PB 224 530

CLEAN FUELS FROM COAL

A report to the Office of Science and Technology Overview Panel by the Chairman of the Study Group

SUMMARY

Detailed study of the production of clean synthetic fuels from coal results in recommendation for a total program of $1.51 billion. The work recommended is divided into a research phase at $33.4 million, a development phase at $315.0 million, and a demonstration phase at $1.15 billion.

Work is outlined for alternate processes to produce clean low-Btu gas, clean liquid fuels, and clean solid fuels from coal. Supporting work on the development of special equipment and improved materials along with economic and engineering studies are proposed and funds provided in the budget estimates.

Crucial to the program is early commitment to demonstration-scale plants in an effort to save 2-5 years of lead time before commercialization. A vigorous program, adequately funded, will lead to commercialization in the late 1970's. Without such a program, commercial development will lag into the 1980's and result in a total higher cost to the citizens of the United States.

This study was originally assigned to the National Academy of Engineering whose report has not been received. Some of the recommended work reflects preliminary recommendations made by the National Academy study group, but this report has not been reviewed or approved by the Academy and does not reflect, therefore, any official Academy viewpoint. Cost estimates contained in the report have resulted from past engineering studies made for the Office of Coal Research by outside companies, modified to reflect current costs and variations in the program.

Neal P. Cochran
Executive Secretary

NOV 10 1972

Program Funding Summary
Clean Fuels From Coal

Program Objective: Production of Clean Liquid, Solid, and Gaseous Fuel From Coal At The Most Economic Price
Estimated Funds ($ x 10^{-6}) By Fiscal Years

	73	74	75	76	77	78	79	80	81	82	83	Total
Research Phase												
1. Low Btu Gas	1.3	1.6	1.7	0.8	0.4	-	-	-	-	-	-	5.8
2. Clean Liquid Fuel	0.3	2.2	2.4	2.0	0.8	0.2	-	-	-	-	-	7.9
3. Support Work	0.7	3.0	4.0	5.0	3.5	2.5	1.0	-	-	-	-	19.7
SUBTOTAL RESEARCH PHASE	2.3	6.8	8.1	7.8	4.7	2.7	1.0					33.4
Development Phase												
1. Low Btu Gas	6.0	20.0	30.0	25.0	20.0	20.0	15.0	10.0	10.0	-	-	156.0
2. Clean Liquid Fuel	13.0	20.0	25.0	25.0	25.0	20.0	10.0	-	-	-	-	138.0
3. High Temperature Clean-up	1.0	5.0	10.0	5.0	-	-	-	-	-	-	-	21.0
SUBTOTAL DEVELOPMENT PHASE	20.0	45.0	65.0	55.0	45.0	40.0	25.0	10.0	10.0	-	-	315.0
Demonstration Phase												
1. Multi-Process Pipeline Gas Plant	-	5.0	20.0	50.0	100.0	75.0	50.0	25.0	25.0	-	-	350.0
2. Multi-Product Clean Energy Plant-Liquid, Solid, Gas	0.5	5.0	10.0	100.0	150.0	150.0	150.0	150.0	85.0	-	-	800.5
SUBTOTAL DEMONSTRATION PHASE	0.5	10.0	30.0	150.0	250.0	225.0	200.0	175.0	110.0	-	-	1,150.5
GRAND TOTAL	24.4	65.6	107.2	215.6	300.9	267.9	226.0	185.0	120.0	-	-	1,512.6

CLEAN FUELS FROM COAL

I. INTRODUCTION

The production of clean fuels from coal includes conversion of coal to pipeline quality gas, producer gas, town-type gas, low-sulfur ash-free liquids, and low-sulfur, low-ash reformed coal. Each of these is expected to find a place in the energy technology of the United States during the remaining years of this century. For purposes of this study, pipeline gas was eliminated from consideration and all other gas was considered as low-B.t.u. fuel gas. Pipeline gas is treated separately and was eliminated from this report by direction.

