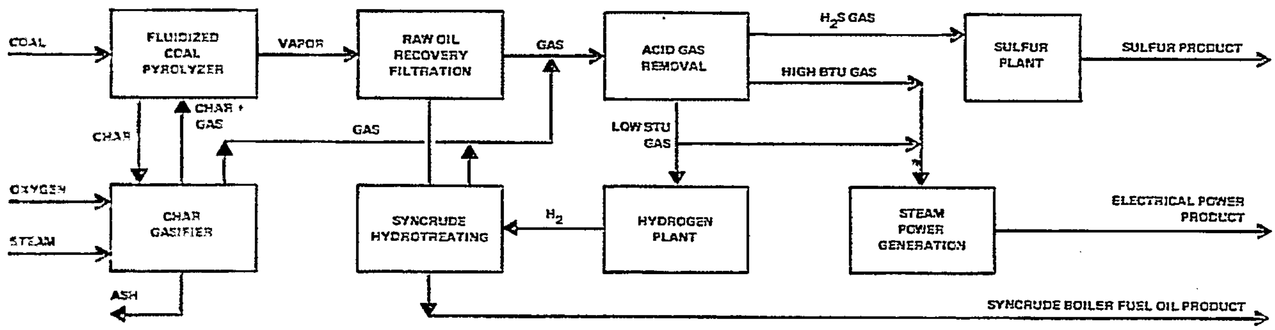


Fig. 5—COED simplified block flow diagram.

PERC and development of a conceptual design for a commercial plant.

CONCEPTUAL DESIGNS

A number of conceptual designs for commercial coal conversion facilities have been, or are being, developed under ERDA sponsorship in a plan equivalent to an extensive feasibility study. Conceptual designs and economic evaluations should provide guidance regarding potential configuration of commercial facilities to practice technology as well as expected economics for these facilities. They also provide feedback to development programs regarding significance of process, system or subsystem elements to the total technology performance and economics. They should help establish development priorities based on predicted economic impact of the separate process and mechanical factors.

Clean boiler fuels. A hydroliquefaction plant to produce approximately 25,000 bpd of liquid products from about 9,100 mtpd of coal using SRC II techniques is shown schematically in Fig. 4. Predicted thermal efficiency of this plant is about 64 percent based on feeding purchased run-of-mine coal. All gas products are consumed in the plant as fuel.

A summary of predicted economics (Table 2) is based on second quarter 1976 dollars. As seen, using purchased $9 per metric ton run-of-mine coal, the predicted required selling price at zero discounted cash flow rate of return (DCF), without financing, is $2 per million Btu (MM Btu); this amount is presented only as a reference value since it represents a minimum value which could be approached but not reached. For the case of financing by a 65/35 debt-equity ratio with interest at 9% and a 12% DCF, the required selling price would be $3.30 per MM Btu.

COED-based pyrolysis complex. A commercial COED-based pyrolysis complex to produce approximately 28,000 bpd of syncrude plus about 830 MW of electrical power, requires approximately 22,700 mtpd of clean, sized bituminous coal. Principal processing steps are shown in Fig. 5.[16]

This design included a captive coal mine. It is the first conceptual design capable of processing feed coal with variations in composition to be expected over a 20-year operating life in the Eastern Region of the U.S. Interior Coal Region. Provision for handling variable feed coal characteristics could add about 10% to the fixed capital investment and 8% to 9% to the required selling price.

Predicted thermal efficiency for the process portion of the plant is estimated to be approximately 58% for production of syncrude and clean fuel gases as feed to electrical power generation.

Predicted economics (Table 3) indicate that typical required product selling prices for the zero DCF case without financing is 4¢ per kilowatt hour (kwh) and $6 per barrel (bbl) for syncrude. Because it is a multiproduct plant, required selling prices are interrelated. For the 65/35 debt-equity financing case with 9% interest rate, typical required selling prices are 4¢/kwh and $35/bbl. Complete estimates for the interrelationship between required selling prices and a complete parametric economic analysis, including sensitivities of required selling prices to fixed capital investment and DCF, have been published.[16]

Fischer-Tropsch. Prior industrial experience in this field included nine plants operated in Germany in the 1940s, the SASOL experience and a natural gas-based plant operated in the United States[17] which was abandoned, largely for economic reasons. A summary of production costs for two German plants which produced 4,000-7,000 metric tons per month (mtpm) each in the early 1940s has been published.[18] Costs were stated to be in the range of 25 pfg/kg of total primary product, which very roughly would translate to the range of $10 to $12/bbl, when expressed in 1940s dollars.

In 1973, general concepts and preliminary economic

TABLE 3—Projected economics COED

Feed Rate (MTPD)	22,700
	$ Millions
Fixed capital	$1,500*
Other including startup and working capital	150
Total capital	$1,650

Example Required Product Selling Prices

DCF	Financing	Syncrude	Power
0%	None	$ 6.00/bbl	$0.04/KWH
12%	65/35 Debt/equity at 9% interest	$35.00/bbl	$0.04/KWH

* Includes captive coal mine

TABLE 4—Projected economics Fischer-Tropsch

	Small Plant	Large Plant
Feed Rate (MTPD)	4,200	125,000
Fuels product rate (equivalent BPD)	11,385	383,500
	$ Millions	$ Millions
Fixed capital	$226*	$3,400*
Other including startup and working capital	34	425
Total capital	$260	$3,825

Example Required Product Selling Prices

DCF	Financing	$/MMBtu	$/MMBtu
0	None	$3.10	$1.40
12	65/35 Debt/equity at 9% interest	4.85	2.35

* Excludes coal mine

estimates were made for two plant sizes based on the Fischer-Tropsch process:

- One to process approximately 4,300 mtpd of high sulfur coal and produce SNG, fuel oil, fuel gas, wax and sulfur. Thermal efficiency was estimated to be about 56%.
- One to process approximately 125,000 mtpd of high sulfur coal to produce 100,000 bpd of fuel oil plus significant SNG.

Predicted judgmental economics for these two cases are shown in Table 4.[19] Results indicate that the small plant is not attractive, based on current economics, but a large plant could be interesting.

A more detailed conceptual design of a Fischer-Tropsch plant to process approximately 27,300 mtpd of coal and to produce liquid products and SNG with a combined heat content in excess of 500 billion Btu per day is under review. Heat content is approximately equally divided between liquids and SNG.[20] The liquid products are considered premium because of their essential nil sulfur, nitrogen and particulate contents. This design envisions large entrained slagging-type pressure gasifiers and use of flame-sprayed catalysts on heat exchanger surfaces. A careful step-by-step analysis of efficiencies has been completed—techniques now defined indicate that thermal efficiency can possibly be greater than 70%, which represents a significant improvement over earlier designs. The combination of large plant size and high thermal efficiency will favor low production costs.

Fischer-Tropsch experience includes nine plants in Germany, the Sasol experience in South Africa and an abandoned natural gas based plant in the U.S.

Oil/gas. A design using a modified SRC hydroliquefaction procedure referred to as SRC II is conceived to process about 32,500 mtpd of coal. Products will consist of liquids and SNG in a ratio of approximately 2:1 on an energy content basis. A description of an early version of the design criteria based on an oil/gas ratio of about 6 has been presented.[21] A number of process preference studies were conducted during the course of this design. In each of these studies, an economic comparison of the effects of each of several alternatives was developed, usually expressed in the differential between required product selling price in dollars per million Btu.

As in the most recent Fischer-Tropsch plant design, large equipment is specified and the combination of large production scale factor and high efficiency favor low production costs.

About the author

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