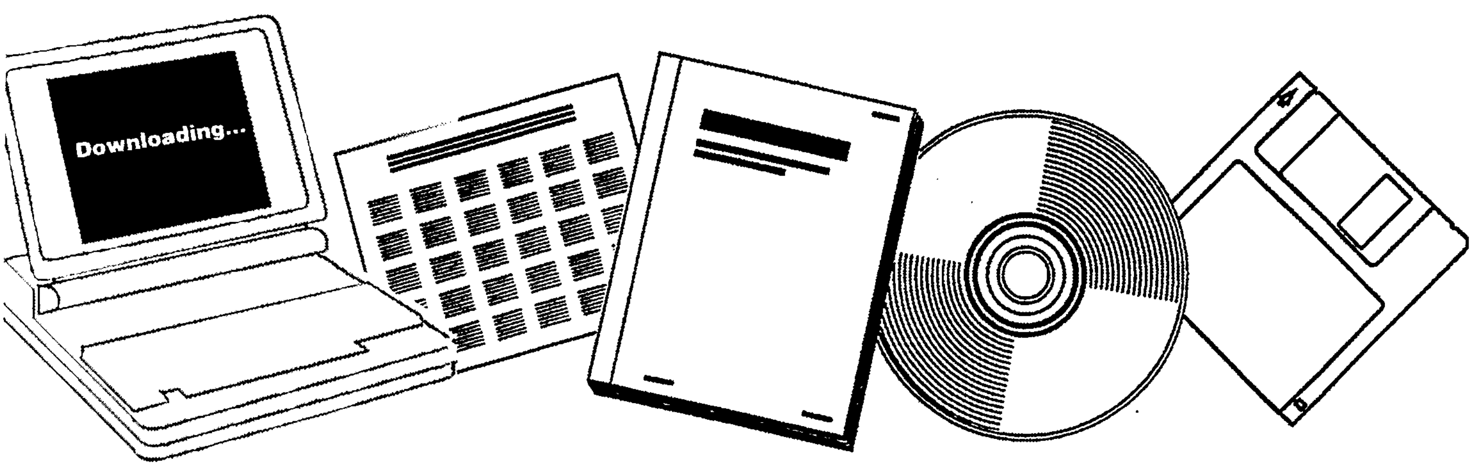
DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS. MONTHLY PROGRESS REPORTS, JANUARY--DECEMBER 1965

INSTITUTE OF GAS TECHNOLOGY, CHICAGO, ILL

1965



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DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Monthly Progress Reports for the Period January - December 1965

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Institute of Gas Technology
IIT Center
Chicago, Illinois 60616

MASTER

Prepared for

Office of Coal Research
U. S. Department of the Interior

OCR Contract No. 14-01-0001-381*

*This contract evolved into OCR Contract No. 14-32-0001-1221 in 1972

FE---81-T-2

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IGT-MPR--1/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report - January 1965

to

Office of Coal Research
Contract No. 14-01-0001-381

Hydrogasification

Rebuilding of the hydrogasification reactor heating furnace was continued. Three of the furnace heating elements have been installed in the reactor shell. Installation of the remaining four heating elements, received from an outside fabricator at the end of the month, was resumed immediately.

To complete the hydrogasification pilot unit modifications outlined in the November 1964 Work Report, fabrication and construction work was continued.

Fabrication of the major assembly components for the elimination of the reduction in cross-section at the reactor bottom and for the screw-feed discharger has been nearly completed. A 4-in.-diameter expansion bellows, to match the diameter of the new reactor tube, has been received from the fabricator. Installation of a coal residue receiver with a larger capacity than the original receiver has been started.

Instrumentation and control valving of the pressure-balancing system between the reactor tube and the outer shell have been installed. Electrical wiring of the system was begun.

Coal Pretreatment

Five coal pretreatment tests were conducted in the continuous-flow fluid pretreater. The purpose of these tests is to define minimum pretreatment conditions for producing nonagglomerating char for the hydrogasifier.

Nominal conditions for these tests are given below:

Run No.	Solids Rate, lb/hr	Avg Solids Residence Time, hr	Gas Rate, SCF/hr	Oxygen, %	Temp, °F
7	131	0.45	800	4	755
8	86	0.43	834	21	680
9	71	0.67	599	21	305
10	50	1.14	603	21	700
11	49	0.89	603	21	765

Oxygen concentrations were increased to 21 percent (air) when it was found that treatment with 4 percent oxygen did not produce a nonagglomerating char. Because the increase in oxygen concentration alone was not sufficient for making the coal nonagglomerating, the coal residence time was increased to about 1 hour. Laboratory tests of the char at conditions simulating those in the hydrogasifier showed the char of Run 10 to be nonagglomerating. Test results of the char produced in Run 11 are not yet available.

Methanation

A meeting was held with Dr. Carberry, consultant on this work, to complete the design details for the reactor and to begin planning the test program. The major pieces of equipment have been designed for the laboratory-scale methanation studies. Suppliers were selected for the purchase of the major pieces of equipment. Designs of the barricading and other facilities, which will be required before the equipment can be operated in the new building, was completed.

Coal Characterization

Dynatech Corp. completed prints of the equipment and instrumentation for the high-temperature, high-pressure heat-of-reaction calorimeter and submitted them for revision and approval. Plans were made for a meeting with them to finalize the design details. The barricades for this unit, which will be located in the new building, were designed.

Work on establishment of a coal petrographic laboratory was continued. United States Steel Applied Research Laboratories were visited to obtain information on their methods and apparatus. Delivery of the microscope was completed except for two objectives. Training in maceral recognition and point count analysis was started, and work on mounting and polishing coal (Pittsburgh No. 8 seam and Ohio No. 6 seam) and coal pretreatment products was continued. Shop fabrication of apparatus parts for the reflectance determination was nearly completed. Work on this aspect will be continued when the reflectance standards and test samples are received from Bituminous Coal Research, Inc.

Process Concept Development

The computer model for catalytic cleanup methanation was used to develop data to establish probable best areas of operation. It was decided to incorporate into the model tests for probable carbon deposition on the catalyst based on system conditions. This model will enable a better definition of the best conditions for achieving operability of the catalyst.

Economic Evaluation

Work was continued on selecting favorable conditions for the state-of-the-art design. Pipeline gas compositions have been determined for the 60 percent total carbon conversion cases. This series of cases also shows an increase in hydrogen requirements with an increase in the temperature of the high-temperature zone.

The bare cost of the hydrogen, oxygen, and methanation sections has been completed. Cost of the hydrogen and oxygen sections increased with an increase in temperature and total carbon conversion. There is no real cost trend for the methanation section, since several of the gases had to be processed differently to obtain the desired product gas.

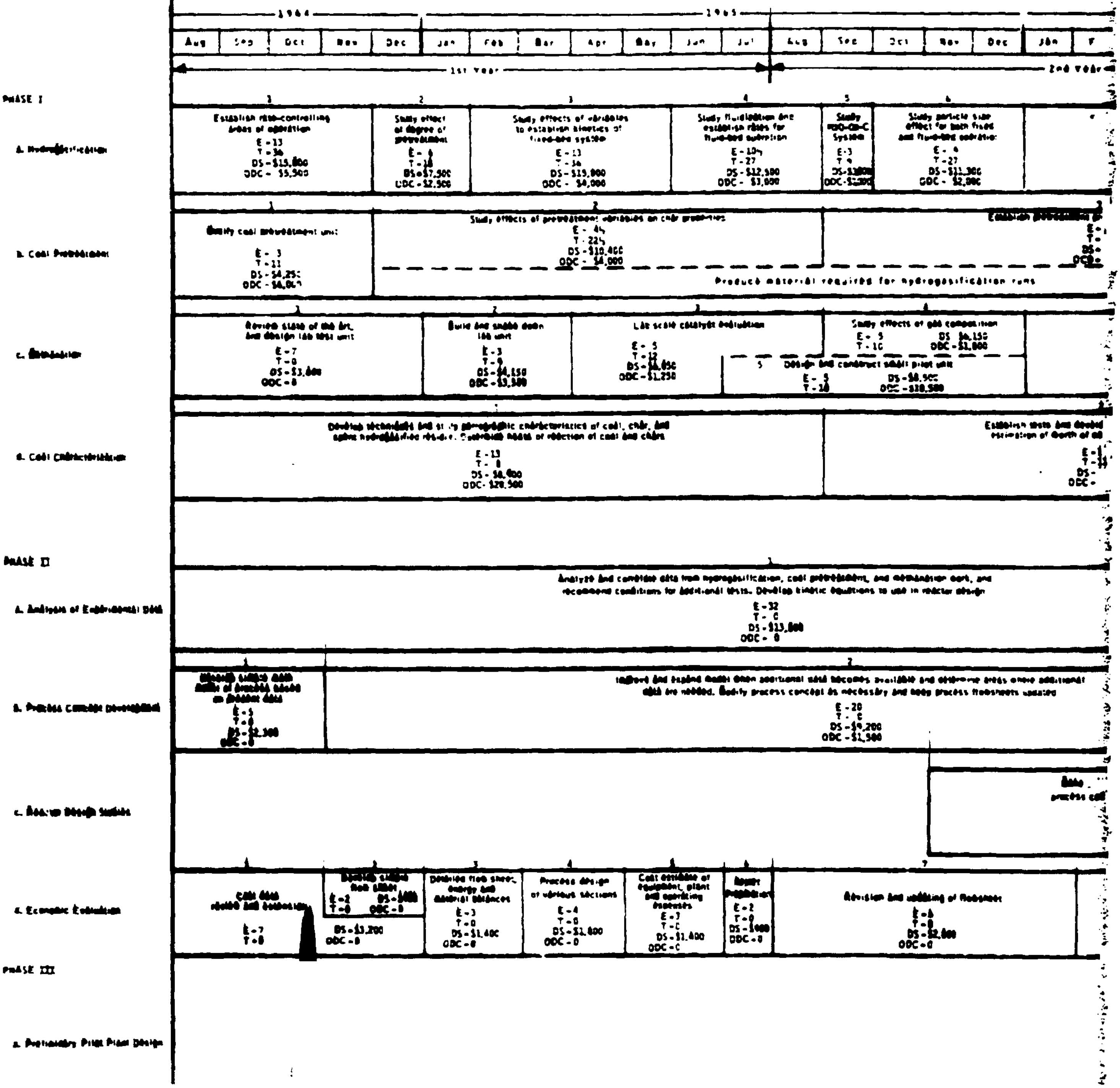
Process materials for the gasifier and hydrogasifier have been determined. The coal and steam for the hydrogasifier decrease as the temperature and total carbon conversion increase, but all other materials increase.

No inventions were made during the month of November on this project. All equipment deliveries for the reactor furnace were back on schedule. Heating element wire, delayed aboard an inbound freighter from Sweden by the dock strike, was replaced by a second shipment which was flown in.

Jack Huebler, Associate Director   Frank Schora, Manager

PROGRAM FOR DEVELOPMENT OF IGT

OCR: Contract No 14-01-0001 381



	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Planned	855,400	23,500	23,500	23,500	23,[illegible]	22,400	24,100	24,300	24,700	23,700	23,300	23,800	30,300	29,300	27,800	27,400	28,100	28,100	23,300
Actual:		0,000	15,000	23,300	14,500	23,000	21,100												
Cumulative		10,000	25,000	48,300	62,800	85,800	06,900												

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

Manpower shown in total man months. E - Engineers
T - Technicians

Costs shown are costs to OCR as one-half of

T HYDROGASIFICATION PROCESS

1 AGA PB 23a

1966											1967						
Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

Year — 3rd Year

1

Study hydrogasification of various coals, lignite, under most suitable conditions
E - 214
T - 63
DS - $21,200
ODC - $7,000

2

Perform any support work necessary for phase III
Double check data on which pilot plant is being designed

1

... properties of various coals
E = 94
T = 274
DS = $11,800
ODC = $4,500

4

Produce material needed for any hydrogasification runs

1

Run small pilot unit and develop kinetic equations for design
E - 18
T - 19
DS - $11,500
ODC - $1,250

2

Perform any support work necessary for phase III

2

... develop conditions to enable ... of coal for hydrogasification
E = 14
T - 11
DS - $10,250
ODC - $500

Laboratory and Pilot Plant Phase I-A8, B4, C7 II-A2	Engineers 24	Salaries $40,400
	Technicians 105	Other Direct Costs 11,400

2

Perform analysis of past data and new data in any areas necessary for phase III work

...

1

... preliminary reactor design based on ... concept and hydrogasification results
E = 5
T = 0
DS = $2,800
ODC = 0

2

Work with subcontractor on design of reactors for hydrogasification and methanation
E = 4
T = 0
DS = $1,800
ODC = 0

3

Revision and refinement of capital and operating costs
E = 6
T = 0
DS = $2,800
ODC = 0

4

Work with subcontractor on capital and operating costs for pilot plant
E = 9
T = 3
DS = $4,100
ODC = 0

1

Develop pilot plant flowsheet with heat and material balances
E = 16
T = 3
DS = $7,700
ODC = 0

Select architect-engineer subcontractor

2

With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.*
E = 38
T = 0
DS = $16,300
ODC = 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

23,300	23,300	23,300	23,300	23,300	23,300	15,800	15,800	15,800	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

... of total costs. DS - Direct Salaries, $
ODC - Other Direct Costs, $

IGT-MPR-2/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report – February 1965

to

Office of Coal Research
Contract No. 14-01-0001-381

Hydrogasification

The hydrogasification reactor heating furnace rebuilding was completed with the installation of the remaining four heating elements. All furnace sections were tested for operability and were found to perform normally.

A new 4-in.-diameter reactor tube of type 446 alloy was installed in the furnace, and the ends of the tube welded to the top and bottom reactor shell closures. Reactor tube-wall thermocouples were drawn through the shell wall, sealed in glands, and connected to the appropriate temperature recorder.

Electrical wiring of the differential pressure control system was completed. While failure of the control system is unlikely, rupture disks were installed in the pressure-equalizing line between the reactor tube and the shell as backup protection.

A larger capacity char residue receiver (7.17 cu ft instead of the original 5.1 cu ft) was installed. To discharge char from the reactor into the receiver at smoother and higher rates, a screw discharger was installed in place of the previously used star valve. The coal feed hopper and the coal feeder were reassembled to the top of the reactor. Piping of the hydrogen feed line and steam feed line to the bottom of the reactor was started.

Coal Pretreatment

Four coal pretreatment tests were conducted in the continuous-flow fluid pretreater using Pittsburgh seam bituminous coal from the Ireland mine. These tests are a part of the program for defining minimum pretreatment conditions required to produce a nonagglomerating char for the hydrogasifier.

Nominal conditions for the tests are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Residence Time, hr	Gas Rate, SCF/hr	Oxygen, %	Temp, °F
12	72	1.27	613	2.1	440
13	73	1.00	602	2.2	536
14	78	1.0	590	9.8	666
15	74	1.0	600	10	708

Pretreatment gas in these tests was a mixture of nitrogen and air. It was found that with 2% oxygen concentration in the gas, sufficiently high bed temperatures could not be maintained for adequate coal pretreatment. Earlier tests showed that the temperature necessary for pretreatment could be maintained with 21% oxygen (air). To better define oxygen requirements, further tests were conducted with a 10% oxygen concentration. It appeared that adequate temperatures were maintained with this concentration. Laboratory evaluations of the chars of these tests for agglomerating characteristics have not yet been completed.

Methanation

Planning of the test program continued. Design of minor pieces of equipment began. Quotations were obtained for most of the major equipment and instrumentation, and orders were placed for some major pieces of equipment. The materials for the barricading were ordered and received, and construction was begun. Drawings of part of the equipment to be fabricated by IGT were submitted to the machine shop.

Service facilities for the new laboratory area were selected, and their design begun.

Coal Characterization

A meeting was held with Dynatech Corp. to discuss revisions made in the design of the high-temperature, high-pressure heat-of-reaction calorimeter. As mentioned in the Methanation section above, service facilities for the new laboratory area, to be shared by the calorimeter and the methanation equipment, were selected and design was begun.

A review of the literature on coal petrography to establish how it may be applied to coal hydrogasification has largely been completed. A report on this topic has been prepared by Dr. G. H. Cady, consultant on the project.

Methods for determining true density and apparent particle density for coal and chars have been reviewed. This determination is desired for developing reaction kinetics as applied to the period of free-fall. Apparatus and procedures for these determinations will be set up next month.

Reflectance standards and reflectance test sample were received from Bituminous Coal Research, Inc. Our apparatus for this determination will be checked out next month.

Process Concept Development

Work continued during the month on the mathematical model of the cleanup methanation step. An analysis of various operating conditions for the methanator was conducted to investigate potential carbon-depositing side reactions in order to indicate areas of best probable operation from this standpoint.

Economic Evaluation

The total bare costs have been calculated for all the cases being considered for the state-of-the-art design. They vary from $108,430,000 to $124,308,000. Although there are many conflicting cost trends, the overall total base cost does vary slightly in a particular pattern.

The cost of the total coal required for all the cases under consideration has been determined. Again, there are conflicting trends in total coal usage. As the coal requirement for the hydrogasifier decreases, the coal required for both hydrogen production and power generation increase. The annual cost varies from $23,495,000 to $28,526,500. If char byproduct credit is taken into account, however, the cost varies only from $22,734,200 to $24,631,000. Taking coal byproduct credit into account, there is a slight increase in coal cost with an increase in carbon conversion.

All this data will be presented in the February Work Report. Since there is no overall trend in plant cost, the conditions for the state-of-the-art design cannot be established until gas production costs have been calculated.

No inventions were made during February on this project. A complete review of patents in this area of technology is underway so that patentable ideas will be more readily identified.

Jack Huebler, Associate Director

Frank C. Schora, Manager

PROGRAM FOR DEVELOPMENT OF IGT H[illegible]

OCR: Contract No 14-01-0001-381 A.G.

Schedule: 1964 — Aug, Sep, Oct, Nov, Dec; 1965 — Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec; Jan, Feb, …
1st Year (Aug 1964 – Jul 1965); 2nd Year (Aug 1965 – …)

PHASE I

A. Hydrogasification

1. Establish rate-controlling areas of operation — E - 13; T - 26; DS - $15,000; ODC - $3,500
2. Study effect of degree of pretreatment — E - 6; T - 18; DS - $7,500; ODC - $2,500
3. Study effects of variables to establish kinetics of fixed-bed system — E - 13; T - 36; DS - $15,600; ODC - $4,000
4. Study fluidization and establish rates for fluid-bed operation — E - 10½; T - 27; DS - $12,500; ODC - $3,000
5. Study H_2-CO-C system — E 3; T 4; DS-$3,[illegible]; ODC-$1,[illegible]
6. Study particle size effect for both fixed and fluid-bed operation — E - 9; T - 27; DS - $11,300; ODC - $2,000
7. Study hydrogasif[illegible] under [illegible]

B. Coal Pretreatment

1. Modify coal pretreatment unit — E - 3; T - 11; DS - $4,25[illegible]; ODC - $4,0[illegible]
2. Study effects of pretreatment variables on char properties — E - 8½; T - 22½; DS - $10,400; ODC - $4,000
3. Establish pretreatment properties of [illegible] — E - 5½; T - 27½; DS - $12,[illegible]; ODC - $4,500

Produce material required for hydrogasification runs

C. Methanation

1. Review state of the art, and design lab test unit — E - 7; T - 8; DS - $5,600; ODC - 0
2. Build and shake down lab unit — E - 3; T - 4; DS - $4,350; ODC - $3,500
3. Lab scale catalyst evaluation — E - 5; T - 12; DS - $4,650; ODC - $1,250
4. Study effects of gas composition — E - 5; T 10; DS $4,150; ODC - $1,000
5. Design and construct small pilot unit — E - 5; T - 20; DS - $8,500; ODC - $10,500
6. Run [illegible]

D. Coal Characterization

1. Develop techniques and study petrographic characteristics of coal, char, and spent hydrogasified residue. Determine rates of reaction of coal and chars — E - 13; T - 8; DS - $8,400; ODC - $20,500
2. Establish tests and develop correlations: estimation of worth of coal for hy[illegible] — E - 16; T - 12; DS $10,200; ODC - $500

PHASE II

A. Analysis of Experimental Data

1. Analyze and correlate data from hydrogasification, coal pretreatment, and methanation work, and recommend conditions for additional tests. Develop kinetic equations for use in reactor design — E - 32; T - 0; DS - $13,600; ODC - 0

B. Process Concept Development

1. Develop simple mathematical model of process based on present data — E - 5; T - 0; DS - $2,100; ODC - 0
2. Improve and expand model when additional data becomes available and determine areas where additional data are needed. Modify process concept as necessary and keep process flowsheets updated — E - 22; T - 0; DS - $9,200; ODC - $1,500

C. Reactor Design Studies

1. Make preliminary re[illegible] process concept and hyd[illegible] — E - [illegible]; T - [illegible]; DS - [illegible]; ODC - 0

D. Economic Evaluation

1. Coal data review and extension — E - 7; T - 0
2. Develop simple flow sheet — E - 2; T - 0; DS - $900; ODC - 0 — DS - $1,200; ODC - 0
3. Detailed flow sheet, energy and material balances — E - 3; T - 0; DS - $1,450; ODC - 0
4. Process design of various sections — E - 4; T - 0; DS - $1,600; ODC - 0
5. Cost estimate of equipment, plant and operating expenses — E - 3; T - 0; DS - $1,400; ODC - 0
6. Report preparation — E - 2; T - 0; DS - $900; ODC - 0
7. Revision and updating of flowsheet — E - 6; T - 2; DS - $2,600; ODC - 0

PHASE III

A. Preliminary Pilot Plant Design

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	…
Planned	[illegible]	21,500	21,500	21,500	23,[illegible]	22,400	24,100	24,300	24,700	23,700	23,300	23,[illegible]	30,300	29,300	27,600	27,400	28,100	28,100	23,300	23,300	23,[illegible]
Actual		10,000	15,000	23,300	14,500	23,000	21,100	19,800													
Cumulative		10,000	25,000	48,300	62,800	85,800	106,900	126,700													

Manpower shown in total man months: E - Engineers; T - Technicians

Costs shown are costs to OCR or one-half of total costs.