The production of clean synthetic fuels, from coal, is vitally important since stack gas purification systems are now known to have many unresolved technical and economic problems. Experience to date has shown that efficiencies are low, costs are high, and the powerplant waste disposal problem is accentuated. Furthermore, stack gas systems will not provide an answer to clean-burning fuels for the rapidly growing industrial energy market, whereas coal conversion processes will.

The production of clean-burning liquid fuel from coal can be applied to existing powerplants as well as new conventional plants and new advanced cycle powerplants. An electric utility is certain to find it much easier to use a low-sulfur fuel produced from coal rather than operating a complicated chemical processing step included in any gas stack cleaning system. This is particularly true of the Eastern United States where power demands are high and substantially all of the coal is of the high-sulfur variety.

II. RESEARCH PROGRAM

The program proposed is based on the technically sound ability to produce a solid, liquid, and gaseous low-sulfur fuel from coal. Substantially more study effort was devoted to the production of low-B.t.u. gas than on the production of clean liquids and solids. For purposes of balance, however, it should be stressed that the production of low-B.t.u. gas is no more important than the production of a clean liquid or a clean solid. Indeed, in many cases low-B.t.u. gas may be a less desirable product than a clean-burning liquid fuel. The recommended research and the program estimates are for the development of processes to produce the clean-burning fuels and do not include any work on advanced power cycles. It is assumed that advanced cycle work will be funded and integrated with the clean fuel cycle.

For purposes of this report, research is defined as the laboratory and small-scale testing needed to prove scientific soundness of a concept. It does not include construction and subsequent operation of pilot plants. Successful research must be followed by pilot plant construction and operation, however.

As processes are developed, unique materials problems may be uncovered. Work in these areas is included in the research program. Additionally, basic data may be needed to define larger-scale experiments and to enable projections to be made on potential economics of full-scale systems. Sufficient funding is allowed for this portion of the effort, also.

As research proceeds, engineering assessment and evaluation must go hand in hand. Sufficient funds are provided for this portion of the work.

III. DEVELOPMENT

As contemplated in this report, development includes the design, construction, and operation of integrated pilot plants capable of converting coal into a clean-burning fuel. As projected here, these pilot plants are expected to have a coal capacity ranging from 1-50 tons/hour depending on the process chosen for development and previous work on it.

Systems Recommended

Low-B.t.u. Gas

Many processes are available for converting coal to low-B.t.u. gas. Much of today's knowledge stems from earlier commercial interest in converting coal to gas and the current national program for the development of pipeline gas from coal. Work, already completed, has established that fixed, fluid, and moving bed processes can be adapted to the production of low-B.t.u. gas. Each of these potential methods has something to recommend it, and this program recommends work on each of the systems. All of these systems can be operated at pressures ranging from atmospheric to perhaps as high as 100 atmospheres. The upper range of pressure appears to be uneconomic, however, so the recommended program concentrates in the range of 1-30 atmospheres. Early in the program engineering studies should establish the exact range of pressure needed.

Typically, work should be undertaken concurrently on multiple fluid bed systems operating from 1 to perhaps 20 atmospheres, with another effort proceeding in the range of 10-30 atmospheres. Capacity of the systems chosen should range upwards to 50 tons/hours as a maximum.

Concurrent with the fluid bed work, development of large diameter fixed bed gasifiers should be undertaken. Typical commercially available equipment is limited to the 10 or 12 ft. diameter range, but practical gasifiers might be built in the 20-40 ft. diameter scale. Operating pressures as high as 20 atmospheres appear reasonable with a 10-20 atmosphere gasifier appearing most likely.

As work with the fluid and fixed bed systems proceeds, moving or entrained bed gasifiers should be undertaken. An operating range similar to the one used for fluid bed systems should be the basis for the experimental program. Particular attention should be directed to the method of firing the entrained gasifier. Operation under slagging conditions appears justified and desirable, and the work should be concentrated in this area.