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HYDROGASIFICATION PROCESS

A.G.A PB 23a

1966 — 1967

Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

3rd Year

7
...y hydrogasification of various coals, lignite, under most suitable conditions
E - 214
T - 63
DS - $27,200
ODC - $7,000

8
Perform any support work necessary for phase III
Double check data on which pilot plant is being designed

...perties of various coals
...5%
...7%
...12,800
...$4,500

4
Produce material needed for any hydrogasification runs

6
Run small pilot unit and develop kinetic equations for design
E - 10
T - 19
DS - $14,500
ODC - $5,250

7
Perform any support work necessary for phase III

... correlations to enable ... for hydrogasification
...
...
...10,200
...500

Laboratory and Pilot Plant Phase I-A8, B4, C7 II-A2 — Engineers 24, Technicians 105 — Salaries $40,400, Other Direct Costs 11,400

2
Perform analysis of past data and new data in any areas necessary for phase III work

1
...minary reactor design based on ... and hydrogasification results
E - 6
T - 0
DS - $2,800
ODC - 0

2
Work with subcontractor on design of reactors for hydrogasification and methanation
E - 4
T - 0
DS - $1,800
ODC - 0

8
Revision and refinement of capital and operating costs
E - 6
T - 0
DS - $2,800
ODC - 0

4
Work with subcontractor on capital and operating costs for pilot plant
E - 9
T - 0
DS - $4,100
ODC - 0

1
Develop pilot plant flowsheet with heat and material balances
E - 14
T - 0
DS - $7,700
ODC - 0
Select architect-engineer subcontractor

2
With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381. *
E - 34
T - 0
DS - $14,300
ODC - 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

...00	23,300	23,300	23,300	23,300	23,300	15,800	15,800	15,800	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

...al costs. DS = Direct Salaries, $
ODC = Other Direct Costs, $

Project Work Report

Institute of Gas Technology • IIT Center • Chicago 60616

Affiliated with Illinois Institute of Technology

Project No.
PB-23a
OCR Contract No.
14-01-0001-381
For Period
February 1965

to American Gas Association – Office of Coal Research

On Pipeline Gas From Coal – Hydrogenation
(IGT Hydrogasification Process)

COAL CHARACTERIZATION

H. L. Feldkirchner
D. M. Mason

ENGINEERING ECONOMICS STUDIES

C. L. Tsaros, Supervisor
S. J. Knabel
A. T. Talwalkar

HIGH-PRESSURE METHANATION

H. L. Feldkirchner

PILOT PLANT STUDIES

Eugene J. Pyrcioch

Approved Jack Huebler
Jack Huebler, Associate Director

Signed Frank C. Schora
Frank C. Schora, Manager

ABSTRACT*

Engineering Economics

The total bare plant costs and gas production costs have been calculated for the cases being considered for the state-of-the-art design study. The total bare plant costs for a 250 MMCF/day plant vary from $117,126,000 to $133,678,000. Although there are many conflicting cost trends, the overall total bare cost tends to vary slightly in a particular pattern. Gas production costs vary from $0.59 to $0.66/MMBtu.

Total coal requirements for the cases under consideration have been determined. Again there are many conflicting trends in total coal usage. The annual cost for coal based on a $5/ton price varies from $23,725,000 to $28,526,000. Assuming char byproduct credit, the coal cost varies from $23,397,000 to $25,606,000, there being only a slight increase in coal usage with an increase in carbon conversion.

Except for coal pretreatment, the process design will follow the form outlined in Fig. 1. A total carbon conversion of approximately 50% will be required in the hydrogasifier to avoid the production of excess char. An operating temperature of 1700°F will be used in the high-temperature zone. Ten % conversion will be used in the low-temperature zone in the state-of-the-art design.

Pilot Plant Studies

Reconstruction of the hydrogasification pilot unit reactor furnace was completed. A new 4-in.-diameter reactor tube with attached thermocouples was installed.

Electrical wiring of the new reactor-shell differential-pressure control system was completed. Rupture disks were installed in a pressure-equalizing line between the reactor tube and the shell to protect the tube from overpressurization in the event of failure of the differential-pressure control system.

A larger capacity residue receiver and a residence discharge screw assembly were installed. The coal feed hopper and the coal screw feeder were reassembled.

Four coal pretreatment tests were conducted in the continuous-flow fluid pretreater as part of the program for developing minimum pretreatment conditions.

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* Abstracts are omitted for those sections whose reports are brief.

WORK IN PROSPECT

Coal Characterization

Calorimetry

Dynatech Corp. will complete the revision of the design of the calorimeter. The new barricading will be completed.

Coal Petrography

Our equipment for determination of reflectance will be checked out. Apparatus and procedures for determination of true and apparent particle density will be set up.

Engineering Economics

Work will begin on the detail process design for the state-of-the-art design.

High-Pressure Methanation

Selection of equipment will be completed and the instrument panels will be fabricated. The new barricading will be completed.

Pilot Plant Studies

The hydrogasification pilot unit will be pressure tested and shakedown operations will be conducted. Hydrogasification tests will be resumed in the pilot unit with hydrogen-steam mixtures.

Coal pretreatment tests will be continued in the fluid pretreater to define optimum pretreatment conditions and to produce feed char for the hydrogasification pilot unit.

Coal Characterization

Calorimetry

Dynatech Corp. continued modification of the original calorimeter design and orders were placed for all major pieces of instrumentation.

The materials for barricading were ordered and some were delivered; construction of the barricading was initiated.

Coal Petrography

Reflectance standards and a test sample were received from Bituminous Coal Research, Inc.

True Density and Apparent Particle Density of Coal and Char

Knowledge of these properties of the hydrogasification feed material is required for calculation of free-fall residence times occurring in the experimental gasification studies. Methods of determination are reviewed here. This review was made in preparation for selecting procedures to be used in our determinations.

To determine true density, the displacement of a fluid that will fill all the pores of the substance must be measured. Helium, water, methyl, alcohol, and other fluids have been used for this purpose from time to time. Because the helium molecule is smaller than most other molecules and thus can more easily penetrate pores, and because it has little tendency to be adsorbed, its determination is generally considered to give the true density.[6] However, several investigators[3,4,5] have shown that helium is adsorbed at room temperature by high-density carbons in amounts sufficient to cause appreciable error in the density. The effect is attributed to the electrical conductivity of graphitized carbons; it has been shown to be appreciable for carbons with densities of 1.9 g/cc and greater, and to be negligible for a number of carbons with densities less than 1.54 g/cc. Determination at elevated temperature is recommended for high-density carbons. It appears, however, that little error should be encountered from this source in measurements at room temperature on hydrogasification feeds and residues, whose densities are not expected to go much above 1.60 g/cc.

Helium densities can be determined with the Beckman air comparison pycnometer, already available in the Institute's analytical laboratories. Some attention will have to be given to procedures for drying and evacuation of the sample.

Particle density of 100 mesh and coarser can be determined by displacement of mercury. The high surface tension of mercury prevents penetration of small pores. At atmospheric pressure, pores down to about 14-micron diameter are penetrated. However, the same effect restricts the filling of small volumes formed about points of contact of the particles. For a given volume of solids, the number of these contact points increases rapidly as the average particle size decreases. Thus the pressure of mercury needed to decrease the sum of these contact volumes to a negligible amount increases as the particle size decreases. According to Cartan and Curtis,[1] pressures greater than atmospheric are required for particles smaller than 20 to 40 mesh, while with a pressure of 100 psi the density of 100-mesh particles (of alumina) have been measured successfully. At this pressure, pores of about 2-micron diameter are penetrated. Higher pressures are probably not feasible with our samples because coals and residues are likely to have appreciable porosity in this size range ($<2\mu$).

Particle density of finer particles can be determined and results from the mercury displacement method on coarse particles checked by means of Ergun's gas flow method.[2] This method is based on measurements of the pressure drop vs. air flow across beds of the powder packed to several different bulk densities. The apparatus is not difficult to construct or run, but requires about 100 grams of a sieve fraction as sample.

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Engineering Economics Studies

Survey of Pipeline Gas Plant Economics

In order to select a favorable basis for making the state-of-the-art design of a plant that will make pipeline gas from coal, a preliminary economic survey of operating variables has been completed. The design under study will use a hydrogen-steam feed to an autothermic hydrogasifier. The study of the effect of total carbon conversion and temperature level in the hydrogasifier on pipeline gas costs was made practical by the availability of a computer program to calculate effluent gas compositions for a large number of cases. Because of the nature of this survey, detailed designs were not made for each case. Instead, unit costs, as a function of capacity, were used to determine investment for a number of sections of the plant such as coal storage, grinding, gas prepurification, oxygen production, hydrogen production, and utilities. These unit costs were derived from a previous study of coal hydrogasification using hydrogen rather than a hydrogen-steam mixture.

Design Basis

This study is based on the process shown in Fig. 1. It was assumed that pretreatment of the coal fed to the hydrogasifier was not required. In a few cases, a portion of the carbon monoxide had to be shifted because the hydrogen concentration was too low for methanation.

In this study, the cost of the coal was assumed to be \$5/ton. The char credit was based on the equivalent cost of heat from coal at \$5/ton. The gas prices were calculated according to the A.G.A. accounting procedure.

Coal Storage

This section consists of equipment for receiving, storing, and reclaiming incoming coal. No detailed process design was undertaken on this section. The cost was determined from costs from the previous study.

Coal Preparation

In this study, the only preparation considered was grinding of the coal feed to the gasifier and hydrogasifier. Actual pretreatment of the hydrogasifier feed coal was not considered as the study was comparative in nature and free-fall devolitilization was assumed. The coal burned as fuel for steam generation was assumed usable as received, without grinding. No treatment or further grinding of the hydrogasifier char fed to the gasifier, or used as fuel, was considered. The bare cost was estimated from the costs determined in the earlier hydrogasification study.

Hydrogasification

This section consists of feed hoppers, hydrogasifiers, residue hoppers, vent-gas surge drums, vent-gas compressors, and hydrogen steam preheat furnaces. Hoppers and vent-gas equipment were sized directly on the basis of volume of solids handled. Hydrogasifiers were all the same size, with the design consisting of a coal preheat section, free-fall devolatilization zone, and a high-temperature reaction zone. The number of hydrogasifiers was set by the allowable solids throughput in the high-temperature reaction zone. There is no pilot plant data available which permits an estimate of the effect of temperature on solids conversion rate. However, data obtained from H. F. Feldkirchner's tests in a semiflow reactor showed that a higher reaction rate will occur as the gasification temperature rises.[2] This correlation showed that specific carbon gasification rate is a function of temperature, percent of carbon gasified, and percent of steam in the feed stream. At the design hydrogasifier conditions used in the current study, the above correlation showed that carbon conversion rates for the 1900° and 2000°F cases are severalfold higher than for the 1700° and 1800°F cases. However, it was found that at hydrogasifier conditions in our study, each pair of temperatures represented similar rate levels.

Rates based on semiflow data do not account for effects of mass transfer that would occur in a countercurrent reactor. These effects would reduce the rate of conversion; to account for them and still show the relative rate advantage of 1900° and 2000°F temperatures in the high-temperature zone, residence times for the 1700° and 1800°F cases are based on 0.5 hour for 50% carbon conversion, with relative rates for 40% and 60% conversions being adjusted in accordance with the semiflow data correlations. For 1900° and 2000°F operation, the rates at corresponding conversion levels were doubled, thus halving the number of hydrogasifiers.

Hydrogasifier calculations were based on steam and process hydrogen entering the reactor at 1200°F. Heat was assumed to be recovered from spent char, with the difference between required and recovered heat being obtained in a separate furnace. The cost of this unit was based on heat transfer duty. Table 1 shows the composition of the hydrogasifier effluent and the pipeline gas.

Gas Prepurification

This section consists of hot carbonate scrubbing and adsorption by activated carbon and iron oxide. Table 2 shows the operating conditions for the hot carbonate process. The target CO_2 concentration remaining in the gas was 2% with variation from 1%-3% depending upon the methanation equilibrium and pipeline gas heating value. The cost for the hot carbonate process was estimated from an article by H. E. Benson.[1] The cost for the activated carbon and iron oxide boxes was calculated from the earlier study.[3] Since the total gas flow rate did not vary significantly in this study, the costs of these items were considered constant.

Methanation

The method of estimating the cost of the methanation section was described in the January 1965 Work Report. The methanation reactor was sized by equilibrium correlations obtained from the Girdler Company. These correlations are based on data obtained from low-pressure gases with a small hydrogen concentration. The heat of reaction is assumed to be removed by cooling a portion of the effluent and recycling it back to the inlet of the reactor. The cost of the individual components of the section was estimated to obtain a bare cost.

Oxygen Production

This section consists of a complete oxygen plant; the cost for it was based on 1600-ton/day plants. Linde's largest plant to date used 1250 tons/day. Their representative indicated that a 1600-ton/day unit would be reasonable by the 1970's when this plant would be built. In this study, two 1600-ton/day plants were used along with a smaller unit. (For one case, however, three 1600-ton/day plants were used.)

The oxygen costs were determined for two cases according to the A.G.A. accounting procedure. The oxygen plant contributes $0.06-$0.10/MMBtu to the gas price. The total cost for oxygen is about $5.70/ton. Approximately 650 hp-hr/ton of oxygen is required.

The bare cost for this section was calculated from Fig. 3 in the January-February 1964 Work Report.

Hydrogen Section

This section will produce the hydrogen to be used in the hydrogasifier. The system used in the January-February 1964 Work Report was also used in this study. Table 3 shows the process data for the hydrogen plant; the bare cost was estimated from Fig. 1 of the January 1965 Work Report.

The cost for the hydrogen produced by this process is about $0.27/MCF. The cost of hydrogen (including O_2) constitutes 40%-60% of the gas price.

Offsite Facilities

This section consists of a steam generation plant, an electrical generation plant, a water treatment plant, and cooling water facilities.

Table 4 shows the various utilities required in each of the sections. The cost estimate for this section was based on the unit costs used in the January-February 1964 Report.

Conclusions

Table 5 shows the materials required for the plant. Figs. 2-4 and Table 6 show the bare cost for the entire plant. The total bare cost increased as the total carbon conversion increased from 40% to 60%. With regard to temperature, the bare cost reached a maximum at 1800°F.

The gas prices are shown as a function of total carbon conversion in Fig. 5. The gas price increases as the total carbon conversion increases from 40% to 60%. Since there was considerable excess char in the 40% cases, no calculations were made to try to obtain an optimum below 40%. At the present time, it is planned to base the state-of-the-art design on a system with little or no excess char.

The 10% carbon conversion in the low-temperature zone is more attractive. In the computer program used for calculating the hydrogasifier operation, the assumption was made that there was no heat produced in this zone. Therefore, not as much steam decomposed so more external hydrogen was required.

At present, 1700°F appears to be the most economical operating temperature. If the system is to operate with little or no excess char, the total carbon conversion would have to be about 50%. If the excess char is not objectionable, the 40% case would be more economical.

REFERENCES CITED

1. Benson, H. E., "Hot Carbonate Plants: How Pressure Affects Costs," Petrol. Refiner 40, 107-08 (1961) April.

2. Feldkirchner, H. L. and Huebler, J., "Pipeline Gas From Coal — Hydrogenation: Reactions of Coal With Hydrogen and Steam at High Temperatures and Pressures," Report No. 6, Project PB-23a May 1964.

3. Khan, A. R., Feldkirchner, H. L. and Joyce, T. J., "Techno-Economic Evaluations of Hydrogasification of Coal and Char," Report to PB-23a Supervising Committee, January 1964.

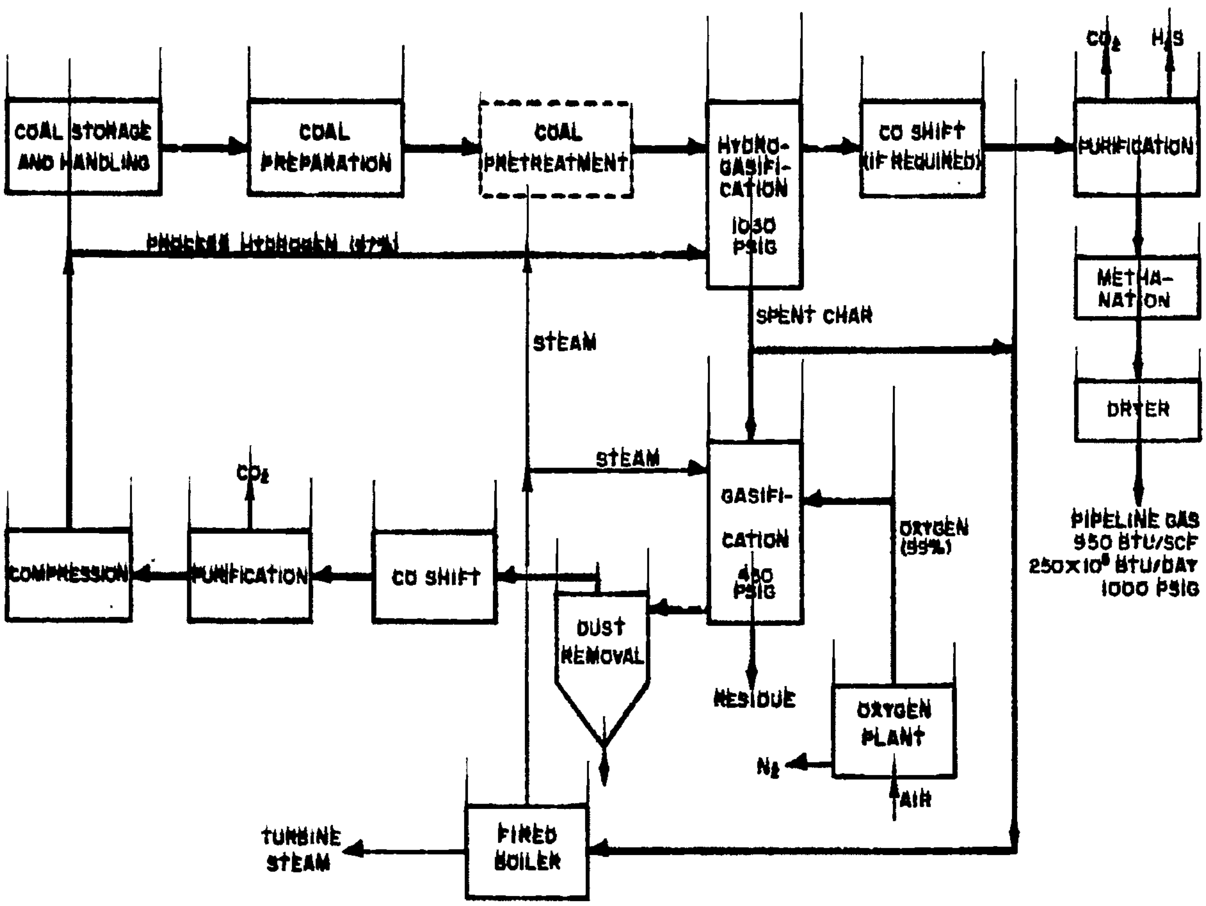

Fig. 1.-PIPELINE GAS BY HYDROGASIFICATION OF COAL

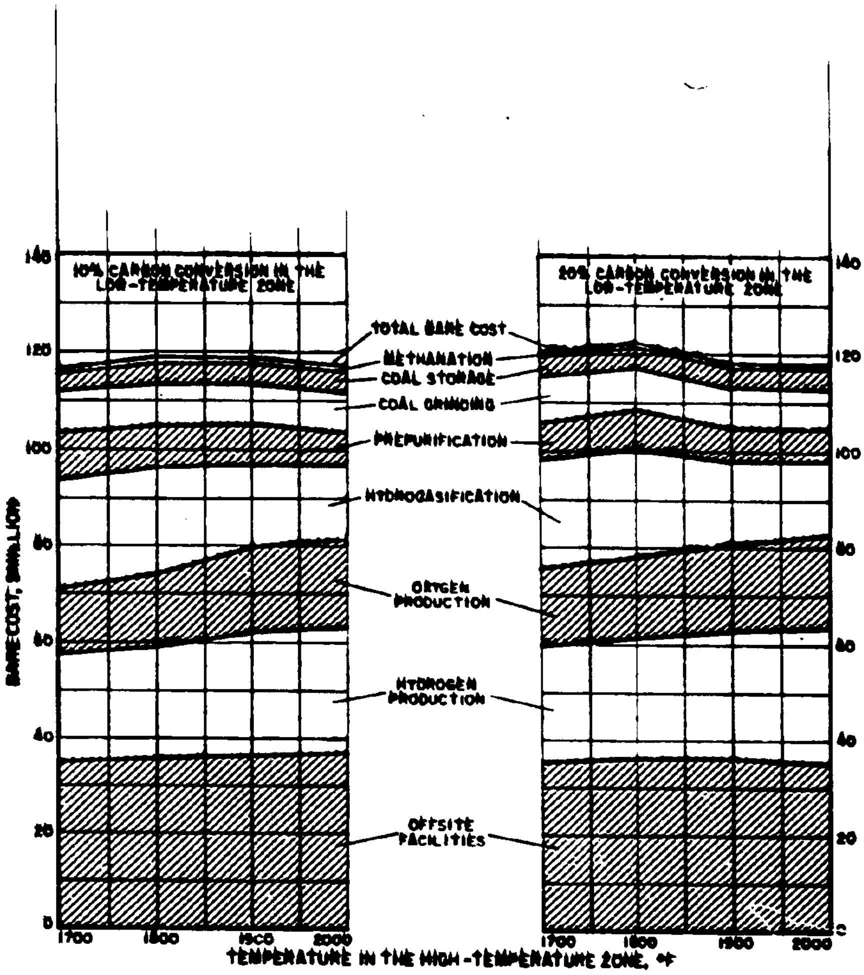

Fig 2.-BARE COST VS TEMPERATURE IN THE HIGH-TEMPERATURE ZONE FOR 40% TOTAL CARBON CONVERSION

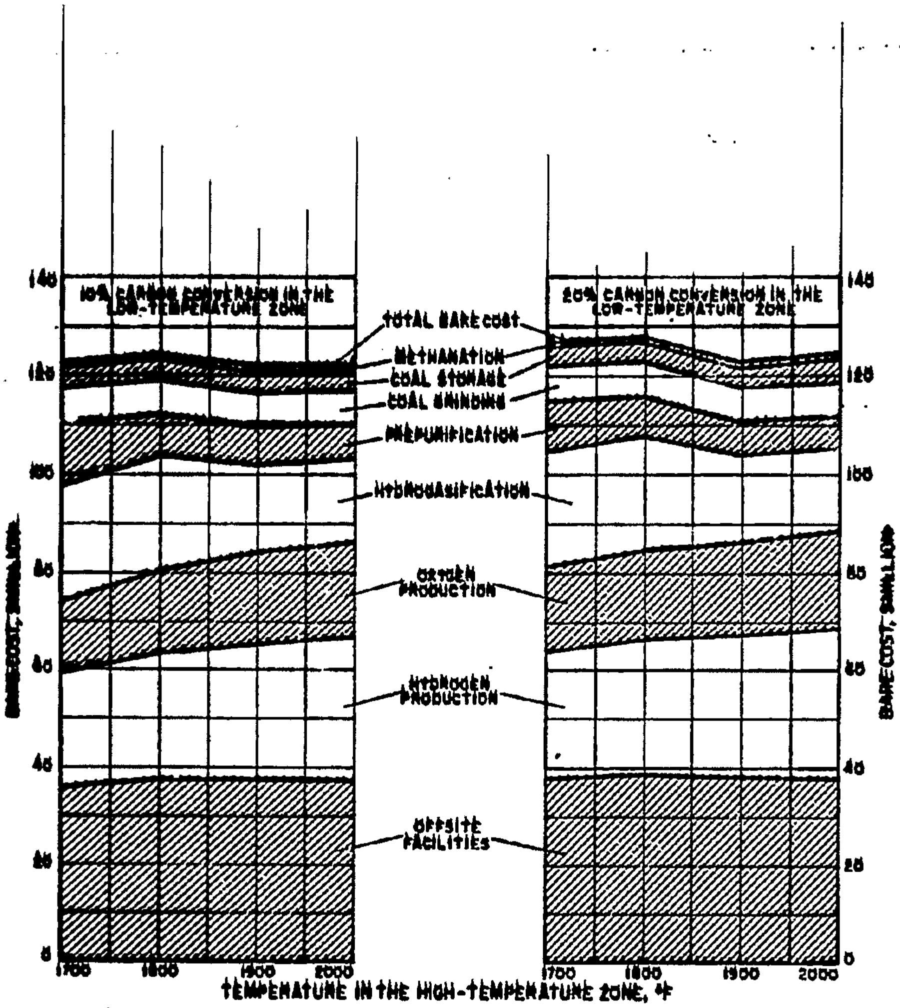

Fig. 3.-BARE COST VS. TEMPERATURE IN THE HIGH-TEMPERATURE ZONE FOR 50% TOTAL CARBON CONVERSION

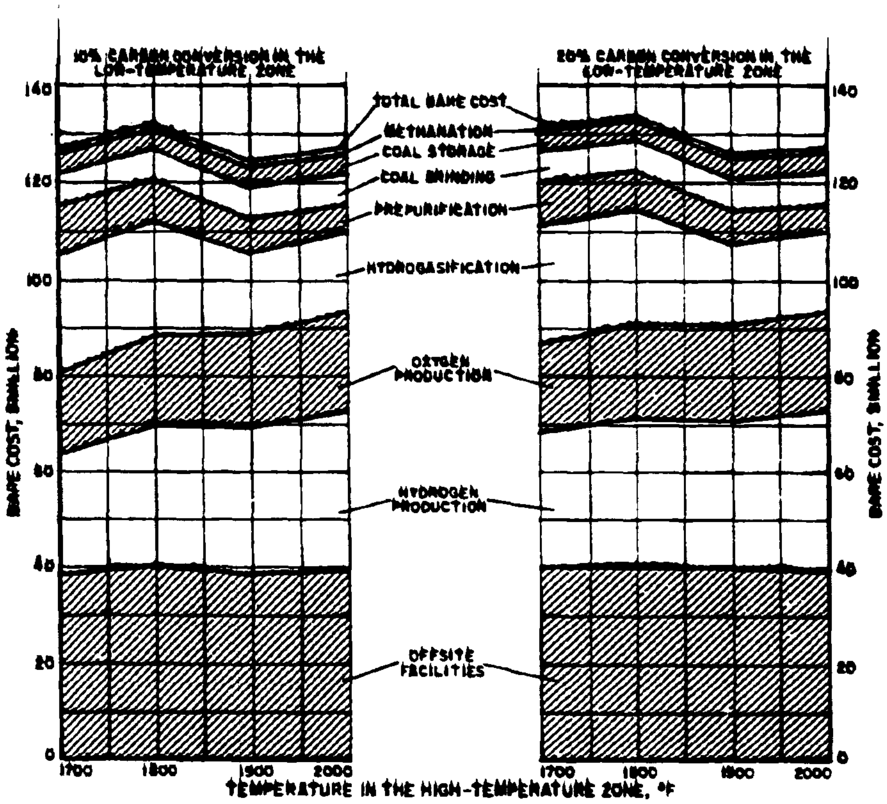

Fig. 4 -BARE COST VS TEMPERATURE IN THE HIGH-TEMPERATURE ZONE FOR 60% TOTAL CARBON CONVERSION

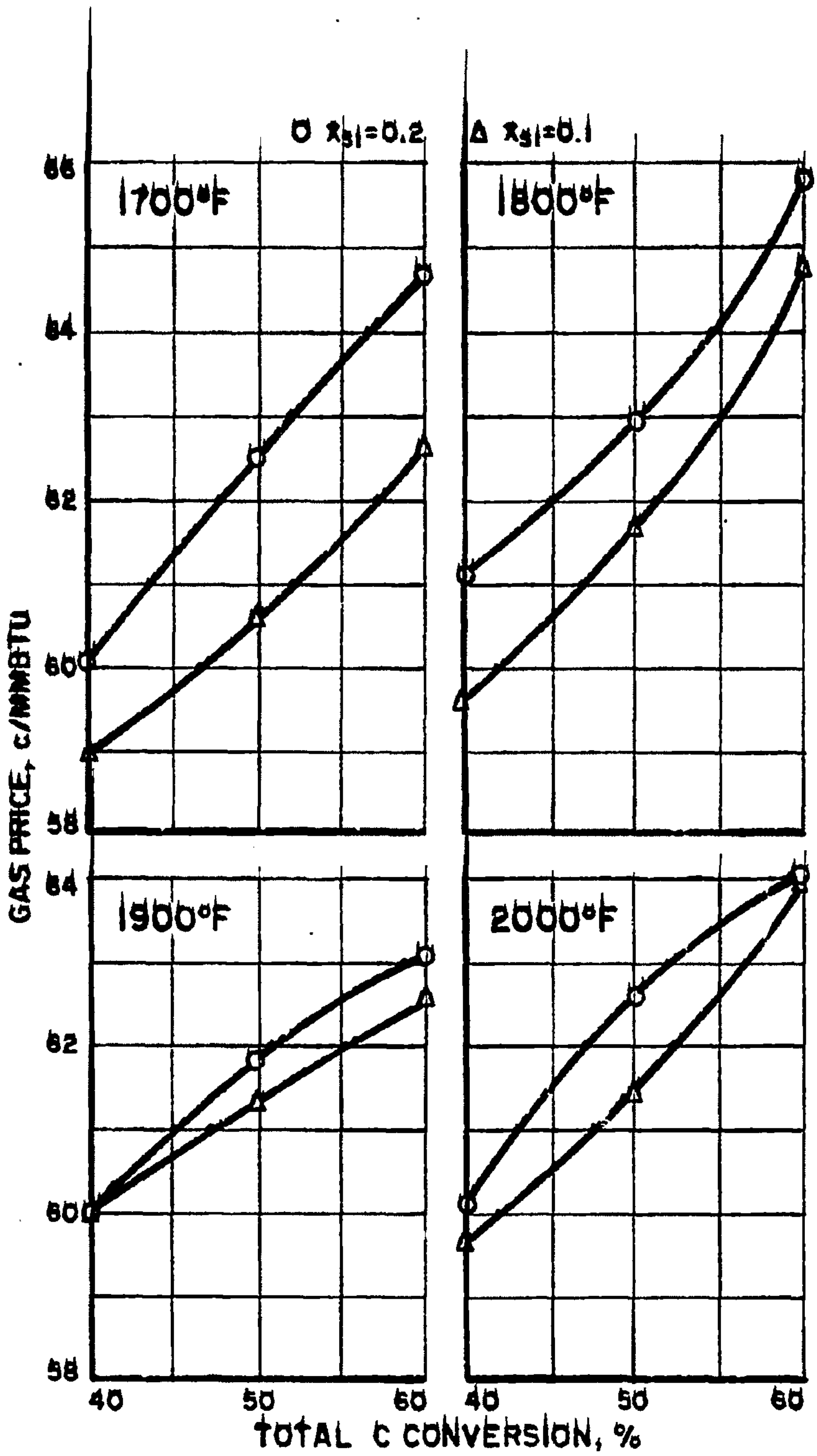

Fig. 5.-CORRELATION OF GAS PRICE WITH TOTAL CARBON CONVERSION AT VARIOUS TEMPERATURES (Temperatures Given Refer to High-Temp Zones)

Table 1.-SUMMARY OF HYDROGASIFIER OPERATION WITH STEAM-HYDROGEN FEEDS AND CALCULATED PIPELINE GAS COMPOSITIONS (Quantities Based on 100-Lb Coal Feed)

Temperature in High-Temperature Zone, °F	1700						1800					
Fraction Feed Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2.
Total Fraction Feed Carbon Converted	0.4	0.4	0.5	0.5	0.6	0.6	0.4	0.4	0.5	0.5	0.6	0.6
Hydrogen/Coal Ratio, % of stoichiometric	15	17	19	23	26.0	31.0	16	18	23	26	34.0	36.0
Moles Hydrogen Feed	1.8775	2.1278	2.378	2.879	3.2543	3.8802	2.0027	2.2530	2.879	3.2543	4.2557	4.5060
Moles Steam Feed	1.4856	1.2874	2.378	2.394	3.8855	3.8802	1.5586	1.3444	2.539	2.4846	3.6707	3.5155
Feed Steam Decomposed, %	43.3	20.8	46.6	29.2	42.0	30.5	41.0	18.5	41.0	25.8	42.6	33.3
Moles Hydrogasifier Effluent	4.1242	3.6138	5.4164	5.3446	7.4409	7.4453	4.3314	3.7932	6.0254	5.8045	7.7960	7.4226
Composition, mole %												
CH_4	45.2	59.3	41.1	47.1	35.64	39.68	42.9	56.5	37.3	43.5	35.45	40.65
H_2	16.8	0.2	17.2	8.0	18.13	12.18	19.0	2.9	21.8	12.9	23.81	16.69
CO	4.6	(<0.1)	4.5	1.3	3.43	1.55	4.7	0.5	4.5	1.8	3.88	2.07
CO_2	11.0	9.9	12.1	10.1	11.32	9.15	10.3	9.0	10.1	8.6	8.70	7.76
N_2	0.9	1.1	0.8	0.8	0.59	0.59	0.9	1.0	0.7	0.7	0.57	0.60
H_2S	1.1	1.3	0.9	0.9	0.62	0.62	1.0	1.2	0.8	0.8	0.58	0.62
H_2O	20.4	28.2	23.4	31.8	30.27	36.23	21.2	28.9	24.8	31.7	27.01	31.61
Total	100.0	100.0	100.0	100.0	100.00	100.00	100.0	100.0	100.0	100.0	100.00	100.00
Dry Pipeline Gas Composition, mole %												
CH_4	93.0	95.9	93.3	94.3	89.5	90.7	91.9	96.1	90.2	87.8	83.9	87.2
H_2	3.2	0.3	3.6	3.2	8.8	7.8	5.0	1.4	6.1	10.4	14.8	11.5
CO	<0.1	<0.1	<0.1	<0.1	(<0.1)	(<0.1)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CO_2	2.0	2.0	1.5	0.9	0.4	0.2	1.3	0.7	1.3	0.4		
N_2	1.7	1.7	1.5	1.5	1.3	1.3	1.7	1.7	2.3	1.3	1.2	1.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pipeline Gas Heating Value, Btu/SCF	952.5	972.5	956.4	965.0	934.7	943.4	946.3	977.9	932.8	922.3	897.7	920.3
MMBtu/100 lb coal	0.7997	0.8224	0.9680	1.0161	1.1778	1.2372	0.8128	0.8348	1.0255	1.0672	1.2810	1.3014
Moles Hydrogen/MMBtu	2.35	2.59	2.46	2.84	2.763	3.136	2.47	2.70	2.81	3.05	3.322	3.462

Table 1.- Cont, SUMMARY OF HYDROGASIFIER OPERATION WITH STEAM HYDROGEN FEEDS AND CALCULATED PIPELINE GAS COMPOSITIONS (Quantities Based on 100-Lb Coal Feed)

Temperature in High-Temperature Zone, °F	1900						2000					
Fraction Feed Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Total Fraction Feed Carbon Converted	0.4	0.4	0.5	0.5	0.6	0.6	0.4	0.4	0.5	0.5	0.6	0.6
Hydrogen/Coal Ratio, % of stoichiometric	19.0	20.0	26	28	36.0	38.1	21	22	29	31	42.1	43.1
Moles Hydrogen Feed	2.378	2.503	3.2543	3.5047	4.5060	4.7563	2.6285	2.7537	3.6230	3.8801	5.2570	5.3822
Moles Steam Feed	1.1214	0.8091	1.6613	1.5526	2.1272	2.0050	0.7432	0.4522	1.0760	0.9254	1.4798	1.3455
Feed Steam Decomposed, %	47.1	22.5	52.0	36.0	55.8	43.3	56.0	22.5	64	45	61.5	48.2
Moles Hydrogasifier Effluent	4.2716	3.4882	5.5264	5.1169	6.7867	6.4166	4.1389	3.3680	5.2930	4.8403	6.8118	6.3540
Composition, mole %												
CH_4	43.5	61.8	40.8	49.4	40.27	46.69	44.9	64.2	42.8	52.5	40.96	47.67
H_2	25.6	7.9	27.4	17.8	29.54	22.39	29.6	12.8	31.8	23.1	35.23	28.52
CO	7.3	1.8	7.7	3.7	7.78	4.60	10.2	3.9	11.2	6.4	9.62	6.48
CO_2	7.8	8.2	8.1	8.0	7.23	7.20	5.4	6.3	5.1	5.7	4.52	4.93
N_2	0.9	1.1	0.7	0.8	0.65	0.69	0.9	1.1	0.8	0.8	0.65	0.70
H_2S	1.1	1.3	0.9	0.9	0.67	0.72	1.1	1.3	0.9	1.0	0.66	0.73
H_2O	13.8	17.9	14.4	19.4	13.86	17.71	7.9	10.4	7.4	10.5	8.36	10.97
Total	100.0	100.0	100.0	100.0	100.00	100.00	100.0	100.0	100.0	100.0	100.00	100.00
Dry Pipeline Gas Composition, mole %												
CH_4	92.1	94.8	90.9	93.2	90.2	90.7	90.0	95.0	93.2	93.1	89.4	90.2
H_2	4.1	2.7	5.5	3.6	6.9	7.4	7.1	1.8	4.0	3.5	7.3	7.7
CO	<0.1	<0.1	<0.1	<0.1	<0.1	(<0.1)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CO_2	2.1	0.8	2.2	1.7	1.6	0.7	1.3	1.5	0.9	2.0	2.0	0.9
N_2	1.6	1.6	1.3	1.4	1.2	1.2	1.5	1.6	1.8	1.3	1.2	1.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pipeline Gas Heating Value, Btu/SCF	945.7	968.2	938.2	955.5	935.2	942.1	934.5	967.6	957.6	954.4	929.3	938.6
MMBtu/100 lb coal	0.8486	0.8596	1.0542	1.0765	1.2966	1.3213	0.8746	0.8831	1.0891	1.1129	1.3691	1.3819
Moles Hydrogen/MMBtu	2.80	2.91	3.09	3.26	3.475	3.600	3.01	3.12	3.33	3.48	3.840	3.895

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Table 2.-OPERATING DATA FOR THE PREPURIFICATION SECTION

Fraction of Total Carbon Converted	0.4							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
CO_2 Removed, moles/100 lb coal	0.4247	0.3047	0.3858	0.3179	0.3012	0.2218	0.1873	0.1922
H_2S Removed, moles/100 lb coal	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453
$CO_2 + H_2S$ Removed, moles/hr	6,122	4,433	5,525	4,532	4,259	3,225	2,770	2,801
$CO_2 + H_2S$ to be Removed, moles/day	146,931	106,396	132,597	108,769	102,208	77,391	66,488	67,235
$CO_2 + H_2S$ Removed, MCF/day	55,613	40,271	50,188	41,169	38,686	29,292	25,166	25,448
$CO_2 + H_2S$ in Feed, %	12.1	11.2	11.3	10.2	8.9	9.5	5.5	7.1
$CO_2 + H_2S$ in Effluent, %	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0

Fraction of Total Carbon Converted	0.5							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
CO_2 Removed, moles/100 lb coal	0.6237	0.4770	0.4923	0.4302	0.4011	0.3009	0.3251	0.2387
H_2S Removed, moles/100 lb coal	0.0470	0.0470	0.0470	0.0470	0.0470	0.0470	0.0470	0.0470
$CO_2 + H_2S$ Removed, moles/hr	8,736	6,637	5,478	4,658	4,286	3,438	3,569	2,674
$CO_2 + H_2S$ to be Removed, moles/day	209,664	159,288	131,472	111,792	102,864	82,512	85,656	64,176
$CO_2 + H_2S$ Removed, MCF/day	79,358	60,291	49,762	42,313	38,934	31,231	32,421	24,290
$CO_2 + H_2S$ in Feed, %	13.0	10.9	10.9	9.4	8.8	8.9	8.8	6.7
$CO_2 + H_2S$ in Effluent, %	1.0	2.0	3.0	2.0	2.0	3.0	2.0	1.0