Generally, it is assumed, and this program recommends, work with air-blown gasifier systems. Under some specialized circumstances, however, the use of oxygen will be worthwhile, and at least one candidate system will be investigated with oxygen used rather than air. The final choice for commercial use will be determined by the projected economics for the systems under development.

Coal can be burned in a molten salt or molten metal system with heat transfer to submerged or adjacent heat transfer surfaces. Such systems can be operated with a deficiency of air and thus become a low-B.t.u. coal gasifier. Work on each system should be pursued at a small scale to determine whether pilot plant development is justified. Prior work on the production of pipeline gas has developed sufficient information on molten salt gasification to suggest near term work at the pilot scale. Such work is recommended and included in the program estimates.

Gas Cleanup

The production of pipeline gas has demonstrated the need for cleanup of the gas manufactured in all coal gasification processes. This is extremely important to the pipeline gas program and systems developed there can be used to clean up low-B.t.u. fuel gas. The development of a high temperature cleanup system could be of material benefit to pipeline gas production, but it is even more important to the production of low-B.t.u. gas. This program recommends study of a minimum of four high temperature gas cleanup systems with additional funding provided as other candidate systems are uncovered.

Clean-Burning Liquid Fuel

Coal can be converted to a clean-burning liquid by direct hydrogenation, by carbonization followed by hydrogenation of the tar produced, by Fischer-Tropsch synthesis, and by extraction followed by hydrogenation of the extract. All of these methods are worthy of detailed study and should be investigated at the bench, process plant, and pilot plant scale. Irrespective of the method employed, detailed consideration should be given to producing the lowest possible sulfur at minimum pressure with minimum hydrogen uptake since each of these features will reduce the cost of the finished product. Prior experimental work has established that the production of a clean liquid along with the production of a clean gas yields a lower cost gas and a lower cost liquid than if either system were produced separately. This, too, should be investigated.

Work currently underway on the production of solvent refined coal should be expanded to include hydrogenation of the extracted coal with pressure and temperature varied to determine the optimum system. This work can best be pursued at the solvent refined coal pilot plant now under construction.

The direct hydrogenation of coal, to produce fuel oil, and alternate systems for extraction-hydrogenation should be studied at the pilot plant scale. It is suggested and strongly recommended that existing facilities be adapted to this purpose wherever possible.

IV. ACCELERATED DEMONSTRATION SCALE PROGRAM

To insure early industrial use of each system developed through the pilot plant, an accelerated demonstration plant is needed. A demonstration plant is defined as having about 10% of the capacity of a commercial-scale plant

Sufficient pilot plant work on the carbonization of coal has been completed to make early construction of a prototype demonstration plant viable. It is recommended that a program for low temperature carbonization of coal at an operating pressure of about 10 atmospheres be undertaken in a demonstration plant. The final system should include complete utilization of the char so that the plant produces only clean liquid and clean gas.

The pipeline gas program has produced data for design of a demonstration plant that could be finalized beginning in the spring of 1973. It is recommended that a pipeline gas demonstration plant program be authorized using alternate processes for each of four operating trains in one plant. Depending on pilot plant results, the final 4-train plant will have a capacity of 200-400 million SCF/day.

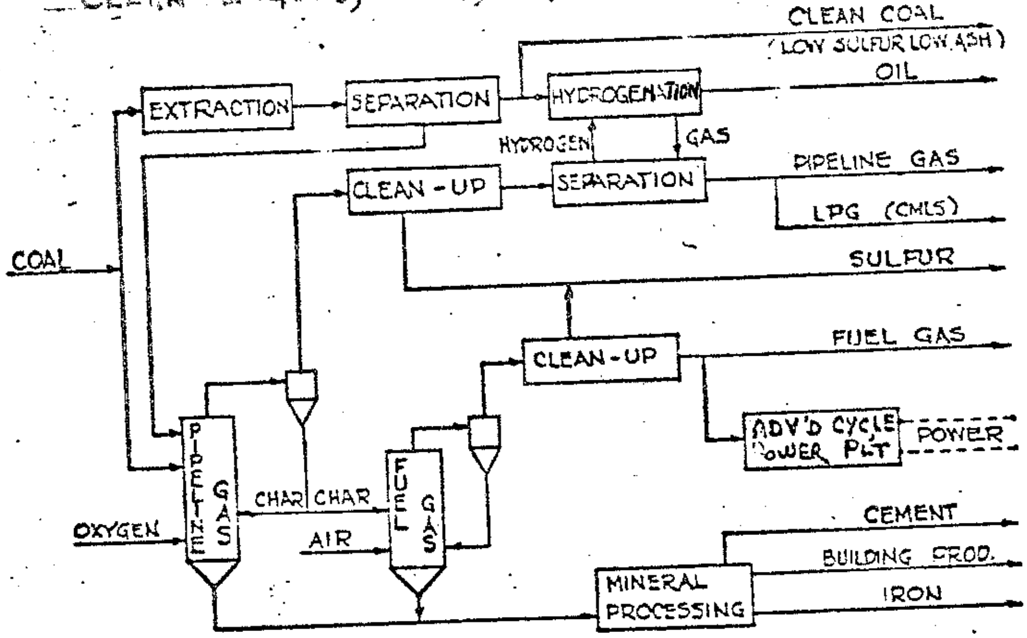
It will materially assist the ultimate technological and economic success of the entire program for high-B.t.u. coal gasification to be able to test variations in the demonstration plant stage, rather than be forced to make premature technological choices. Continuation of the processes under test in the pilot plant stage will allow four chances for ultimate commercial success. Besides providing demonstration of technological alternatives, the 4-train (commercial-size) demonstration plant will more readily enable the Government to sell the plant, plant products, or both, to recover a portion of the Government's costs. (Such cost-recovery could involve delivery of gas and oil to the Government in various parts of the country, the Government being a large consumer of these products.)

As individual processes are established at the demonstration plant scale, industry will be able to pick up these processes for final commercialization. This does not conflict in any way with the current plan for a demonstration plant. It is an effort to accelerate total program development with little or no additional final cost. A saving of 2-4 years in the availability of synthetic pipeline gas is the reason for this recommendation.

The ability to produce synthetic "oil," low-sulfur fuel oil, pipeline gas, and clean fuel gas is vitally important to the Nation's well-being. Experimental work and engineering studies that project the economics of multiproduct plants have established that a final process choice can be made during FY 1974. It is recommended that a demonstration-scale plant be authorized with a capacity ranging from 5,000-10,000 tons of coal per day to establish economic viability of this concept. Cost estimates for four plants are included for planning purposes, with the first plant scheduled for the Appalachian region. The second plant should be projected for the Midcontinent, followed by a Northern Plains plant and a Four Corners area plant. (See Plant Schedule attached.)

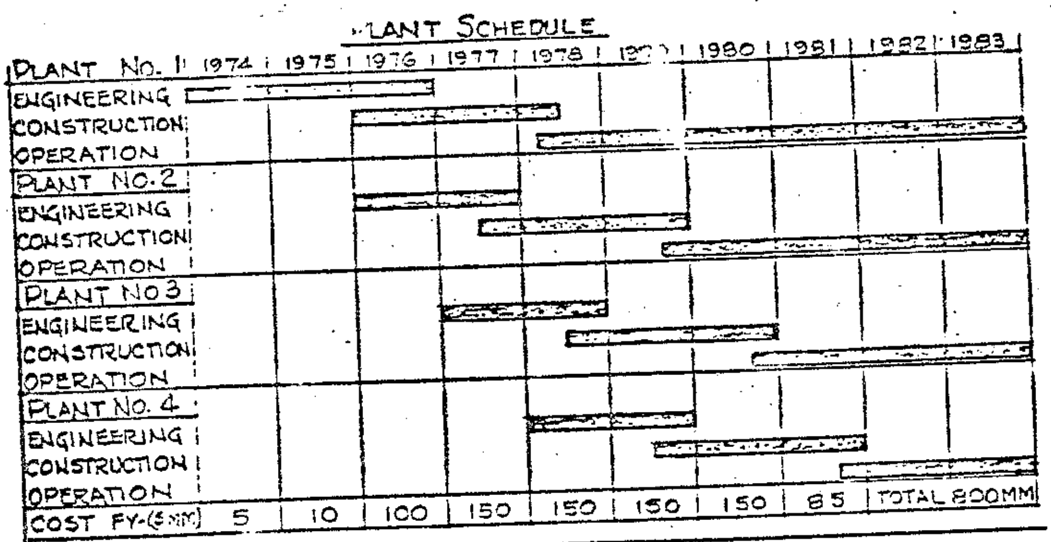
It is vitally important to proceed with large-scale testing of individual processes for converting coal to alternate energy forms to insure an early industrial capability. The availability of these plants would have a significant effect on near-term (late 1970's) prices for imported oil and LNG. Nationally, we would have a much stronger hand in future dealings with OPEC if a synthetic fuel industry were in an early state of development with the continental U.S. Over the longer term, the plants would provide vitally needed