Fraction of Total Carbon Converted	0.6							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
CO_2 Removed, moles/100 lb coal	0.7561	0.6003	0.5793	0.4869	0.3643	0.3667	0.1900	0.2074
H_2S Removed, moles/100 lb coal	0.0461	0.0464	0.0450	0.0459	0.0455	0.0463	0.0452	0.0462
$CO_2 + H_2S$ Removed, moles/hr	7,095	5,445	5,077	4,264	3,452	3,256	1,789	1,836
$CO_2 + H_2S$ to be Removed, moles/day	170,280	130,680	121,848	102,336	82,848	78,144	42,936	44,064
$CO_2 + H_2S$ Removed, MCF/day	64,440	49,464	46,128	38,736	31,368	29,568	16,248	16,656
$CO_2 + H_2S$ in Feed, %	11.9	9.8	9.3	8.3	7.9	7.6	5.2	5.7
$CO_2 + H_2S$ in Effluent, %	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

Table 3 · OPERATING DATA FOR HYDROGEN PRODUCTION SECTION

Fraction of Total Carbon Converted	0.4							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Char Composition, wt %								
C	0.7998	0.7998	0.7998	0.7998	0.7988	0.7988	0.7998	0.7998
H_2	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218	0.0218
O_2	0.0142	0.0142	0.0142	0.0142	0.0142	0.0142	0.0142	0.0142
N_2	0.0057	0.0057	0.0057	0.0057	0.0057	0.0057	0.0057	0.0057
S	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009
Ash	0.1576	0.1576	0.1576	0.1576	0.1576	0.1576	0.1576	0.1576
Moles H_2/100 lb Coal	1.8775	2.1278	2.0027	2.2530	2.3785	2.5033	2.6285	2.7537
lb Char/100 lb Coal	56.3452	56.3452	56.3452	56.3452	56.3452	56.3452	56.3452	56.3452
Hourly Scaleup Factor	13,025.8	12,666.2	12,815.8	12,478.1	12,275.2	12,118.1	11,910.2	11,795.6
Process Hydrogen, moles/hr	25,160.4	27,727.5	26,405.0	28,923.0	30,013.3	31,205.4	32,207.8	33,925.7
Total Char Available, lb/hr	733,941	713,679	722,109	703,081	691,646	682,797	671,002	664,625
Process Hydrogen, moles/hr								
CO	75.60	83.31	79.34	86.90	90.24	93.76	96.77	101.94
H_2	24,455.9	26,951.1	25,665.7	28,113.2	29,190.4	30,331.6	31,306.0	32,975.8
CH_4	125.8	138.6	132.0	114.6	150.2	150.0	161.0	169.6
N_2	226.4	249.5	237.6	260.3	270.3	280.8	289.9	305.3
H_2O	25.2	27.7	26.4	28.9	30.0	31.2	32.2	33.9
CO_2	251.6	277.3	264.0	289.0	300.3	312.1	322.1	339.3
Char Required, lb/hr	304,216	335,255	319,265	349,710	362,893	377,307	389,427	410,199
Excess Char, lb/hr	429,725	378,424	402,844	353,371	328,755	305,490	281,655	254,426
Coal Required, lb/hr	0	0	0	0	0	0	0	0
Process Oxygen Required, lb/hr	234,246	258,146	245,834	269,277	279,428	290,526	299,859	315,853
Steam Required, lb/hr	121,686	134,102	127,706	139,884	145,157	150,923	155,770	164,080

Fraction of Total Carbon Converted	0.5							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Char Composition wt %								
C	0.77113	0.77113	0.77113	0.77113	0.77113	0.77113	0.77113	0.77113
H_2	0.02523	0.02523	0.02523	0.02523	0.02523	0.02523	0.02523	0.02523
O_2	0.01644	0.01644	0.01644	0.01644	0.01644	0.01644	0.01644	0.01644
N_2	0.00485	0.00485	0.00485	0.00485	0.00485	0.00485	0.00485	0.00485
S	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ash	0.18235	0.18235	0.18235	0.18235	0.18235	0.18235	0.18235	0.18235
Moles H_2/100 lb Coal	2.775	2.879	2.879	3.2543	3.2543	3.504	3.6230	3.8801
lb Char/100 lb Coal	48.69755	48.69755	48.69755	48.69755	48.69755	48.69755	48.69755	48.69755
Hourly Scaleup Factor	10,751.1	10,251.5	10,157.7	9,760.9	9,591.[illegible]	9,6[illegible]6.5	9,564.5	9,360.0
Process Hydrogen, moles/hr	26,[illegible]27.1	30,[illegible]4.6	30,080.4	32,[illegible]3.5	33,[illegible]2.4	34,850.2	35,650.4	37,363.9
Total Char Available, lb/hr	524,039	499,228	494,655	475,32[illegible]	481,105	[illegible]1,222	465,[illegible]68	455,809
Process Hydrogen, moles/hr								
CO	79.11	91.23	90.40	98.17	97.[illegible]	104.83	107.12	112.2[illegible]
H_2	25,589.9	29,514.4	29,244.0	31,[illegible]64.6	32,[illegible]	33,919.[illegible]	34,652.2	36,317.7
CH_4	131.6	151.8	150.4	163.5	[illegible]	174.5	178.3	186.8
N_2	236.9	273.3	270.8	294.1	[illegible]	314.0	320.9	336.3
H_2O	26.3	30.4	30.1	32.[illegible]	34.1	34.9	35.[illegible]	37.4
CO_2	263.3	303.6	300.9	326.8	336.8	349.6	356.5	373.6
Char Required, lb/hr	323,926	373,649	370,225	402,1[illegible]	40[illegible],092	429,338	438,69[illegible]	455,809
Excess Char, lb/hr	200,073	125,579	124,430	[illegible]3,191	[illegible]4,07[illegible]	41,883	27,[illegible]	0
Coal Required, lb/hr	0	0	0	0	0	0	0	3,548
Process Oxygen Required, lb/hr	242,974	280,237	2[illegible],669	301,662	305,310	322,003	329,[illegible]20	344,518
Steam Required, lb/hr	129,586	149,460	148,030	160,854	162,63[illegible]	171,[illegible]35	175,4[illegible]	183,743

Table 3.—Cont. OPERATING DATA FOR HYDROGEN PRODUCTION SECTION

Fraction of Total Carbon Converted	0.6							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Char Composition, wt %								
C	0.73085	0.73085	0.73085	0.73085	0.73085	0.73085	0.73085	0.73085
H_2	0.02989	0.02989	0.02989	0.02989	0.02989	0.02989	0.02989	0.02989
O_2	0.01948	0.01948	0.01948	0.01948	0.01948	0.01948	0.01948	0.01948
N_2	0.00371	0.00371	0.00371	0.00371	0.00371	0.00371	0.00371	0.00371
S	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ash	0.21604	0.21604	0.21604	0.21604	0.21604	0.21604	0.21604	0.21604
Moles H_2/100 lb Coal	3.2543	3.2543	3.2543	3.2543	3.2543	3.2543	3.2543	3.2543
lb Char/100 lb Coal	41.1035	41.1035	41.1035	41.1035	41.1035	41.1035	41.1035	41.1035
Hourly Scaleup Factor	8.844	8.420	8.132	8.004	8.032	7.886	7.600	7.538
Process Hydrogen, moles/hr	29,610.1	33,617.2	35,608.6	37,105.0	37,234.8	38,578.7	41,1[illegible]	41,760
Total Char Available, lb/hr	353,519	346,071	334,254	328,772	330,143	324,060	312,433	309,858
Process Hydrogen, moles/hr								
CO	88.8	100.77	106.74	111.47	111.88	115.72	123.66	125.42
H_2	28,781.0	32,671.1	34,607.[illegible]	36,066.1	36,172.2	37,498.[illegible]	39,944.2	40,571.3
CH_4	148.1	168.1	170.0	185.6	186.2	192.9	205.[illegible]	208.7
N_2	266.5	302.5	320.4	353.9	335.1	347.2	370.2	375.7
H_2O	29.6	33.6	35.6	37.1	37.2	38.6	41.1	41.7
CO_2	296.1	336.1	352.1	371.0	372.3	385.8	411.4	417.6
Char Required, lb/hr	353,519	346,071	334,254	328,772	330,143	324,060	312,633	309,828
Excess Char, lb/hr	0	0	0	0	0	0	0	0
Coal Required, lb/hr	5,481	67,350	91,746	135,009	121,375	140,059.5	181,092.3	190,100.0
Process Oxygen Required, lb/hr	265,680	297,533	306,000	326,880	325,080	334,160	350,413	364,955
Steam Required, lb/hr	147,600	165,296	170,000	181,600	180,600	185,648	197,440	199,975

Table 4.-UTILITY REQUIREMENTS FOR THE PLANT

Fraction of Total Carbon Converted	0.4							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Power for Coal Handling, hp	4,553	4,427	4,479	4,361	4,290	4,235	4,163	4,123
Power for Hydrogasifier, hp	27,900	27,130	27,450	26,727	26,293	25,956	25,511	25,265
Power for Prepurification, hp	6,234	5,065	5,821	5,134	4,945	4,230	3,916	3,937
Power for Oxygen Production, hp	76,558	84,012	79,524	87,460	91,197	94,069	97,645	102,348
Power for Hydrogen Compressor, hp	18,727	20,638	19,653	21,527	22,339	23,226	23,972	25,251
Power for Fluor Process, hp	26,731	29,458	28,053	30,728	31,887	33,153	34,218	36,043
Total Power, hp	150,715	170,730	164,980	175,957	180,951	184,869	189,425	[illegible]
Steam for Power, lb/hr at 525 psia	1,237,130	1,297,300	1,269,800	1,339,570	1,369,510	1,398,690	1,424,250	1,442,310
Steam to Gasifier, lb/hr at 525 psia	121,686	134,102	127,706	139,884	145,157	150,923	155,770	164,080
Steam to 2nd Shift, lb/hr at 525 psia	161,693	178,191	169,692	185,874	192,880	200,542	206,983	218,024
Total 525 psia Steam, lb/hr	1,520,509	1,609,593	1,567,198	1,665,328	1,707,547	1,750,155	1,787,003	1,824,414
Steam to Hydrogasifier, lb/hr at 1025 psia	348,635	293,780	359,860	302,393	247,987	176,640	159,487	96,093
Heat Required for 1025 psia Steam, MMBtu/hr	338.70	285.47	349.68	293.84	240.97	171.64	154.98	93.38
Heat Required for 525 psia Steam, MMBtu/hr	1,494.66	1,582.03	1,540.47	1,636.76	1,678.18	1,719.97	1,756.12	1,792.78
Heat for H_2 Preheat, MMBtu/hr	52.00	58.00	69.40	65.20	52.50	49.00	7.48	7.00
Total Heat Required, MMBtu/hr	1,885.36	1,925.50	1,959.55	1,995.80	1,971.65	1,940.61	1,918.58	1,893.16
Heat From Excess Char, MMBtu*	4,422.50	3,894.74	4,146.07	3,536.90	3,383.54	3,144.10	2,898.79	2,598.60
Excess Heat From Remaining Char, MMBtu/hr*	2,537.14	1,968.24	2,186.52	1,541.10	1,411.89	1,203.49	980.21	705.44
Heat Required From Additional Coal, MMBtu/hr	0	0	0	0	0	0	0	0
Coal Required, ton/hr*	0	0	0	0	0	0	0	0
Total Power Generated, hp	10,787	9,492	10,300	9,495	9,235	8,465	8,079	8,060
Process Water to Coal Handling, MM lb/hr	1.156	1.124	1.137	1.107	1.089	1.075	1.057	1.047
Process Water to Prepurification, MM lb/hr	0.860	0.732	0.888	0.757	0.839	0.676	0.789	0.636
Process Water to 1st Shift, MM lb/hr	0.523	0.576	0.549	0.601	0.624	0.649	0.670	0.705
Process Water to Scrubber, MM lb/hr	0.119	0.132	0.125	0.137	0.142	0.148	0.153	0.161
Total Process Water, MM lb/hr	2.658	2.564	2.699	2.602	2.694	2.548	2.669	2.549
Boiler Feed Water, MM lb/hr	2.924	2.820	2.969	2.862	2.963	2.803	2.936	2.804
Total Process and Boiler Feed Water, MM lb/hr	5.582	5.384	5.668	5.464	5.657	5.351	5.605	5.353
Total Process and Boiler Feed Water, gpm	11,164	10,768	11,336	10,928	11,314	10,702	11,210	10,706
Cooling Water for Coal Handling, gpm	34,850	33,900	34,350	33,400	32,800	32,450	31,900	31,600
Cooling Water for Hydrogasifier, gpm	37,100	35,600	36,500	35,500	35,000	34,500	33,800	33,550
Cooling Water for Prepurification, gpm	18,500	13,390	16,680	13,690	12,860	9,740	8,380	8,460
Cooling Water for Methanation, gpm	10,080	0	10,080	3,450	10,080	5,550	10,080	10,080
Cooling Water for Oxygen Production, gpm	118,800	130,800	124,640	136,520	141,670	147,300	152,030	160,140
Cooling Water for Hydrogen Production, gpm	24,260	26,740	25,460	27,890	28,440	30,090	31,060	32,710
Total Process Cooling Water, gpm	243,590	240,430	247,710	250,450	261,850	259,630	267,280	276,540
Cooling Water for Power gpm	419,310	431,300	426,760	443,560	450,690	456,850	462,500	460,180
Total Cooling Water, gpm	662,900	671,730	674,470	694,010	712,540	716,480	729,780	736,720

* Based on 80% fuel efficiency

Table 4 -Cont. UTILITY REQUIREMENTS FOR THE PLANT

Fraction of Total Carbon Converted	0.5							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Power for Coal Handling, hp	3,761	3,583	3,550	3,411	3,453	3,382	3,343	3,254
Power for Hydrogasifier, hp	21,921	20,884	20,693	19,864	20,129	19,712	19,484	19,058
Power for Prepurification, hp	8,041	6,590	5,788	5,221	4,900	4,378	4,468	3,849
Power for Oxygen Production, hp	40,531	46,745	46,313	50,103	52,507	52,566	55,572	55,958
Power for Hydrogen Compressor, hp	19,595	22,600	22,393	24,323	24,623	25,969	26,535	27,810
Power for Fluor Process, hp	27,970	32,260	31,268	34,739	35,147	37,068	37,876	39,696
Total Power, hp	121,819	132,652	130,701	137,851	140,759	143,075	147,278	149,665
Steam for Power, lb/hr at 525 psia	1,218,190	1,326,620	1,307,002	1,379,606	1,407,582	1,442,176	1,472,780	1,519,970
Steam to Gasifier, lb/hr at 525 psia	129,583	149,460	148,090	160,854	162,837	171,735	175,477	183,743
Steam to 2nd Shift, lb/hr at 525 psia	169,191	195,139	193,354	210,016	212,605	225,222	229,103	240,119
Total 525 psia Steam, lb/hr	1,516,964	1,671,219	1,648,446	1,749,478	1,783,030	1,839,133	1,877,360	1,942,832
Steam to Hydrogasifier, lb/hr at 1025 psia	461,028	442,155	464,640	436,918	295,741	270,667	185,410	156,050
Heat Required for 1025 psia Steam, MMBtu/hr	447.99	429.65	451.50	424.56	287.38	263.01	180.17	151.54
Heat Required for 525 psia Steam, MMBtu/hr	1,496.06	1,648.19	1,625.73	1,725.37	1,758.46	1,813.79	1,851.49	1,908.87
Heat for H_2 Preheat, MMBtu/hr	179.00	200.00	200.50	187.00	159.00	145.00	131.90	130.60
Total Heat Required, MMBtu/hr	2,123.05	2,277.84	2,277.73	2,336.93	2,204.84	2,221.80	2,163.56	2,191.11
Heat From Excess Char, MMBtu*	2,043.46	1,282.62	1,270.88	747.54	756.76	427.78	276.54	0
Excess Heat From Remaining Char, MMBtu/hr*	0	0	0	0	0	0	0	0
Heat Required From Additional Coal, MMBtu/hr	79.59	995.22	1,006.85	1,589.39	1,448.08	1,794.02	1,887.02	2,191.11
Coal Required, ton/hr*	3.67	45.94	46.48	73.37	66.84	82.66	87.10	101.14
Total Power Generated, hp	11,802	10,173	9,338	8,632	8,353	7,760	7,811	7,133
Process Water to Coal Handling, MM lb/hr	0.955	0.910	0.901	0.866	0.877	0.859	0.849	0.834
Process Water to Prepurification, MM lb/hr	0.932	0.877	0.979	0.907	0.874	0.792	0.810	0.725
Process Water to 1st Shift, MM lb/hr	0.547	0.631	0.626	0.679	0.688	0.725	0.741	0.777
Process Water to Scrubber, MM lb/hr	0.125	0.144	0.143	0.155	0.157	0.165	0.169	0.177
Total Process Water, MM lb/hr	2.559	2.562	2.649	2.607	2.596	2.541	2.569	2.513
Boiler Feed Water, MM lb/hr	3.069	3.083	2.987	2.960	2.849	2.831	2.866	2.850
Total Process and Boiler Feed Water, MM lb/hr	5.628	5.645	5.636	5.567	5.445	5.372	5.435	5.363
Total Process and Boiler Feed Water, gpm	11,256	11,290	11,272	11,134	10,890	10,744	10,870	10,726
Cooling Water for Coal Handling, gpm	28,800	26,450	26,200	26,150	26,400	25,850	25,600	25,100
Cooling Water for Hydrogasifier, gpm	26,400	25,200	25,000	24,000	24,300	23,800	23,550	23,000
Cooling Water for Prepurification, gpm	26,380	20,042	16,542	14,066	12,942	10,382	10,777	8,075
Cooling Water for Methanation, gpm	10,080	6,500	10,080	9,500	10,080	10,080	10,080	10,080
Cooling Water for Oxygen Production, gpm	123,190	142,100	140,770	152,910	156,830	163,250	166,810	174,670
Cooling Water for Hydrogen Production, gpm	25,390	29,280	29,010	31,510	31,900	33,640	34,380	36,030
Total Process Cooling Water, gpm	240,240	249,572	247,602	258,136	262,452	267,002	271,197	276,955
Cooling Water for Power gpm	407,014	432,909	425,481	443,031	447,164	459,146	465,543	476,667
Total Cooling Water, gpm	647,254	682,481	673,183	701,167	709,616	726,148	736,740	753,622