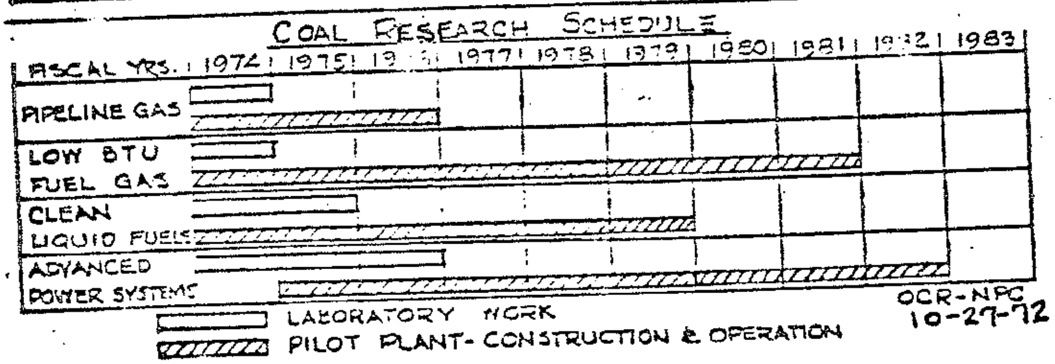
MULTI-PRODUCT COAL DEMONSTRATION PLANT
CLEAN LIQUID, SOLID, & GAS WITH POWER



BASIS:

FOUR PLANTS REQUIRED TO SUIT REGIONAL COAL RESOURCES AND PROJECTED ENERGY DEMAND FOR THE REGION. TYPICAL LOCATIONS ARE: APPALACHIA, NORTHERN PLAINS, INTER-MOUNTAIN WEST, AND MID-CONTINENT. EACH PLANT WILL HAVE A CAPACITY OF 10% OF A COMMERCIAL PLANT AND WILL COST $ 200,000,000.





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cost figures as well as engineering design data for large-scale plants. By providing funds for construction of these plants, the Federal Government will assume the leadership role that is desperately needed if industry is to move.

Based on the assumption that synthetic fuel plants will be in being, local and regional economic surveys should be made to show the range of housing and related development required in some of the more remote areas of the country. Ultimate commercial plants processing 50,000-100,000 tons of coal per day (see Multiproduct Schematic attached) will generate many jobs directly during construction and operation. Even more important, however, small business ventures can be expected to grow in the area of these large plants and the final policy should be shaped to encourage this to happen since this will create population growth in many rural areas, thus alleviating some of the pressures on the large urban centers. We would call this regional resource development.

To support the multiproduct plant concept, economic studies should be undertaken to determine the mix of products from the plant as a function of the regional energy market. Advanced mining system concepts should be incorporated by either making the mine part of the plant or developing a joint effort with the mining company involved. Any power system incorporated in the plant should embody advanced power cycle concepts. The estimate includes funding for these supporting efforts.