* Based on 80% fuel efficiency

Table 4 -Cont. UTILITY REQUIREMENTS FOR THE PLANT

Fraction of Total Carbon Converted	0.5							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Power for Coal Handling, hp	3,110	3,178	3,165	3,234	3,231	3,245	3,291	3,299
Power for Hydrogasifier, hp	17,096	16,277	15,720	15,473	15,527	15,240	14,703	14,572
Power for Prepurification, hp	6,907	5,766	5,511	4,949	4,387	4,254	3,237	3,270
Power for Oxygen Production, hp	86,129	95,620	99,039	106,527	105,221	111,405	107,115	108,880
Power for Hydrogen Compressor, hp	22,039	25,018	26,501	27,517	27,734	28,714	30,518	31,067
Power for Fluor Process, hp	31,458	36,710	37,827	39,521	39,559	40,987	43,704	44,255
Total Power, hp	166,739	182,569	187,761	197,221	195,539	203,845	202,555	205,454
Steam for Power, lb/hr at 525 psia	1,247,390	1,355,690	1,397,610	1,452,210	1,446,390	1,498,450	1,556,680	1,574,330
Steam to Gasifier, lb/hr at 525 psia	147,600	165,296	170,000	181,600	180,600	185,648	197,490	199,975
Steam to 2nd Shift, lb/hr at 525 psia	190,295	216,010	228,815	238,460	239,287	247,925	264,365	268,241
Total 525 psia Steam, lb/hr	1,585,285	1,736,996	1,796,425	1,872,270	1,866,277	1,932,023	2,018,535	2,042,546
Steam to Hydrogasifier, lb/hr at 1025 psia	619,138	588,601	537,693	506,935	307,815	284,786	202,777	182,731
Heat Required for 1025 psia Steam, MMBtu/hr	601.63	571.96	522.49	492.60	299.11	276.73	197.04	177.56
Heat Required for 525 psia Steam, MMBtu/hr	1,563.44	1,713.06	1,771.67	1,846.47	1,840.56	1,905.40	1,990.72	2,014.40
Heat for H_2 Preheat, MMBtu/hr	310.10	335.00	322.52	302.00	213.40	195.00	216.50	214.00
Total Heat Required, MMBtu/hr	2,475.17	2,620.02	2,616.68	2,641.07	2,353.07	2,377.13	2,404.26	2,405.96
Heat From Excess Char, MMBtu*	0	0	0	0	0	0	0	0
Excess Heat From Remaining Char, MMBtu/hr*	0	0	0	0	0	0	0	0
Heat Required From Additional Coal, MMBtu/hr	2,475.17	2,620.02	2,616.68	2,641.07	2,353.07	2,377.13	2,404.26	2,405.96
Coal Required, ton/hr*	114.25	120.99	120.78	121.91	108.62	109.78	110.98	111.06
Total Power Generated, hp	10,017	8,944	8,674	8,183	7,618	7,499	6,528	6,569
Process Water to Coal Handling, MM lb/hr	0.785	0.747	0.722	0.710	0.713	0.700	0.675	0.669
Process Water to Prepurification, MM lb/hr	1.053	1.003	1.014	0.951	0.871	0.809	0.829	0.766
Process Water to 1st Shift, MM lb/hr	0.616	0.699	0.740	0.771	0.774	0.802	0.855	0.868
Process Water to Scrubber, MM lb/hr	0.140	0.159	0.169	0.176	0.177	0.183	0.195	0.198
Total Process Water, MM lb/hr	2.594	2.608	2.645	2.608	2.535	2.494	2.554	2.501
Boiler Feed Water, MM lb/hr	2.853	2.869	2.909	2.869	2.789	2.743	2.809	2.751
Total Process and Boiler Feed Water, MM lb/hr	5.447	5.477	5.554	5.477	5.324	5.237	5.363	5.252
Total Process and Boiler Feed Water, gpm	10,894	10,954	11,108	10,954	10,648	10,474	10,726	10,504
Cooling Water for Coal Handling, gpm	23,650	22,550	21,750	21,400	21,500	21,100	20,400	20,200
Cooling Water for Hydrogasifier, gpm	18,400	17,500	16,900	16,600	16,650	16,350	15,800	15,600
Cooling Water for Prepurification, gpm	21,429	16,445	15,334	12,878	10,426	9,834	5,403	5,545
Cooling Water for Methanation, gpm	10,080	10,080	10,080	10,080	10,080	10,080	10,080	10,080
Cooling Water for Oxygen Production, gpm	134,130	150,850	155,140	165,730	164,820	174,510	182,730	185,030
Cooling Water for Hydrogen Production, gpm	28,550	32,412	34,330	35,780	35,900	37,200	39,670	40,250
Total Process Cooling Water, gpm	236,239	249,837	253,534	262,468	259,376	269,074	274,083	276,705
Cooling Water for Power gpm	397,037	425,738	439,648	451,265	449,765	461,405	477,799	482,990
Total Cooling Water, gpm	633,276	675,575	693,182	713,733	709,141	730,479	751,882	759,695

* Based on 80% fuel efficiency

Table 5 MATERIALS FOR HYDROGASIFIER AND GASIFIER
(Quantities Based on 1 Hr Operation at 250 Billion Btu/Day)

Fraction of Total Carbon Converted	0.4								0.5			
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000		1700		1800	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Coal to Hydrogasifier, ton	651.29	633.31	640.79	623.90	613.76	605.90	595.51	580.78	538.01	512.58	507.88	488.04
Coal to Gasifier, ton	0	0	0	0	0	0	0	0	0	0	0	0
Total Processed Coal, ton	651.29	633.31	640.79	623.90	613.76	605.90	595.51	580.78	538.01	512.58	507.88	488.04
Coal for Power, ton	0	0	0	0	0	0	0	[illegible]	[illegible]	45.94	46.48	[illegible]
Total Coal, ton	651.29	633.31	640.79	623.90	613.76	605.90	595.51	580.78	541.60	558.52	554.36	561.41
Processed Hydrogen to Hydrogasifier, moles	25,160.4	27,727.5	26,405.0	28,923.0	30,013.3	31,205.4	32,207.9	33,325.7	26,327.1	30,764.6	30,086.4	32,679.6
Processed Oxygen to Gasifier, ton	117.12	129.07	122.92	134.64	139.71	145.26	143.93	157.37	121.40	140.12	138.83	150.801
Steam to Hydrogasifier, lb	348,635	293,780	359,860	302,393	247,987	176,040	159,487	[illegible]	461,028	442,155	464,640	436,918
Steam to Gasifier, lb	121,686	134,102	127,706	139,894	145,157	150,723	155,770	164,080	129,586	149,460	148,090	160,858

Fraction of Total Carbon Converted	0.5				0.6							
Temperature in High-Temperature Zone, °F	1900		2000		1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Coal to Hydrogasifier, ton	494.06	483.82	478.22	468.00	442.20	421.00	406.60	400.20	401.60	394.20	380.30	376.90
Coal to Gasifier, ton	0	0	0	1.77	2.74	33.58	45.87	62.50	60.69	70.03	90.55	95.05
Total Processed Coal, ton	494.06	483.82	478.22	469.77	444.94	454.58	452.47	462.70	462.29	464.23	470.85	471.95
Coal for Power, ton	66.84	82.66	87.10	101.14	114.25	120.99	120.78	121.91	108.62	109.76	110.98	111.06
Total Coal, ton	560.90	566.48	565.32	570.91	559.19	575.57	573.25	594.61	570.91	574.01	581.83	583.01
Processed Hydrogen to Hydrogasifier, moles	33,082.4	34,890.2	35,650.4	37,363.9	29,610.1	33,612.2	35,604.6	37,105.0	37,234.8	38,578.9	41,116.0	41,740.0
Processed Oxygen to Gasifier, ton	154.66	161.00	164.51	172.26	132.28	148.77	153.00	163.84	162.54	172.08	180.21	182.48
Steam to Hydrogasifier, lb	235,742	270,667	185,410	156,050	619,138	583,501	537,633	506,935	307,815	284,786	202,777	182,731
Steam to Gasifier, lb	162,837	171,735	175,477	133,743	147,600	165,293	170,000	181,600	180,600	185,648	197,490	199,975

Table 6. SUMMARY OF COST DATA

Fraction of Total Carbon Converted	0.4							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Coal Storage, $ million	4.622	4.549	4.580	4.505	4.461	4.424	4.380	4.357
Coal Grinding, $ million	8.520	8.357	8.395	8.280	8.173	8.098	8.013	7.948
Hydrogasification, $ million	22.630	22.720	22.450	22.500	17.500	17.450	15.510	15.590
Prepurification, $ million	9.721	8.454	8.578	8.270	8.189	6.807	6.844	6.735
Shift, $ million	0	0	0	0	0	0	0.060	0.060
Methanation, $ million	0.783	0.401	0.905	0.684	0.997	0.682	1.052	0.600
Oxygen Production, $ million	13.745	16.256	15.066	16.718	17.511	17.908	18.238	18.809
Hydrogen Production, $ million	22.300	24.100	23.200	24.900	25.700	26.500	27.200	28.400
Offsite Facilities, $ million	34.928	35.105	35.504	36.272	36.216	36.032	35.829	35.088
Total Bare Cost, $ million	117.249	119.942	118.678	122.129	118.747	117.901	117.125	117.677
Coal Cost, $ million/yr	28.5265	27.7390	28.0666	27.3268	26.8827	26.5384	26.0833	25.8324
Char Credit, $ million/yr	5.129	3.980	4.421	3.116	2.855	2.433	1.982	1.426
Gas Price, $/MMBtu	0.58938	0.60052	0.59597	0.61110	0.59994	0.59856	0.59605	0.60085

Fraction of Total Carbon Converted	0.5							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Coal Storage, $ million	4.123	4.133	4.115	4.141	4.131	4.159	4.128	4.700
Coal Grinding, $ million	7.452	7.203	7.159	6.952	7.022	6.924	6.867	6.784
Hydrogasification, $ million	23.500	23.550	23.250	23.300	17.770	17.720	16.750	16.680
Prepurification, $ million	12.391	9.821	8.374	8.019	7.609	6.625	6.971	6.674
Shift, $ million	0	0	0	0	0.060	0	0.060	0
Methanation, $ million	0.786	0.654	0.895	0.627	1.080	0.820	1.250	0.848
Oxygen Production, $ million	15.066	17.577	17.181	18.238	18.899	19.163	19.428	20.088
Hydrogen Production, $ million	23.200	26.000	25.700	27.600	27.800	29.100	29.600	30.800
Offsite Facilities, $ million	35.789	37.603	37.417	38.568	37.314	37.883	37.190	37.606
Total Bare Cost, $ million	122.307	126.541	124.091	127.455	121.685	122.394	122.244	124.180
Coal Cost, $ million/yr	23.725	23.670	23.495	23.737	23.676	23.907	23.614	24.031
Char Credit, $ million/yr	0	0	0	0	0	0	0	0
Gas Price, $/MMBtu	0.60530	0.62532	0.61652	0.62926	0.61301	0.61799	0.61447	0.62533

Table 6.-Cont, SUMMARY OF COST DATA

Fraction of Total Carbon Converted	0.6							
Temperature in High-Temperature Zone, °F	1700		1800		1900		2000	
Fraction of Carbon Converted in Low-Temperature Zone	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Coal Storage, $ million	4.139	4.207	4.194	4.238	4.202	4.186	4.215	4.220
Coal Grinding, $ million	6.516	6.501	6.490	6.472	6.477	6.457	6.448	6.436
Hydrogasification, $ million	24.650	24.700	23.600	23.650	16.820	16.770	16.600	16.520
Prepurification, $ million	10.045	8.808	8.519	7.830	6.962	6.799	5.393	5.353
Shift, $ million	0	0	0	0	0	0	0	0
Methanation, $ million	0.900	0.600	0.970	0.700	1.180	0.970	1.300	1.080
Oxygen Production, $ million	16.784	18.238	18.635	19.428	19.428	20.088	20.617	20.617
Hydrogen Production, $ million	25.400	28.200	29.500	30.600	30.730	31.600	33.300	33.800
Offsite Facilities, $ million	38.241	39.964	40.158	40.760	38.425	39.085	39.214	39.227
Total Base Cost, $ million	126.675	131.218	132.066	133.678	124.194	125.955	127.087	127.253
Coal Cost, $ million/yr	24.493	25.207	25.109	25.606	25.006	25.139	25.484	25.536
Char Credit, $ million/yr	0	0	0	0	0	0	0	0
Gas Price, $/[illegible]	0.62602	0.64659	0.64764	0.65787	0.62507	0.63141	0.63844	0.63948

PB-23a

High-Pressure Methanation

Laboratory Methanation Study

Quotations were received for most major equipment; selecting and ordering major equipment and other equipment having a long delivery time was continued.

A survey was made of ways to continuously analyze the feed and product gases for carbon monoxide and carbon dioxide. Because of the 0.10 mole percent limit set for synthetic pipeline gas, special analytical techniques are required for analyzing exit gases. In addition, a dual-range analyzer is required to operate accurately at composition ranges of 0-2 mole percent and 0-20 mole percent. For these reasons, a continuous process monitoring-type infrared analyzer was decided upon; the appropriate manufacturers will be contacted and quotations obtained.

Pilot Plant Studies

The objective of this study is to investigate the hydrogasification of suitably treated coals in a continuous-flow pilot unit in order to develop data for the design of an integrated pilot plant. In the present phase of hydrogasification studies, tests are being conducted in a high-temperature, balanced-pressure pilot unit. Gas-solids contacting is achieved in a 4-in.-diameter reactor tube, the hydrogen or hydrogen-steam mixture flowing upward and the coal flowing downward as either a moving or fluid bed, or in free fall.

Hydrogasification

Rebuilding of the hydrogasification pilot unit reactor heating furnace was completed with the installation of the remaining four heating elements. The entire furnace was tested for operation to a temperature of 600°F.

A new 4-in.-diameter reactor tube, type 446 alloy, and an expansion bellows was installed in the reactor shell. Before installation, the reactor tube was wrapped with a 1/2-in.-thick layer of Fiberfrax insulation so that temperature profiles could be recognized. The lower 31 inches of the reactor was left uninsulated to improve heat transfer to the tube in this zone where the heat loss is high, and final preheating of the steam and hydrogen feed is accomplished.

Reactor tube-wall thermocouples were drawn through the shell and sealed in glands against pressure. Six of the 31 reactor tube thermocouples were positioned on the outside of the Fiberfrax insulation at approximately 31-inch intervals, and at nearly the midpoints of each of the top six heating zones. Temperatures sensed by these thermocouples, and those sensed by thermocouples on the tube wall at corresponding levels will be used to determine temperature gradients across the insulation to establish direction of heat flow. Location of the reactor tube thermocouples is shown in Fig. 1.

Electrical wiring of the seven solenoid valves for the new reactor-shell differential-pressure control system was completed. Rupture disks were installed in a pressure-equalizing line between the reactor tube and the shell. These disks are designed to rupture and equalize the pressure between the reactor tube and the shell in the extreme case of failure of the differential-pressure control system.

The modified pressure vessel, which will serve as a temporary residue receiver, was installed in the pilot unit. This receiver has a volume of 7.7 cu ft compared to 5.1 cu ft in the original receiver. The reactor discharge screw housing, the discharge screw, drive shaft, and the variable speed drive were installed. A feed calibration of the screw was made, correlating weight of coal discharged with screw rpm.

Piping the hydrogen and steam feed lines to the bottom of the reactor was started.

The coal feed hopper and the coal screw feeder were reassembled to the top of the reactor. Reconnection of the six gas-sampling probes was started.

Coal Pretreatment

Four coal pretreatment tests were conducted in the continuous-flow fluidized bed pretreater. These tests are a part of the program for defining minimum pretreatment conditions for producing nonagglomerating char for the hydrogasification pilot unit.

Nominal conditions for these tests are given below:

Run No.	Solids Rate, lb/hr	Avg Solids Residence Time, hr	Gas Rate, SCF/hr	Feed Oxygen, %	Temp, °F
FP-12	72	1.27	613	2.1	440
FP-13	73	1.0	602	2.2	536
FP-14	78	1.0	590	9.8	666
FP-15	74	1.0	600	10	708

It was found that with a 2% oxygen concentration in the pretreatment gas, sufficiently high bed temperatures for adequate coal pretreatment could not be maintained in test Runs FP-12 and FP-13. In earlier tests, it was shown that sufficiently high bed temperatures for pretreatment could be maintained with 21% oxygen (air). To investigate oxygen concentrations with respect to oxidation rate,

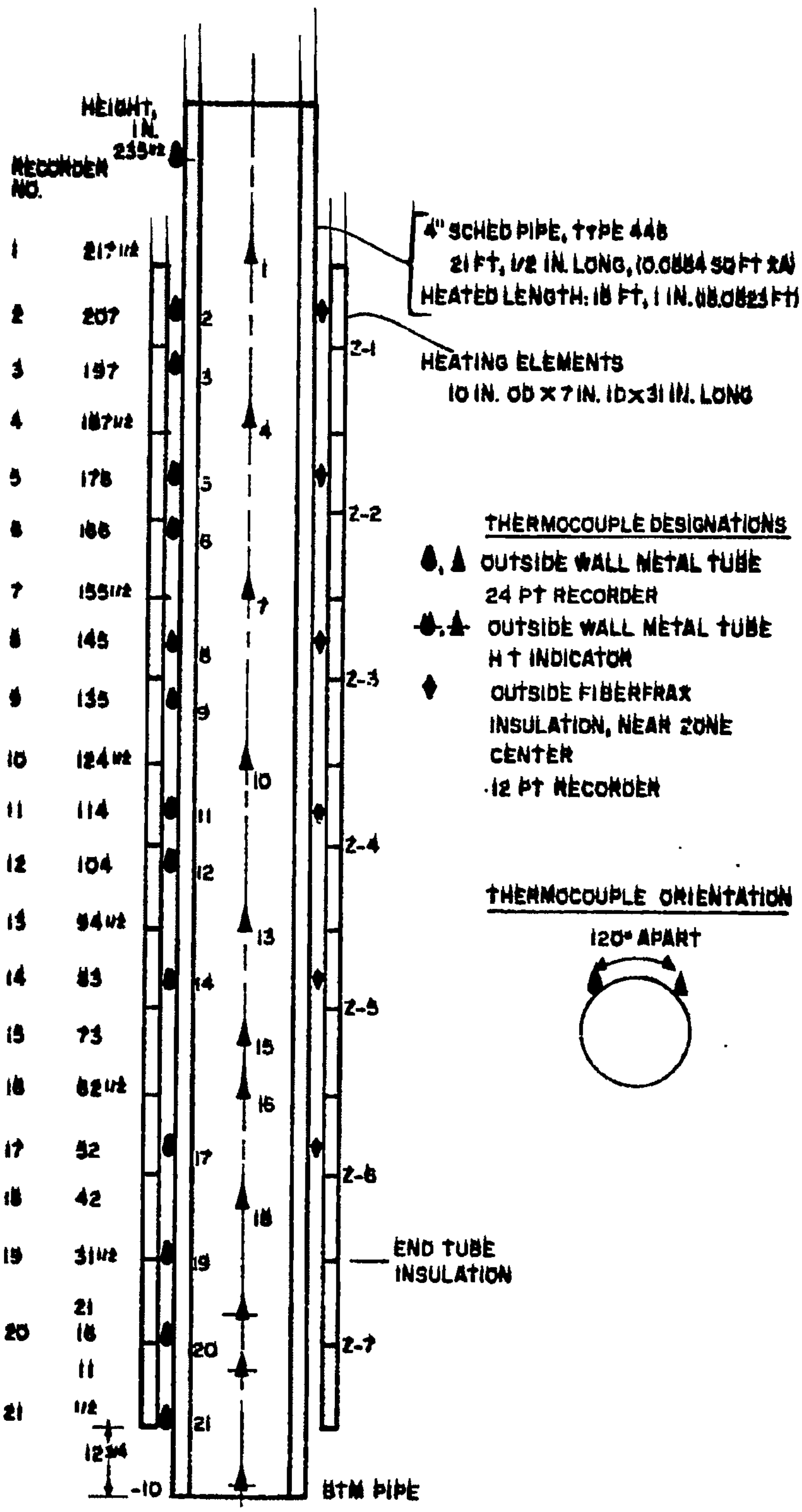

Fig. 1 -BALANCED-PRESSURE REACTOR THERMOCOUPLE LOCATIONS

further tests (Runs FP-14 and FP-15) were conducted with a 10% oxygen concentration. Bed temperatures in these tests were maintained at a level adequate for pretreatment. Chars produced in these tests have not yet been evaluated for agglomeration characteristics. A more detailed data presentation of these tests will be made when other analytical results are completed.

Operating conditions and results of four coal pretreatment tests conducted last month are presented in Table 1. Chemical and screen analyses of the feeds and residues of these tests are given in Table 2.

Pittsburgh seam bituminous coal obtained from Consolidation Coal Company was pretreated in these tests. In Run FP-7 the coal was from Montour 4 mine; in the other tests the coal was from the Ireland mine.

When it was found that an oxygen concentration of 4% and coal residence times of 27 to 40 minutes were not sufficient for adequate pretreatment, the oxygen concentration was increased to 21% in the pretreatment gas; the average coal residence time was increased to about 1 hr by increasing the bed height to 5 ft and by decreasing the coal feed rate to 50 lb/hr.

Laboratory evaluations of the chars produced in these tests (procedure described in the January 1965 Work Report) showed that only the char of Run FP-11 may have been sufficiently treated to prevent agglomeration when hydrogasified. As shown in Table 2, there was a significant reduction in the volatile matter and in the hydrogen content of the char produced, compared to the feed content. The reactor residue analyses do not truly reflect the pretreatment operating conditions because these residues remained in the reactor during the cooldown period for about 18 hours.

Table [illegible].-OPERATING RESULTS OF THE PRETREATMENT OF MONTOUR 4 BITUMINOUS COAL IN CONTINOUS-FLOW PILOT UNIT

Run No.	FP-7	FP-8	FP-9	FP-10
Sieve Size, USS	10/40	-10	-10	-10
Pretreatment Gas	Nitrogen + Air	Air	Air	Air
Purge Gas	Nitrogen	Air	Air	Air
Duration of Test, hr	2	2-1/2	2	2-3/4
Steady-State Operating Period, min	40-113	99-159	51-123	--
OPERATING CONDITIONS				
Standpipe				
OD, in.	3	3	3	3
Height, ft	3	3	3	5
Bed Inventory, lb	58.90	37.49	47.41	56.34
Reactor Pressure, psig	1.50	3.40	1.25	7.25
Bed Temperature, °F				
Bottom	656	833	239	700
1/2 ft	777	560	239	700
1 ft	773	510	246	--
1-1/2 ft	777	844	266	700
2 ft	773	--	370	705
2-1/2 ft	781	643	462	705
5 ft	--	--	--	--
Average	756	678	304	702
Coal Rate (dry), lb/hr	131.4	86.4	71.2	49.6
Air Rate, SCF/hr	167.9	833.6	598.8	602.8
Nitrogen Rate, SCF/hr	632.5	--	--	--
Oxygen Concentration, mole %	4.4	21.0	21.0	21.0
Nitrogen Purge Rate, SCF/hr	3.0	--	--	--
Air/Coal Feed Ratio, SCF/lb	1.278	9.64	8.41	12.15
Air/Coal Bed Ratio, SCF/hr-lb	2.851	22.24	12.63	10.70
Coal Bed Pressure Differential, in. Hg	1.88	1.84	1.80	2.28
Coal Space Velocity, lb/cu ft-hr	85.31	58.10	47.86	20.84
Coal Residence Time, min	26.9	25.0	40.0	68.2
Pretreatment Gas Residence Time, min	0.0570	0.0585	0.1066	0.1565
Superficial Pretreatment Gas Velocity, ft/sec	0.878	0.852	0.460	0.511
OPERATING RESULTS				
Product Gas Rate, SCF/hr	771.2	952.8	606.0	601.2
Residue Char (dry), wt % dry coal	96.0	92.5	88.8	76.8
Knockout Drum Residue, wt % dry coal	0.3	0.1	0.6	5.8
Condenser and Filter Residue, wt % dry coal	0.6	0.5	0.8	2.1
Total Residue Char, wt % dry coal	96.9	93.1	90.2	84.7
Water and Other Condensates, wt % dry coal	--	--	--	2.1 (Liquid) 1.8 (Tar)
Overall Material Balance, %	96.6	100.7	96.8	94.8[c]
Carbon Balance, %[a]	100.0	93.1	90.2	85.8[d]
PRODUCT GAS PROPERTIES				
Gas Composition, mole %				No Gas Samples
N_2	94.0	84.1	79.5	
CO	0.9	--	1.5	
CO_2	0.9	0.7	1.3	
O_2	1.4	14.5	16.8	
H_2	1.9	--	--	
Ar	0.89	0.74	0.93	
Total	99.99	100.04	100.03	
Heating Value, Btu/SCF[b]	8.9	0.0	4.7	
Nitrogen and Argon-Free Heating Value, Btu/SCF	17.4	0.0	24.2	
Specific Gravity, Air = 1.00	0.965	0.997	1.005	
Laboratory Agglomeration Test of Residue Evaluation				
1350°F	--	Fused	Fused	Partially Caked
1700°F	Fused	Fused	--	--

a. Carbon in liquids not included
b. Gross, gas saturated at 60°F, 30 in. Hg pressure. SCF = dry gas volume in SCF at 60°F, 30 in. Hg pressure
c. Feed and product gases not included
d. Carbon in liquids, tar and product gas not included

Table 2 - CHEMICAL ANALYSES OF PRETREATMENT COAL FEED AND PRODUCT CHAR

Run No.	PP-7			PP-8			PP-9			PP-10		
Sample	Feed	Reactor Residue	Residue Receiver	Feed	Reactor Residue	Residue Receiver	Feed	Reactor Residue	Residue Receiver	Feed	Reactor Residue	Residue Receiver
Proximate Analysis, wt %												
Moisture	1.0	0.3	0.7	0.9	0.3	0.5	0.7	0.1	0.3	0.4	0.1	1.1
Volatile Matter	34.0	32.8	34.3	34.3	35.7	34.1	31.8	31.6	35.6	33.1	22.7	24.2
Fixed Carbon	48.8	45.1	52.6	50.5	52.8	50.5	51.9	48.1	49.7	51.5	62.0	58.6
Ash	16.2	21.8	12.4	14.3	11.2	14.9	15.6	20.2	14.4	15.0	15.2	16.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %												
Carbon	67.3	62.5	70.5	69.8	71.6	68.7	67.9	63.2	68.9	68.2	69.6	67.6
Hydrogen	4.50	4.67	4.94	5.15	4.95	4.86	4.85	4.52	4.80	4.76	3.86	3.67
Nitrogen*	--	--	--	--	--	--	--	--	--	--	--	--
Oxygen*	--	--	--	--	--	--	--	--	--	--	--	--
Sulfur*	--	--	--	--	--	--	--	--	--	--	--	--
Ash	16.37	21.87	12.51	14.47	11.21	15.02	15.75	20.23	14.39	15.05	15.17	16.27
Screen Analysis, USS, wt %												
+10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.2
+12	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.8
+16	2.4	4.6	1.8	1.8	0.3	0.9	1.9	1.5	1.2	1.2	8.9	2.1
+20	10.6	19.8	9.0	11.9	3.7	5.3	8.5	7.7	6.0	5.8	15.3	3.8
+30	21.5	29.7	17.7	18.3	9.3	10.5	10.7	14.6	11.9	11.0	18.0	5.4
+40	24.8	23.7	22.9	17.9	12.6	13.2	11.1	16.6	13.6	12.2	14.4	5.3
+100	34.0	20.9	35.9	33.2	53.5	37.7	36.4	42.6	34.3	37.5	27.0	15.0
-100	6.6	1.0	12.7	16.9	20.6	32.4	31.4	17.0	33.0	32.3	12.2	66.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Not analyzed

IGT-HPR--3/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report – March 1965

to

Office of Coal Research
Contract No. 14-01-0001-381

Hydrogasification

Reassembly of the hydrogasification pilot unit was completed. Hydrogen and steam feed piping to the bottom of the reactor was installed along with gas-sampling probes for sampling gases at different levels inside the reactor. For sensing coal bed temperatures, three thermocouples were installed inside the reactor. The pilot unit was pressure tested and readied for shakedown tests.

Calibration and setting of the radiation-type coal bed-level sensor by a representative of Nuclear-Chicago, supplier of the level gage, is in progress. The use of a radiation gage for sensing solids in a small-diameter tube with a relatively large-diameter outer shell and insulation represents a novel application of the gage. The amplification unit for detecting the coal bed level has required extremely fine adjustments for sensitivity. To improve the sensitivity level, changes in the amplifier circuitry are being made.

Three hydrogasification runs were made in the pilot unit when the reassembly of the unit was completed (Runs HT-53, HT-54, and HT-55). These runs were made with the low-temperature bituminous coal char used in previous tests, and with hydrogen-steam feed mixtures. The purpose of these runs was to shake down the rebuilt reactor, and to check results of the last run made in the pilot unit prior to rupture of the reactor tube.

Coal Pretreatment

Four coal pretreatment tests were conducted in the continuous-flow fluidized-bed pretreater using Pittsburgh seam coal from the Ireland mine. The objective of these tests was to continue investigation for defining minimum pretreatment conditions for producing nonagglomerating char for the pilot unit hydrogasifier.

Nominal conditions for the tests are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Residence Time, hr	Gas Rate, SCF/hr	Oxygen, %	Temp, °F
FP-16	73	1.34	567	5.1	658
FP-17	89	1.11	580	2.7	629
FP-18	73	1.39	567	2.9	587
FP-19	68	0.77	554	9.7	706

A mixture of nitrogen and air was used as the pretreatment gas. It was found that with 3%-5% oxygen concentration in the feed gas, temperatures above 600°F could be maintained. Laboratory evaluations of the chars produced in these tests showed that the char of Run HT-16 was fused, that of Run HT-17 lightly fused, and that of Run HT-18 was free flowing, when heated to 1400°F at atmospheric pressure in a hydrogen atmosphere. Evaluation of the char of Run HT-19 has not yet been completed. Based on the above results there does not seem to be as yet a correlation between pretreatment conditions and laboratory test results. The reason may be because of fluctuation in composition of feed material. Further analysis on char and feed compositions should show this.

About a year ago, the same laboratory evaluation for agglomeration was made on four chars pretreated at 1000 psig in another reactor. These chars were found to be free flowing when originally tested at 1050°F. They were also found to be free flowing in this test at 1400°F.

Methanation

Work continued on planning the test program and on design and ordering of major pieces of equipment. Construction work on the barricading was given top priority so that the laboratory area will be ready when the equipment arrives.

Design of service facilities for the new laboratory area was continued.

Coal Characterization

Dynatech Corp. continued redesigning the high-temperature, high-pressure heat-of-reaction calorimeter. As was mentioned in the Methanation section above, work on construction of the barricading and design of the service facilities for the new laboratory area was continued.

Apparatus for determination of the reflectance of coal macerals was checked out this month. Light filters for the microscope and a constant-voltage transformer for the microscope lamp were received. The constant-voltage transformer in the photometer was found to be defective and a replacement has been requested. Tests with a borrowed constant-voltage transformer were made to "iron out" procedure and apparatus problems. On the basis of the observations made so far, it appears that the apparatus will be satisfactory.

Apparatus for determination of particle density by mercury displacement was built except for shop fabrication of a pressure vessel. Precision-bore glass tubing for determination of particle density by a gas flow method was ordered; this will be used on particle sizes smaller than about 80 mesh.

Process Concept Development

Work has involved developing a mathematical model describing the state-of-the-art of coal partial oxidation or suspension gasification processes. This work to aid the economic study is in preparation for estimating operating parameters when using spent char from the hydrogasifier as feed for these processes.

Economic Evaluation

In preparation for design of the hydrogen section of the pipeline gas plant, a study is being made of synthesis gas production by suspension gasification of coal. Contacts with Texaco Corp. and Babcock and Wilcox Co. will be made for state-of-the-art information. These two companies have developed pressurized gasification processes (300-400 psig). Gasification at atmospheric pressure would not be economical for our process because of the need to compress hydrogen to 1000 psig. A study of basic gasification reactions is being made.

Fluidized-bed gasification will also be considered. Spent char from hydrogasification would be a good feed for this process since there would probably be little tendency toward agglomeration. The fluidized gasification process has some advantages over suspension gasification in the operation at nonslagging conditions, possibly giving higher yields per unit of reactor volume. However, carbon gasification efficiencies would probably be lower for fluidized operations.

No inventions were made during the month of March; however, we are now reviewing our work to establish any patentable aspects of the process as it is presently envisioned.

Jack Huebler, Associate Director | Frank Schora, Manager

PROGRAM FOR DEVELOPMENT OF IGT

OCR Contract No. 14-01-0001-381

	1964					1965												1966	
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
	1st Year												2nd Year						

PHASE I

a. Hydrogasification

1. Establish rate-controlling areas of operation. E - 13, T - 36, DS - $15,800, ODC - $5,500
2. Study effect of degree of pretreatment. E - 4, T - 10, DS - $7,500, ODC - $2,500
3. Study effects of variables to establish kinetics of fixed-bed system. E - 13, T - 36, DS - $25,800, ODC - $4,300
4. Study fluidization and establish rates for fluid-bed operation. DS - $12,500, ODC - $1,300
5. Study fluid-bed system. DS - [illegible], ODC - [illegible]
6. Study particle size effect for both fixed and fluidized-bed operation. DS - $12,500, ODC - $2,300
7. Study [illegible]

b. Coal Pretreatment

1. Modify coal pretreatment unit. E - 3, T - 12, DS - $4,250, ODC - $6,000
2. Study effects of pretreatment variables on char properties. DS - $10,400, ODC - $4,300
3. Establish pretreatment [illegible]

Produce material required for hydrogasification runs

c. Methanation

1. Review state of the art, and design lab test unit. E - 7, T - 2, DS - $3,800, ODC - 0
2. Build and shake down lab unit. E - 3, T - 4, DS - $4,150, ODC - $3,500
3. Lab scale catalyst evaluation. E - 5, T - 12, DS - $6,050, ODC - $2,250
4. Study effects of gas composition. ODC - $2,200
5. Design and construct small pilot unit. E - 5, T - 28, DS - $8,500, ODC - $18,500

d. Coal Characterization

1. Develop techniques and study petrographic characteristics of coal, char, and spent hydrogasified residue. Determine heats of reaction of coal and chars. E - 33, T - 9, DS - $8,900, ODC - $22,500
2. Establish tests and develop estimation of worth of coal [illegible]. E - 24, T - 11, DS - $10,[illegible], ODC - $500

PHASE II

a. Analysis of Experimental Data

Analyze and correlate data from hydrogasification, coal pretreatment, and methanation work, and recommend conditions for additional tests. Develop kinetic equations for use in reactor design. E - 32, DS - $13,900

b. Process Concept Development

1. Develop simple mathematical model of process based on present data. E - 5, T - 0, DS - $2,500, ODC - 0
2. Improve and expand model when additional data become available and determine areas where additional data are needed. Modify process concept as necessary and keep process flowsheets updated. DS - $4,200, ODC - $1,500

c. Reactor Design Studies

Base preliminary [illegible] process concept

d. Economic Evaluation

1. Cost data review and extension. E - 7, T - 0
2. Develop simple flow sheet. E - 2, T - 0, DS - $400, ODC - 0; DS - $3,200, ODC - 0
3. Detailed flow sheet, energy and material balances. E - 3, T - 0, DS - $1,800, ODC - 0
4. Process design of various sections. E - 4, T - 0, DS - $1,800, ODC - 0
5. Cost estimate of equipment, plant and operating expenses. E - 3, DS - $1,400
6. Report preparation. E - 2, T - 0, DS - $900, ODC - 0
7. Revision and updating of flowsheet. DS - $2,800, ODC - 0

PHASE III

a. Preliminary Pilot Plant Design

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Planned	[illegible]	23,500	23,500	23,500	21,800	22,400	24,100	24,300	24,700	23,700	23,300	23,800	30,300	29,300	27,800	27,400	28,100	28,100	23,300	23,300
Actual		10,000	15,000	23,300	14,500	23,000	21,100	19,800	28,900											
Cumulative		10,000	25,000	48,300	62,800	85,800	106,900	126,700	[illegible]											

Manpower shown in total man months: E - Engineers, T - Technicians

Costs shown are costs to OCR or one-half of total [illegible]

HYDROGASIFICATION PROCESS

GA PB 23a

1966 — 1967

Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

3rd Year

Hydrogasification of various coals ... under most suitable conditions
E = 2[illegible]
T = [illegible]
DS = $[illegible]
ODC = $[illegible]

6
Perform any support work necessary for phase III
Double check data on which pilot plant is being designed

... of various coals

4
Produce material needed for any hydrogasification runs

Run small pilot unit and develop kinetic equations for design
E = [illegible]
DS = $[illegible]
ODC = $[illegible]

7
Perform any support work necessary for phase III

Improvement to enable hydrogasification

Laboratory and Pilot Plant
Phase I-A8, B4, C7 II-A2
Engineers 24 Salaries $40,400
Technicians 105 Other Direct Costs 11,400

2
Perform analysis of past data and new data in any areas necessary for phase III work

... reactor design based on ... and hydrogasification results
E = 6
DS = $2,800
ODC = 0

3
Work with subcontractor on design of reactors for hydrogasification and methanation
E = 4
T = 0
DS = $1,800
ODC = 0

Revision and refinement of capital and operating costs
E = 6
T = 0
DS = $2,800
ODC = 0

4
Work with subcontractor on capital and operating costs for pilot plant
E = 9
T = 0
DS = $4,100
ODC = 0

1
Develop pilot plant flowsheet with heat and material balances
E = 14
T = 0
DS = $7,700
ODC = 0

Select architect-engineer subcontractor

2
With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.*
E = 34
T = 0
DS = $18,380
ODC = 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

23,300	23,300	23,300	23,300	23,300	15,800	15,800	15,800	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

DS - Direct Salaries, $
ODC - Other Direct Costs, $

IGT-HPDR--4/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report — April 1965

to

Office of Coal Research
Contract No. 14-01-0001-381

Hydrogasification

Analytical results have been completed for Run HT-53 — the first test made last month in the rebuilt hydrogasification reactor. A low-temperature bituminous coal char was hydrogasified in this run at 1000 psig and an average reactor temperature of 1485°F, with a hydrogen-steam mixture containing 36 mole percent steam and a hydrogen/char ratio 41 percent of stoichiometric. Results show that 52% of the carbon was gasified, and 41% of the steam was reacted.

Five hydrogasification tests (Runs HT-56, HT-56b, HT-56c, HT-57, and HT-57b) were attempted in the pilot unit to gasify a lightly treated Pittsburgh seam (Ireland mine) bituminous coal. These tests are being run to establish the minimum amount of pretreatment required for satisfactory operation in the 4-in. reactor. The pretreated coal was prepared in the pilot plant pretreater in Run FP-15 (February 1965 Report) and was shown to be nonagglomerating based on our laboratory test.

Three of these tests lasted only up to 7 minutes, as difficulties were encountered in feeding the coal. The coal feed tube eventually became plugged at the screw. To correct this problem, the feed tube was enlarged from 0.4 in. to 1.0 in. ID, and was shortened to keep the discharge end somewhat cooler. After these changes, two hydrogasification tests were run for 34 and 27 minutes. These tests were terminated when the coal eventually bridged in the 4-in. reactor tube, and the coal level built up to choke the coal feed tube. Product gas samples were taken during these tests; a partial evaluation will be made when analytical results of the tests are completed.

Coal Pretreatment

Two coal pretreatment tests were conducted in the continuous fluidized-bed pretreater with a Pittsburgh seam coal from the Ireland mine. These tests continue the study for defining minimum pretreatment conditions necessary for producing a nonagglomerating char for the pilot unit hydrogasifier.

Nominal conditions for these tests are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Residence Time, hr	Gas Rate, SCF/hr	Oxygen, %	Temp, °F
FP-20	67	1.26	582	10.1	649
FP-21	75	1.35	600	10	700

Pretreatment gas was a mixture of nitrogen and air. These tests were designed to increase the degree of pretreatment over that in earlier tests by using a higher temperature and an oxygen concentration of 10%. Laboratory evaluations of the chars for agglomerating characteristics have not yet been completed. A laboratory evaluation showed the char produced in Run FP-19 (March 1965 Report) at 706°F to be nonagglomerating.

The pilot plant swing hammer mill, which pulverizes coal for the pretreater, has been modified to produce a smaller fraction of fines. The speed of the mill was reduced and the screen removed.

Methanation

With construction of the barricading nearly completed, work was begun on the instrument panels. Nearly all the major pieces of instrumentation were received.

Design of service facilities for the new laboratory area was completed.

Coal Characterization

The high-temperature, high-pressure heat-of-reaction calorimeter redesign was completed by Dynatech Corp. Barricading for the calorimeter was completed.

Construction and assembly of apparatus for determination of particle density by mercury displacement was completed. Determinations on the coarser sieve fractions (100 mesh and larger) of feeds and residues from several free-fall runs were started.

Development of procedures for determination of reflectance of coal macerals was continued. Determination on an area of only 2.8-micron diameter appears feasible with the addition of a recorder or output meter having somewhat greater sensitivity than that which the instrument now provides. This will make it possible to read reflectance on vitrinite and other macerals in attrital coal grains that have only small areas of uniform reflectance.

Process Concept Development

During the month integration of presently developed kinetic equations into the process model was begun, the purpose of which is directed to improve the accuracy of the model in predicting process operation.

Economic Evaluation

Texaco has been contacted about their gasification process for making hydrogen. They indicated that it may be possible to operate at 1000 psig.

A study is under way to determine the effect of the hydrogasifier feed composition on the external hydrogen required.

An economical evaluation of the various methods of controlling the temperature for methanation is also in progress.

No inventions were made during the month. The work to establish patentable aspects of the process is continuing.

Jack Huebler, Associate Director

Frank Schora, Manager

PROGRAM FOR DEVELOPMENT OF IGT H

OCR: Contract No. 14-01-0001-381 A.G.