V. CLEAN FUEL SYSTEMS

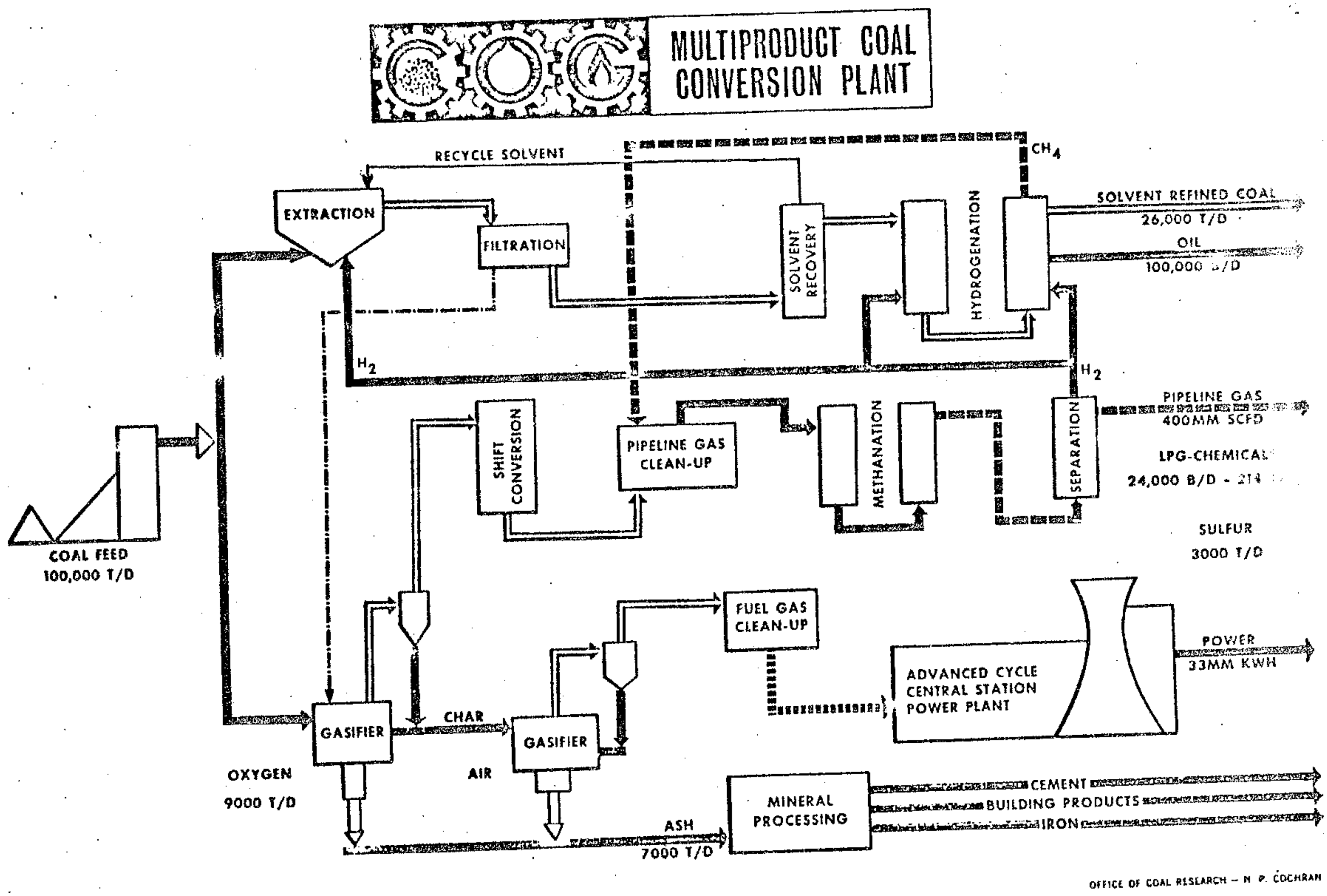
Low-B.t.u. Coal Fuel Gas for Central Station Powerplant

Description

Coal is gasified in an on-site air and steam-blown gasifier to make a low heating value (100-200 B.t.u.) fuel gas. Particulates and sulfur (in the form of H_2S) are removed and the clean gas is burned as a gas turbine and/or boiler fuel. Because of the much smaller volume of gas to be cleaned, vis-a-vis flue gas, and the fact that H_2S can be scrubbed by commercially available methods, this system holds the promise of being a better solution to the sulfur cleanup problem than projected systems designed to remove SO_2 from flue gas exiting from powerplant boilers.