1964					1965												1966		
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	M

1st Year (Aug 1964 – Jul 1965) — 2nd Year (Aug 1965 –)

PHASE I

a. Hydrogasification

1. Establish rate-controlling areas of operation. E-15, T-36, DS-$15,800, ODC-$5,500 (Aug–Nov)
2. Study effect of degree of pretreatment. E-6, T-18, DS-$7,500, ODC-$2,500 (Dec–Jan)
3. Study effects of variables to establish kinetics of fixed-bed system. E-13, T-36, DS-$15,500, ODC-$4,000 (Feb–May)
4. Study fluidization and establish rates for fluid-bed operation. E-10½, T-27, DS-$12,500, ODC-$3,000 (Jun–Aug)
5. Study H₂O-CO₂-C System. E-3, T-9, DS $4,000, ODC $1,000 (Sep)
6. Study particle size effect for both fixed and fluid-bed operation. E-9, T-27, DS-$11,300, ODC-$2,000 (Oct–Dec)
7. Study hydroga[...] unde[...] (Jan–)

b. Coal Pretreatment

1. Modify coal pretreatment unit. E-3, T-11, DS-$4,250, ODC-$6,500 (Aug–Nov)
2. Study effects of pretreatment variables on char properties. E-4½, T-12½, DS-$12,400, ODC-$4,000 (Dec–Aug)
3. Establish pretreatment properties a[...]. E-5½, T-27½, DS-$12,600, ODC-$6,500

Produce material required for hydrogasification runs (Dec –)

c. Methanation

1. Review state of the art, and design lab test unit. E-7, T-0, DS-$3,800, ODC-0 (Aug–Dec)
2. Build and shake down lab unit. E-3, T-6, DS-$4,150, ODC-$3,500 (Jan–Mar)
3. Lab scale catalyst evaluation. E-5, T-12, DS-$6,850, ODC-$1,250 (Apr–Aug)
4. Study effects of gas composition. E-5, T-10, DS $6,150, ODC-$1,000 (Sep–Dec)
5. Design and construct small pilot unit. E-5, T-16, DS-$8,500, ODC-$18,500
6. Run [...]

d. Coal Characterization

1. Develop techniques and study petrographic characteristics of coal, char, and spent hydrogasified residue. Determine heats of reaction of coal and chars. E-13, T-9, DS-$8,900, ODC-$20,500 (Aug–Aug)
2. Establish tests and develop correlati[...] estimation of worth of coal for hydrog[...]. E-14, T-11, DS-$10,200, ODC-$500

PHASE II

a. Analysis of Experimental Data

1. Analyze and correlate data from hydrogasification, coal pretreatment, and methanation work, and recommend conditions for additional tests. Develop kinetic equations to use in reactor design. E-32, T-0, DS-$13,800, ODC-0

b. Process Concept Development

1. Develop simple math model of process based on present data. E-5, T-0, DS-$2,300, ODC-0 (Aug–Oct)
2. Improve and expand model when additional data becomes available and determine areas where additional data are needed. Modify process concept as necessary and keep process flowsheets updated. E-20, T-0, DS-$9,200, ODC-$1,500

c. Reactor Design Studies

1. Make preliminary reac[...] process concept and opt[...]. E-[...], T-[...], DS-[...], ODC-[...]

d. Economic Evaluation

1. Cost data review and extension. E-7, T-0
2. Develop simple flow sheet. E-2, T-0, DS-$900, ODC-0 — DS-$3,200, ODC-0
3. Detailed flow sheet, energy and material balances. E-3, T-0, DS-$1,400, ODC-0
4. Process design of various sections. E-4, T-0, DS-$1,800, ODC-0
5. Cost estimate of equipment, plant and operating expenses. E-3, T-0, DS-$1,400, ODC-0
6. Report Preparation. E-2, T-0, DS-$900, ODC-0
7. Revision and updating of flowsheet. E-6, T-0, DS-$2,800, ODC-0

PHASE III

a. Preliminary Pilot Plant Design

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	M
Planned	[illegible]	23,500	23,500	23,[illegible]	23,800	22,400	24,100	24,300	24,700	23,700	23,300	23,800	30,300	29,300	27,800	27,400	28,100	28,100	23,300	23,300	23.[illegible]
Actual		10,000	15,000	23,3[illegible]0	14,500	23,000	21,100	19,800	28,900	23,400											
Cumulative		10,000	25,000	48,[illegible]	62,800	85,800	06,900	26,700	155,600	179,000											

Manpower shown in total man months: E - Engineers, T - Technicians

Costs shown are costs to OCR or one-half of total costs.

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...GT HYDROGASIFICATION PROCESS

...-381 AGA PB 23a

1966												1967						
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
2nd Year							3rd Year											

7
Study hydrogasification of various coals, lignite, under most suitable conditions
E = 2¼
T = 6½
DS = $27,200
ODC = $7,300

8
Perform any support work necessary for phase III
Double check data on which pilot plant is being designed

1
... properties of various coals
E = 5¼
T = 2¼
DS = $12,600
ODC = $4,500

4
Produce material needed for any hydrogasification runs

9
Run small pilot unit and develop kinetic equations for design
E = 10
T = 20
DS = $11,900
ODC = $5,250

7
Perform any support work necessary for phase III

...
...sts and develop correlations to enable ... of ... of coal for hydrogasification
E = 14
T = ...
DS = $...,200
ODC = $530

Laboratory and Pilot Plant Phase I-A8, B4, C7 II-A2 — Engineers 24, Technicians 105 — Salaries $40,600, Other Direct Costs 11,600

3
Perform analysis of past data and new data in any areas necessary for phase III work

... ...

1
Make preliminary reactor design based on process concept and hydrogasification results
E = 6
T = 0
DS = $2,600
ODC = 0

2
Work with subcontractor on design of reactors for hydrogasification ... methanation
E = 4
T = 0
DS = $1,600
ODC = 0

4
Revision and refinement of capital and operating costs
E = 6
T = 0
DS = $2,600
ODC = 0

4
Work with subcontractor on capital and operating costs for pilot plant
E = 4
T = 0
DS = $4,100
ODC = 0

1
Develop pilot plant flowsheet with heat and material balances
E = 14
T = 0
DS = $7,700
ODC = 0
Select architect-engineer subcontractor

2
With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.*
E = 14
T = 0
DS = $16,300
ODC = 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
23,300	23,300	23,300	23,300	23,300	23,300	23,300	15,600	15,600	15,600	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

... one-half of total costs. DS = Direct Salaries, $
ODC = Other Direct Costs, $

FE-MPR-5/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report - May 1965

to

Office of Coal Research
Contract No. 14-01-0001-381

Hydrogasification

Seven hydrogasification tests (Runs HT-58, HT-59, HT-60, HT-61, HT-61b, HT-61c, and HT-62) were attempted in the balanced-pressure pilot unit to gasify lightly treated Pittsburgh seam bituminous coal. Coal from the Montour 4 mine was used in Run HT-58; the other tests used coal from the Ireland mine. The Montour 4 coal was pretreated at 1000-psig pressure in tests conducted in the early part of 1964. The Ireland mine coal was pretreated in the fluidized-bed pilot plant pretreater at atmospheric pressure (Runs FP-22, FP-23, and FP-24). These pretreated coals were non-agglomerating according to laboratory test.

Two of the hydrogasification tests were completely successful, one with coal char in free-fall, and one with a moving char bed. In these tests, no operational difficulties were experienced in feeding the coal char or in discharging the residue. Three of the tests were only partially successful. After falling through the heated reactor tube, the coal bridged in the lower end of the reactor tube below the furnace and could not be discharged. The bridging probably resulted from steam condensation rather than from stickiness of the coal char. Two of the tests had to be terminated shortly after they were started due to difficulties in the operation of the reactor-shell differential control system. The trouble was traced to a pneumatically operated control valve that was sticking. The faulty valve was replaced. Evaluation of the successful hydrogasification tests will be made when analytical results of the tests are completed.

Coal Pretreatment

Three coal pretreatment tests were conducted in the fluidized-bed pretreater with a Pittsburgh seam bituminous coal from the Ireland mine. The primary objective here was to produce a nonagglomerating char for the pilot unit hydrogasifier and, at the same time, study pretreatment conditions.

Nominal conditions for these tests are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Residence Time, hr	Gas Rate, SCF/hr	Oxygen, %	Temp, °F
FP-23	35	1.50	597	9.6	764
FP-24	34	1.89	830	9.2	738
FP-25	37	1.86	760	9.8	749

A mixture of nitrogen and air was used for pretreatment. The solids rate was reduced to half of that of previous tests in order to increase the coal residence time and thus increase the degree of pretreatment. Laboratory evaluations at 1400°F show the chars produced to be nonagglomerating. The chars of Runs FP-23 and FP-24 were used as feed to the pilot unit hydrogasifier.

Fluidization tests were conducted in a bench-scale glass tube to study the fluidization characteristics of 10 to 40 mesh and −10 mesh coal, and to define more accurately minimum fluidization rates. These tests are to provide information for improved operation of the pilot plant pretreater.

Methanation

The methanation reactor test program was formulated in a meeting with Dr. James Carberry, consultant to the Institute on this work. The barricade and instrument panel structures were completed for the test program. The reactor and most of the instrumentation were received.

Coal Characterization

Dynatech Corp. continued construction of the heat-of-reactor calorimeter. The drop calorimeter has been essentially completed; the instrument console is being constructed.

Characteristics required of a recorder to be used with the reflectance apparatus in the coal petrographic work were determined. Feeds and products of pretreatment Runs FP-4A and FP-8 were analyzed petrographically. No significant difference between feed and product was evident in either run. Small differences between the two feeds, one of Montour 4 coal and the other Ireland mine coal, were found. Particle densities of two sieve fractions of the feed and residue of a free-fall hydrogasification run were determined.

Process Concept Development

The work on integrating the kinetic equations for the two stages of hydrogasification into the process model is continuing. Although the kinetic equations describing the hydrogen char and steam-char reactions will undergo modification as the operation of the pilot unit continues, integration of the kinetics into the process model will provide significant insight into the variation in equipment size with various operating parameters.

Economic Evaluation

During the past month the study to determine the effect of hydrogasifier feed composition on the required amount of external hydrogen has been completed. A study has now been undertaken to determine the total carbon conversion that will eliminate the production of excess spent char.

Determinations have been started on the design criterion for the pretreatment section to be used in the state-of-the-art design.

Gasification requirements for hydrogen production from spent char have been discussed with the Texaco Development Corp. Char partial combustion appears feasible. Texaco has given us tentative synthesis composition and reactant requirements. We have calculated synthesis gas costs as affected by oxygen/carbon and steam/carbon ratios.

No inventions were made during the month. Some problems on delivery of the special heat-of-reaction calorimeter are anticipated. Dynatech Corporation informs us that, due to problems in nickel plating one of the large enclosures, the delivery date of July 1 might not be met. We plan to keep in close touch with Dynatech to expedite this item.

Jack Huebler, Associate Director

Frank Schora, Manager

PROGRAM FOR DEVELOPMENT OF IGT HY

OCR: Contract No. 14-01-0001-381 A.G.A.

1964: Aug, Sep, Oct, Nov, Dec — 1965: Jan, Feb, Mar, Apr, May, Jun, Jul (1st Year) | Aug, Sep, Oct, Nov, Dec — Jan, Feb, Mar (2nd Year)

PHASE I

A. Hydrogasification

1. Establish rate-controlling areas of operation — E-13, T-36, DS-$15,800, ODC-$5,500
2. Study effect of degree of pretreatment — E-8, T-28, DS-$7,500, ODC-$2,500
3. Study effects of variables to establish kinetics of fixed-bed system — E 23, T 36, DS-$15,800, ODC-$4,000
4. Study fluidization and establish rates for fluid-bed operation — E 10½, T 27, DS $12,500, ODC-$3,000
5. Study H_2O-O_2-C System — E 1, T 6, DS $3,800, ODC $1,000
6. Study particle size effect for both fixed and fluid-bed operation — E-9, T-27, DS-$11,300, ODC $2,000
7. Study hydrogasific… under most…

B. Coal Pretreatment

1. Modify coal pretreatment unit — E-3, T-11, DS-$4,250, ODC $6,0…
2. Study effects of pretreatment variables on char properties — E-4½, T 22½, DS $10,400, ODC $4,000
3. Establish pretreatment properties of varie… — E-5½, T-27½, DS-$12,600, OCD-$4,500

Produce material required for hydrogasification runs

C. Methanation

1. Review state of the art, and design lab test unit — E-7, T-3, DS-$3,800, ODC-0
2. Build and shake down lab unit — E-3, T-9, DS-$4,150, ODC-$3,500
3. Lab scale catalyst evaluation — E 5, T-12, DS-$6,850, ODC-$2,250
4. Study effects of gas composition — E-5, T 12, DS $6,150, ODC-$1,000
5. Design and construct small pilot unit — E-5, T 18, DS-$8,500, ODC-$18,500
6. Run small… kinetic…

D. Coal Characterization

1. Develop techniques and st…p petrographic characteristics of coal, char, and spent hydrogasified residue. Determine heats of reaction of coal and chars — E 13, T 9, DS-$6,900, ODC $20,500
2. Establish tests and develop correlations & estimation of worth of coal for hydrogasi… — E-14, T-11, DS $10,200, ODC $500

PHASE II

A. Analysis of Experimental Data

1. Analyze and correlate data from hydrogasification, coal pretreatment, and methanation work, and recommend conditions for additional tests. Develop kinetic equations to use in reactor design — E-32, T-3, DS $23,800, ODC-0

B. Process Concept Development

1. Develop simple math model of process based on present data — E 5, T-3, DS-$2,300, ODC-0
2. Improve and expand model when additional data becomes available and determine areas where additional data are needed. Modify process concept as necessary and keep process flowsheets updated — E-20, T 3, DS-$9,200, ODC $1,500

C. Reactor Design Studies

1. Make preliminary reactor… process concept and hydro… — E-6, T-0, DS-$2,6…, ODC-0

D. Economic Evaluation

1. Cost data review and extension — E-7, T-0, DS-$3,200, ODC-0
2. Develop simple flow sheet — E-2, T-0, DS-$900, ODC-0
3. Detailed flow sheet, energy and material balances — E-3, T-0, DS-$1,400, ODC-0
4. Process design of various sections — E-4, T-0, DS-$1,800, ODC-0
5. Cost estimate of equipment, plant and operating expenses — E 3, T-0, DS $1,400, ODC-0
6. Report Preparation — E 2, T-0, DS-$900, ODC-0
7. Revision and updating of flowsheet — E-6, T-0, DS-$2,800, ODC-0

PHASE III

A. Preliminary Pilot Plant Design

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Planned	[illegible]	23,500	23,500	23,500	23,600	22,400	24,100	24,300	24,700	23,700	23,300	23,800	30,300	29,300	27,600	27,400	28,100	28,100	23,300	23,300	23,300
Actual		10,000	15,000	23,300	14,500	23,000	21,100	19,800	28,900	23,400	30,200										
Cumulative		10,000	25,000	48,300	62,800	85,800	106,900	126,700	155,600	179,000	209,200										

Manpower shown in total man months: E - Engineers, T - Technicians

Costs shown are costs to OCR or one-half of total costs.

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... Hydrogasification Process

A.G.A. PB 23a

1966											1967						
Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

...Year (Feb–Jul 1966) | 3rd Year (Aug 1966 – Jul 1967)

Feb–Jul 1966:

Study hydrogasification of various coals, lignite, under most suitable conditions

E = 21½
T = 41
DS = $22,300
ODC = $7,200

Aug 1966 – Jul 1967:

Perform any support work necessary for phase III
Double check data on which pilot plant is being designed

Feb–Jul 1966:

...nt properties of various coals

E = 5½
T = 27½
DS = $12,600
ODC = $4,500

Aug 1966 – Jul 1967:

Produce material needed for any hydrogasification runs

Feb–Jul 1966:

Run small pilot unit and develop kinetic equations for design

E = 12
T = 19
DS = $11,500
ODC = $5,250

Aug 1966 – Jul 1967:

Perform any support work necessary for phase III

Feb–Jul 1966:

...nd develop correlations to enable ...th of coal for hydrogasification

E = 14
T = ..
DS = $10,200
ODC = $500

Aug 1966 – Jul 1967:

Laboratory and Pilot Plant Phase I-4B, 6A, 27 II-A2 | Engineers 24 | Technicians 105 | Salaries $40,400 | Other Direct Costs 11,400

Aug 1966 – Jul 1967:

Perform analysis of past data and new data in any areas necessary for phase III work

---

Feb–Jul 1966:

...ional

Feb–Jul 1966:

Make preliminary reactor design based on ...ess concept and hydrogasification results

E = 6
T = 0
DS = $2,800
ODC = 0

Aug 1966 – Jul 1967:

Work with subcontractor on design of reactors for hydrogasification and methanation

E = 4
T = 0
DS = $1,800
ODC = 0

Feb–Jul 1966:

Revision and refinement of capital and operating costs

E = 6
T = 0
DS = $2,800
ODC = 0

Aug 1966 – Jul 1967:

Work with subcontractor on capital and operating costs for pilot plant

E = 4
T = 0
DS = $4,100
ODC = 0

Aug – Oct 1966:

Develop pilot plant flowsheet with heat and material balances

E = 14
T = 0
DS = $7,700
ODC = 0

Select architect-engineer subcontractor

Nov 1966 – Jul 1967:

With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.*

E = 34
T = 0
DS = $16,300
ODC = 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
...	23,300	23,300	23,300	23,300	23,300	23,300	15,600	15,600	15,600	21,700	23,700	21,700	21,700	21,700	21,700	21,700	21,700	23,700

...-half of total costs. DS – Direct Salaries, $
ODC – Other Direct Costs, $

9 B9 – MPR – – 6/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report – June 1965

to

Office of Coal Research

Contract No. 14-01-0001-381

Hydrogasification

Seven hydrogasification tests (Runs HT-63 to HT-69) were conducted in the balanced-pressure pilot unit to study the gasification of lightly pretreated Pittsburgh seam bituminous coal from the Ireland mine. The coal was pretreated in the fluidized-bed pilot plant pretreater with nitrogen and air at 750°F (Runs FP-25, 27, 28, and 29). When tested in the laboratory at conditions simulating hydrogasification operation, these pretreated coals were found to be nonagglomerating.

The partially hydrogasified residue from one of the tests conducted at 1300°F was used as a feed for a following hydrogasification test designed to simulate the high-temperature reaction zone of a two-stage hydrogasification process. The test was conducted at a nominal temperature of 1700°F with a hydrogen-steam feed gas containing 50 mole percent steam. Approximately 20% of the carbon in the already partially hydrogasified feed was gasified. A product gas having a heating value of 414 Btu/SCF on a nitrogen-free basis was produced.

In four other tests, the low-temperature reaction zone of a two-stage hydrogasification process was simulated. Lightly pretreated Ireland mine bituminous coal was reacted at 1300°F with feed gas of the following composition: hydrogen, 45 mole percent; methane, 25 mole percent; and steam, 30 mole percent. This composition approximates that of a gas leaving the high-temperature zone. Two of these tests lasted only 30 minutes, as coal caked at the top of the reactor tube and plugged it. The feed coal for these tests, pretreated in Run FP-27, apparently did not have its agglomerating characteristics entirely destroyed in pretreatment. In the other two tests, pretreated coal from Runs FP-28 and FP-29 was used. Both tests were completely successful, lasting 8 hours. Bed-level control was ideal, and the coal did not cake. To develop data for studying reaction rates within the coal bed, product gases were sampled in these two tests at levels of 6, 18, and 42 inches below the top of the 7-ft bed.

The partially hydrogasified residue from the two successful, simulated low-temperature tests was hydrogasified in another test simulating the high-temperature zone of a two-stage operation. The coal feed rate was reduced in proportion to the fraction of coal already converted to approximate the rate at which coal would be entering the high-temperature zone. The coal was reacted at 1700°F with a hydrogen-steam feed gas containing 50 mole percent steam. Approximately 20% of the remaining carbon in the partially hydrogasified feed was converted in this second-stage test.

Components have been machined for adapting the hydrogasification reactor to fluid-bed operation. These include a feed gas distributor and a sectional support tube for positioning the gas distributor at different levels within the reactor. A reactor head assembly was machined to accommodate an internal cyclone which will be necessary for gas-solids separation in fluid-bed operation. The head assembly also has accommodations for a coal feed tube, product gas off-take tube, gas sampling probes, and thermocouples.

Fabrication of larger capacity coal feed hopper and residue receiver vessels for the hydrogasification pilot plant is proceeding in the IGT shop. Major welding of the residue receiver has been completed. Hydrogasification tests at higher coal feed rates and of longer duration will be possible when these larger vessels are installed.

Coal Pretreatment

Four pretreatment tests were made in the pilot unit fluidized-bed pretreater using a Pittsburgh seam bituminous coal from Consolidation Coal Co.'s Ireland mine. The objectives of these tests were to produce a nonagglomerating char for the pilot hydrogasification unit and to study minimum pretreatment requirements and conditions.

Nominal conditions for these runs are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Res Time, hr	Feed Gas Rate, SCF/hr	Oxygen Conc, %	Bed Temp, °F
FP-26	31	1.73	987	9.1	731
FP-27	31	--	1325	8.5	719
FP-28	34	1.85	637	9.8	744
FP-29	34	1.61	609	9.9	756

An air and nitrogen mixture was used as the feed gas. The coal feed particle size for Runs FP-26 and FP-27 was -10 + 40 mesh. Fluidization was erratic with this particle size distribution even at substantially increased feed gas rates. Because of plugging in the reactor the computed average solids residence time for Run FP-27 was unreliable. The coal feed particle size for

Runs FP-28 and FP-29 was changed to −20 mesh and −16 + 80 mesh, respectively. The standpipe for these runs was increased from 5 ft to 7 ft to prevent solids residence time from decreasing due to greater bed expansion of the smaller sized particles. There were no operational difficulties during either of these tests. Laboratory agglomeration tests showed FP-26 char to be fused and FP-27 char to be lightly caked, whereas FP-28 and FP-29 chars were nonagglomerating and were successfully run in the pilot unit hydrogasifier.