Advantages

In its elementary form, atmospheric pressure gasification, gas cooling before H_2S scrubbing, and then burning in a boiler furnace


MULTIPRODUCT COAL CONVERSION PLANT
RECYCLE SOLVENT
CH_4
EXTRACTION
FILTRATION
SOLVENT RECOVERY
HYDROGENATION
SOLVENT REFINED COAL
26,000 T/D
OIL
H_2
COAL FEED
100,000 T/D
SHIFT CONVERSION
PIPELINE GAS CLEAN-UP
METHANATION
SEPARATION
PIPELINE GAS
400MM SCFD
LPG-CHEMICAL
SULFUR
3000 T/D
FUEL GAS CLEAN-UP
ADVANCED CYCLE CENTRAL STATION POWER PLANT
POWER
33MM KWH
GASIFIER
CHAR
GASIFIER
OXYGEN
9000 T/D
AIR
MINERAL PROCESSING
CEMENT
BUILDING PRODUCTS
IRON
ASH
7000 T/D
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only, the system is within the present state of the art. Such a system would have a relatively low thermal efficiency but in certain circumstances (availability of low-priced high-sulfur coal) may be the optimum solution of the sulfur emission problem.

In its ultimate, most advanced form the system has the potential of around 50 percent--well above the best of present day pilot plants. There are a number of possible configurations of such an advanced system but the essentials are as follows. The gasifier is operated at a pressure slightly above gas turbine inlet temperature of 2,500°-3,000° F. After expansion in the gas turbine to around 1 atmosphere pressure, the gas is still at a high enough temperature to energize a high-temperature steam boiler powering an efficient turbo-electric generator.

Research and Development Program

The gasifier may be one of several types--fixed bed, fluidized-bed, moving-bed, slagging, each of which may have a number of configurations. Coal is highly variable among ranks and origin and this controls the gasifier type. Gasifier development work is proceeding. Sulfur and particulate removal systems are being developed. These may be wholly or in part integral with the gasifier. Dolomite or limestone inclusion in the gasifier for sulfur removal is one approach. Independent hot sulfur scrubbing systems are not presently available and are being investigated. Particulate removal systems, for satisfactory gas turbine operation, are beyond the present state of the art and must be developed for the ultimate system. Hopefully, one or more of the hot sulfur removal systems under development will also remove particulates. Allowable gas turbine inlet temperatures must be greatly increased for the ultimate system and this is also being pursued.

Clean Liquids and Solids from Coal

The work on clean solids and liquids from coal involves four similar processes.

Description

1. Solvent Refined Coal

Raw coal is pulverized and mixed with a coal-derived aromatic solvent having a boiling range of about 550° F. to 800° F. The resulting slurry, together with hydrogen at about 1,000 pounds pressure, is passed through a preheater to a reactor or dissolver at a temperature of about 800° F. The coal is depolymerized and solution is almost complete in the preheater and dissolver. The material remaining undissolved consists primarily of the inorganic matter in the coal.

Upon leaving the dissolver, the excess hydrogen with the hydrogen sulfide, carbon dioxide and light hydrocarbons produced in the reaction are separated from the slurry of undissolved solids and coal solution. The gas is then scrubbed to remove H_2S and CO_2. The excess hydrogen is recycled after removing some of the methane as well as other light hydrocarbons produced in the dissolver. To maintain hydrogen purity in the circulating gas, fresh hydrogen is added before recycling to the dissolving step. The solution is filtered to remove ash and a small amount of insoluble organic material and fractionated to recover the solvent. Small quantities of hydrocarbon gases and light liquids are produced. The primary product is solvent refined coal, a heavy organic material which has a melting point of about 350° F. It contains about 0.1% ash and less than 1% sulfur. The heating value is about 16,000 B.t.u.'s per pound regardless of the quality of the coal input. All of the inorganic sulfur and 60 to 70 percent of the organic sulfur in the coal is removed in the solvent refining process.

The hydrocarbon gas produced can be used as process fuel or sold. The CO_2 and H_2S after conversion to sulfur are potential by-products. Potential uses for the mineral residue are (1) fuel, (2) gasification, (3) raw material in cement or mineral wool manufacture, and (4) as source of sulfur and iron depending on the origin of the coal.

The solvent refined coal can be used directly as liquid fuel or it can be solidified for storage. This product can be remelted and burned as liquid or pulverized and burned as a solid fuel. The product can be processed in a delayed coking unit. The coke could be used in the ferrous metals industry or converted to carbon electrodes for metallurgical and chemical applications. The liquid resulting from the coking operation could be utilized directly, or alternately blended with solvent refined coal to produce a heavy liquid fuel.

2. Extraction and Hydrogenation

Raw coal is crushed and suspended in a heavy recycle distillate stream. The slurry passes through a preheater to achieve a temperature from 700° to 800° F. and into an extractor. The effluent from the extractor is filtered and the char containing the unextracted carbon with the mineral residue is separated. The extract is then hydrogenated and fractionated into a clean fuel oil and a heavy distillate stream recycled to the extraction step. The char can be gasified or utilized as fuel. Sulfur can be recovered as a byproduct.

3. Carbonization and Hydrogenation

In this process, coal is upgraded to gas, oil, and char by heating in multistage fluidized beds. In these stages, dried and crushed coal is shockheated to successively higher temperatures until a major fraction of the volatile matter of the coal is evolved. The optimum temperature and number of stages vary with the type of coal. Stage temperatures are selected to be just short of the maximum to which the coal can be heated without softening and agglomerating into larger particle sizes which would interfere with fluidization.

Heat for the pyrolysis is obtained by burning a portion of the char with oxygen in the last stage. The hot gases flow countercurrently from the last stage to supply heat for the intermediate stages. The first stage fluidizing medium is supplied by burning a portion of the product char or gas.

The oil product is sent to the hydrotreater for conversion to fuel oil. The gas after processing is a soluble product. The hydrogen for the oil hydrotreating could be produced from this gas or from the char. The residual char would be used as a powerplant fuel or, preferably, be gasified.

4. Direct Hydrogenation

Powdered coal, usually minus 100 mesh, is slurried with recycle oil produced from coal. The slurry with the addition of hydrogen is preheated and charged to an ebullated bed reactor containing a catalyst which is suspended in the lower liquid phase in the reactor by recirculation of a liquid stream. Gas from the reactor is recycled after scrubbing along with fresh hydrogen makeup. The product from the reactor is separated by flashing and distillation to recover fuel oil and recycle slurry oil. The slurry material remaining after flashing can be vacuum flashed or separated by centrifuge to obtain classified liquid and a solids concentrate which could be used as fuel or gasified. The gas would be processed to remove sulfur.

Advantages

Use of clean coal liquids will decrease capital and operating costs for powerplants by eliminating the need for extensive fly ash removal and gaseous air-pollution control equipment. Also, the consistent fuel characterisitics would be less costly standard boiler design with improved efficiency. They will eliminate erosion of equipment in the combustion cycle due to ash particles, which is of particular importance in gas turbines. Another promising use could be in magnetohydrodynamic power generation and fuel cells.

Research and Development

Bench scale development and pilot plant work has developed sufficient information for design of a pilot and demonstration plants. This work is continuing to determine the effect of operating conditions on each process for a variety of coals from lignite to high-volatile bituminous in rank. Operation of the plant will provide data necessary for commercial-scale development.