Coal Characterization

The product from pretreatment Run FP-22, which was used successfully as feed for hydrogasification, was examined petrographically. Substantial modification of the coal, with appearance of vesicles, disappearance of exinite, increase in the reflectance throughout the particle, and appearance of a skin of still higher reflectance, was observed of many but not all particles.

A comparison of our reflectance determination with that at Bituminous Coal Research, Inc. was made on two coal samples. Reasonably good agreement, within 0.02% on a high-volatile coal and 0.04% on a low-volatile coal, was obtained.

Apparatus is being constructed for determination of particle density by the Ergun gas flow method.

Dynatech Corp. continued construction of the heat-of-reaction calorimeter. The drop calorimeter and the instrument console have been completed.

Methanation

Instruments for the methanation reactor were installed and are being tested. Water and air supplies and drain facilities were installed in the barricade.

During the month of June, no inventions were made in the course of this work. To ensure maximum efficiency in the pilot plant work, the pilot plant program will be suspended for the first two weeks in July for vacation purposes.

Approved ______________________ Signed ______________________
Jack Huebler, Associate Director Frank C. Schora, Manager

PROGRAM FOR DEVELOPMENT OF IGT H

OCR: Contract No. 14-01-0001-381 A.

Schedule: 1964 — Aug, Sep, Oct, Nov, Dec; 1965 — Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec; Jan, Feb
1st Year | 2nd Year

PHASE I

a. Hydrogasification

1. Establish rate-controlling areas of operation — E-13, T-34, DS-$13,800, ODC-$3,500
2. Study effect of degree of pretreatment — E-6, T-18, DS-$7,500, ODC-$2,500
3. Study effects of variables to establish kinetics of fixed-bed system — E-13, T-36, DS-$13,800, ODC-$4,000
4. Study fluidization and establish rates for fluid-bed operation — E-10½, T-27, DS-$12,500, ODC-$3,000
5. Study H₂O-O₂-C System — E-3, T-9, DS-$1800, ODC-$1000
6. Study particle size effect for both fixed and fluid-bed operation — E-9, T-27, DS-$11,100, ODC-$2,000
Study hydr…

b. Coal Pretreatment

1. Modify coal pretreatment unit — E-3, T-11, DS-$4,250, ODC-$4,000
2. Study effects of pretreatment variables on char properties — E-4½, T-22½, DS-$10,450, ODC-$4,000
Produce material required for hydrogasification runs
3. Establish pretreatment properties — E-4½, T-17½, DS-$12,… ODC-$…

c. Methanation

1. Review state of the art, and design lab test unit — E-7, T-6, DS-$3,800, ODC-0
2. Build and shake down lab unit — E-3, T-6, DS-$4,150, ODC-$3,500
3. Lab scale catalyst evaluation — E-13, T-12, DS-$8,850, ODC-$1,250
4. Study effects of gas composition — E-5, T-10, DS $4,150, ODC-$1,000
5. Design and construct small pilot unit — E-5, T-10, DS-$8,300, ODC-$18,500

d. Coal Characterization

1. Develop techniques and study petrographic characteristics of coal, char, and spent hydrogasified residue. Determine heats of reaction of coal and chars — E-13, T-9, DS-$8,400, ODC-$20,500
2. Establish tests and develop correl. estimation of worth of coal for h… — E-14, T-11, DS-$10,150, ODC-$500

PHASE II

a. Analysis of Experimental Data

1. Analyze and correlate data from hydrogasification, coal pretreatment, and methanation work, and recommend conditions for additional tests. Develop kinetic equations to use in reactor design — E-32, T-0, DS-$13,800, ODC-0

b. Process Concept Development

1. Develop simple math model of process based on present data — E-3, T-0, DS-$1,500, ODC-0
2. Improve and expand model when additional data becomes available and determine areas where additional data are needed. Modify process concept as necessary and keep process flowsheets updated — E-20, T-0, DS-$9,200, ODC-$1,500

c. Reactor Design Studies

Make preliminary a… process concept and…

d. Economic Evaluation

1. Cost data review and extension — E-2, T-0
2. Develop simple flow sheet — E-1, T-0, DS-$1,300, ODC-0
3. Detailed flow sheet, energy and material balances — E-3, T-0, DS-$1,400, ODC-0
4. Process design of various sections — E-4, T-0, DS-$1,600, ODC-0
5. Cost estimates of equipment, plant and operating expenses — E-3, T-0, DS-$1,400, ODC-0
6. Report Preparation — E-2, T-0, DS-$900, ODC-0
7. Revision and updating of flowsheet — E-6, T-0, DS-$2,800, ODC-0

PHASE III

a. Preliminary Pilot Plant Design

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Planned	555,400	21,500	21,500	21,500	21,800	22,400	24,100	24,300	24,700	21,700	21,100	23,800	30,300	29,300	27,800	27,400	28,100	28,100	23,300	23,300
Actual		10,000	15[redacted]00	23,300	14,500	23,000	21,100	19,800	28,800	23,400	38,100	14,500								
Cumulative		10,000	25[redacted]00	48,300	62,800	85,800	106,900	126,700	155,500	179,000	217,100	231,700								

Manpower shown in total man months: E = Engineers, T = Technicians

Costs shown are costs to OCR or one-half of total cost…

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[illegible] HYDROGASIFICATION PROCESS

A.G.A. PB-23a

	1966											1967						
	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

Year ← → 3rd Year

7 — Study hydrogasification of various coals, lignite, under most suitable conditions
E = 234
T = 63
DS = $27,200
ODC = $7,000

8 — Perform any support work necessary for phase III
Double check data on which pilot plant is being designed

1 — [illegible] properties of various coals
E = [illegible]
T = [illegible]
DS = [illegible]
ODC = [illegible]

4 — Produce material needed for any hydrogasification runs

6 — Run small pilot unit and develop kinetic equations for design
E = 10
T = 14
DS = $11,500
ODC = $5,250

7 — Perform any support work necessary for phase III

3 — And develop correlations to enable [illegible] of coal for hydrogasification
E = 14
T = 11
DS = $10,200
ODC = $500

Laboratory and Pilot Plant Phase I-[illegible] II-[illegible] — Engineers [illegible]; Technicians [illegible]; Salaries [illegible]; Other Direct Costs [illegible]

4 — Perform analysis of past data and new data in any areas necessary for phase III work

1 — Make preliminary reactor design based on [illegible] concept and hydrogasification results
E = 6
T = 0
DS = $4,000
ODC = 0

2 — Work with subcontractor on design of reactors for hydrogasification and methanation
E = 4
T = 0
DS = $1,600
ODC = 0

6 — Revision and refinement of capital and operating costs
E = 6
T = 0
DS = $2,000
ODC = 0

4 — Work with subcontractor on capital and operating costs for pilot plant
E = 4
T = 0
DS = $4,100
ODC = 0

1 — Develop pilot plant flowsheet with heat and material balances
E = 14
T = 0
DS = $7,700
ODC = 0

Select architect-engineer subcontractor

2 — With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.*
E = 34
T = 0
DS = $16,300
ODC = 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

[illegible]	23,300	23,300	22,300	23,300	23,300	23,300	15,000	15,000	15,000	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

[illegible] one-half of total costs. DS - Direct Salaries, $
ODC - Other Direct Costs, $

IGT-MPR..7/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report — July 1965

to

Office of Coal Research

Contract No. 14-01-0001-381

Hydrogasification

Two hydrogasification tests (Runs HT-70 and HT-71) were conducted in the balanced-pressure pilot unit to study the gasification of lightly pretreated Pittsburgh seam bituminous coal from the Ireland mine. The coal was pretreated in the fluidized-bed pilot plant pretreater with nitrogen and air at 750°F (Runs FP-28, FP-29, and FP-31). These pretreated coals were found to be nonagglomerating when tested in the laboratory at conditions simulating hydrogasification operation.

Both hydrogasification tests were conducted at similar conditions to simulate the upper, low-temperature reaction zone of a two-stage hydrogasification process, and to produce a sufficient quantity of partially hydrogasified coal to use as feed for a high-temperature hydrogasification test. The lightly pretreated bituminous coal was reacted at 1300°F with a feed gas containing 45 mole percent hydrogen, 25 mole percent methane, and 30 mole percent steam. This gas is typical of one that would be leaving the lower, high-temperature hydrogasification zone. The two tests were completely successful; each lasted about 6 hours and hydrogasified about 130 lb of coal. Product gases also were sampled in these tests at levels of 6, 18, and 42 inches below the top of the 7-ft coal bed to develop data for studying reaction rates within the coal bed.

Installation of a feed gas distributor inside the hydrogasification reactor was started. The gas distributor is a 3-inch, porous, stainless steel disk that will also act as a coal bed support plate to keep the bottom of the coal bed well within the heated portion of the reactor tube. Installation of the gas distributor is necessary for fluid-bed hydrogasification operations.

To facilitate the handling and conveying of high-moisture-content coals after being crushed, a used, rotary-type dryer was purchased. The gas-fired dryer has a 12-ft-long double shell, the inner shell having a 17-inch ID. It will be installed outdoors for drying coals used in pretreatment and hydrogasification tests before they are ground in the hammer mill.

Coal Pretreatment

Four pretreatment tests were conducted in the fluidized-bed pretreatment pilot unit. A Pittsburgh seam bituminous coal from Consolidated Coal Company's Ireland mine was used as the feed in the first two runs (FP-30 and FP-31). The purpose of these tests was to continue providing a nonagglomerating char for the pilot hydrogasification unit. Laboratory agglomeration tests showed the chars to be free-flowing, and both were successfully tested in the hydrogasification unit.

In the latter two tests (FP-32 and FP-33), the study of the Broken Arrow mine coal was initiated. It is a high-volatile bituminous coal like the Pittsburgh seam coal but of a slightly higher rank. The coal was acquired from the Ohio No. 6 seam (Middle Kittanning) and is one of the seven coals selected to be evaluated in the hydrogasification project. The purpose here is to study minimum pretreatment conditions and to supply the pilot hydrogasification unit with nonagglomerating char.

A typical proximate analysis of the Broken Arrow coal is as follows:

Moisture, %	Volatiles, %	Fixed Carbon, %	Ash, %	Heating Value, Btu/lb
4.0	39.0	51.6	5.4	12,400

Nominal conditions for the four tests are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Res Time, hr	Feed Gas Rate, SCF/hr	Oxygen Conc, %	Bed Temp, °F
FP-30	19.5	3.23	598	10.1	756
FP-31	18.2	3.80	584	9.9	750
FP-32	28.4	2.56	589	10.5	702
FP-33	28.2	2.01	630	10.2	749

An air and nitrogen mixture was used as the pretreatment gas. Coal feed particle size was -16, + 80 mesh for the four runs. Run FP-30 was terminated when solids plugged the cyclone, thus restricting the gas flow from the reactor. The remaining three tests operated successfully and were voluntarily terminated.

Laboratory agglomeration tests showed the char from Run FP-32 to be caked, whereas char from Run FP-33 was free-flowing. These results illustrate the effect an increase in bed temperature has on the severity of pretreatment.

Coal Characterization

Problems of mounting pretreated coal, which consists largely of relatively fragile hollow spheroids, were investigated. An apparatus and procedure for mounting the coal without particle breakage by attrition or by application of high pressure was devised. A low-power oil immersion objective was received with which photographs of whole particles so mounted were made.

The behavior of mineral constituents of the Ireland coal during pretreatment was investigated. The coal contains about 3 volume percent of shale particles unassociated with coal: these tend to accumulate in the reactor, as shown by a 12 volume percent content found, by petrographic examination, in the reactor residue from Run FP-31. Coal particles high in pyrite also concentrate in the reactor. About half of the pyrite in the Run FP-31 reactor residue had reacted with oxygen to form a product tentatively identified as magnetite.

Dynatech Corp. continued construction of the heat-of-reaction calorimeter. Most of the parts have been completed and are being assembled. The water, drain, air, and vent facilities have been installed in the barricade area.

Methanation

The inserts for the methanation reactor were fabricated and installed. Instruments were installed and tested.

State-of-the-Art Design

During June and July, the following was accomplished:

The pretreatment, hydrogasification, and methanation sections were designed. Drawings were given to Chicago Bridge & Iron Company for estimating the cost of vessels for these sections.

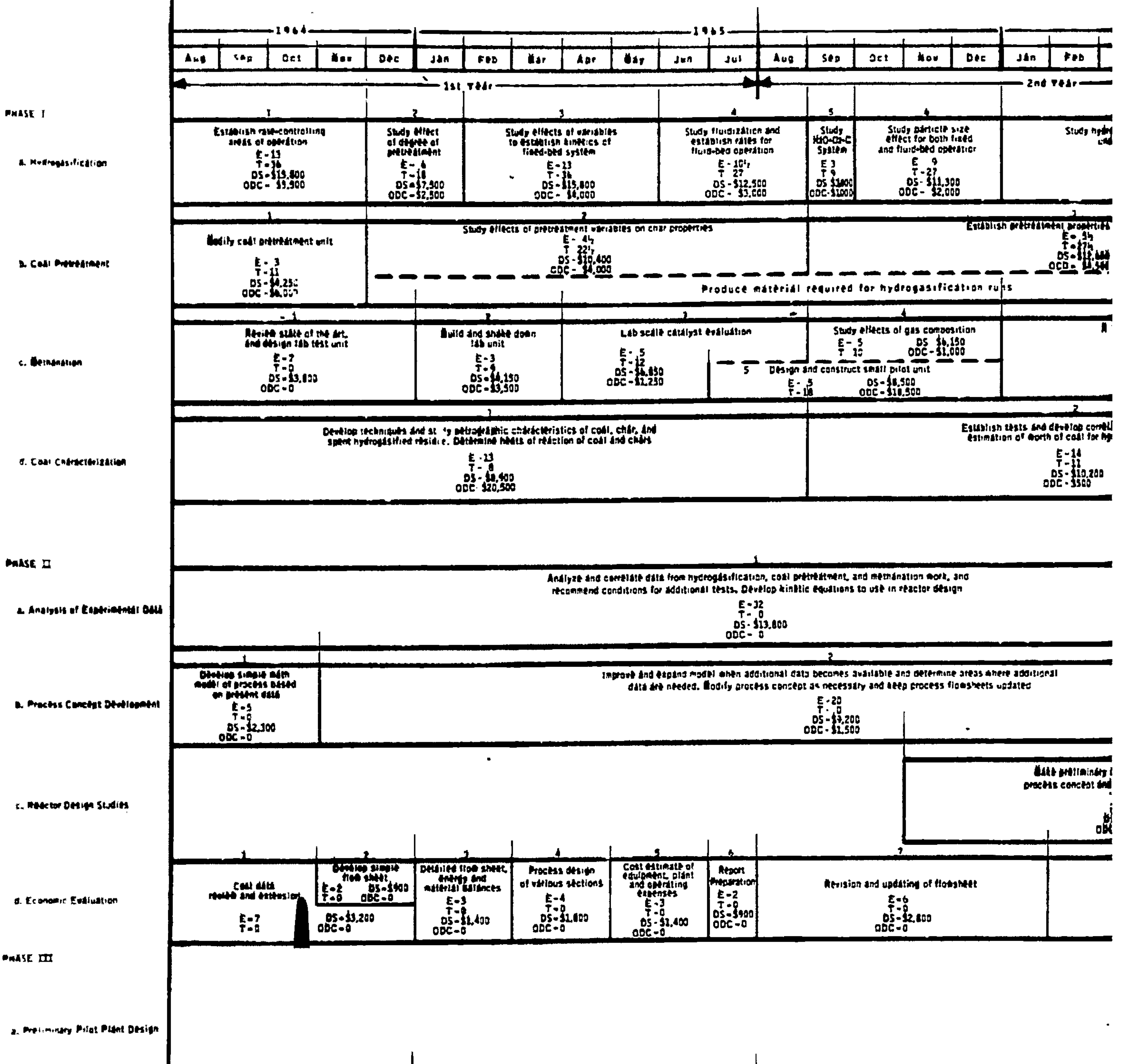
Discussions were held with engineers of The Lummus Co., the firm recommended to us by Texaco. They have made an estimate of capital and operating costs for producing the process hydrogen by partial oxidation of spent hydrogasification char.

During the month of July, no inventions were made in the course of this work.

Approved Jack Huebler Signed
Jack Huebler, Associate Director Frank C. Schora, Manager

PROGRAM FOR DEVELOPMENT OF IGT H

OCR: Contract No. 14-01-0001-381 A.G



TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Planned	855,400	23,500	23,500	23,500	23,800	22,400	24,100	24,300	24,700	23,700	23,300	23,800	30,300	29,300	27,800	27,400	28,100	28,100	23,300	23,300
Actual		10,000	15,000	23,300	14,500	23,000	21,100	19,800	28,900	23,400	30,100	24,500	22,900							
Cumulative		10,000	25,000	48,300	62,800	85,800	106,900	126,700	155,600	179,000	209,100	233,700	256,800							

Manpower shown in total man months: E - Engineers
T - Technicians

Costs shown are costs to OCR or one-half of total costs

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HYDROGASIFICATION PROCESS

A.G.A. PB-23a

1966						1967											
--	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

3rd Year

6

By hydrogasification of various coals, lignite, under most suitable conditions
E - 21
T - 61
DS - $21,200
ODC - $7,200

Perform any support work necessary for phase III
Double check data on which pilot plant is being designed

4

[illegible] of various coals
[illegible]
$11,400
$1,300

Produce material needed for any hydrogasification runs

Run small pilot unit and develop kinetic equations for design
E - 13
T - 19
DS - $11,500
ODC - $5,250

7

Perform any support work necessary for phase III

[illegible] correlations to enable [illegible] for hydrogasification
E - 14
T - 11
DS - $10,200
ODC - $300

Laboratory and Pilot Plant Phase I-A8, B4, C7 II-A2
Engineers 24 Salaries $40,400
Technicians 105 Other Direct Costs 11,400

2

Perform analysis of past data and new data in any areas necessary for phase III work

[illegible] preliminary reactor design based on [illegible] and hydrogasification results
E - 6
T - 2
DS - $2,800
ODC - 0

3

Work with subcontractor on design of reactors for hydrogasification and methanation
E - 4
T - 0
DS - $1,800
ODC - 0

Revision and refinement of capital and operating costs
E - 6
T - 0
DS - $2,800
ODC - 0

9

Work with subcontractor on capital and operating costs for pilot plant
E - 9
T - 0
DS - $4,100
ODC - 0

1

Develop pilot plant flowsheet with heat and material balances
E - 14
T - 0
DS - $7,700
ODC - 0

Select architect-engineer subcontractor

2

With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.*
E - 34
T - 0
DS - $16,300
ODC - 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

.	23,300	23,300	23,300	23,300	23,300	15,800	15,800	15,800	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

[illegible] costs. DS - Direct Salaries, $
ODC - Other Direct Costs, $

IAr.MPR-D/AE

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DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report - August 1965
to
Office of Coal Research
Contract No. 14-01-0001-381

Hydrogasification

Three hydrogasification tests (Runs HT-72, HT-73, and HT-74) were conducted in the balanced-pressure pilot unit to study the gasification of lightly pretreated bituminous coal. Pittsburgh seam bituminous coal from the Ireland mine, partially hydrogasified in Runs HT-70 and HT-71 (July 1965 Progress Report), was the feed in the first two tests. Feed in the third test was a pretreated Ohio No. 6 seam bituminous from the Broken Arrow mine. This coal, supplied by Peabody Coal Company, was pretreated with nitrogen and air at 750°F in the IGT fluidized-bed pilot plant pretreater (Runs FP-32, FP-33, and FP-34). When tested in the laboratory at conditions simulating hydrogasification operation, the pretreated coal was found to be nonagglomerating.

Runs HT-72 and HT-73 were conducted to simulate the lower, high-temperature reaction zone of a two-stage hydrogasification process. Partially hydrogasified coal was reacted at 1850°F in Run HT-72 with a hydrogen-steam mixture containing 40 mole percent steam, and a hydrogen/coal ratio 37% of the stoichiometric ratio. In Run HT-73 partially hydrogasified coal was reacted at 2000°F with a hydrogen-steam mixture containing 20 mole percent steam, and a hydrogen/coal ratio 42% of stoichiometric. Both tests were conducted at coal feed rates of 15 lb/hr in a 7-ft moving bed. The bottom of the coal bed was located at about the midpoint of the reactor tube, the coal resting on a gas distributor disk. The two tests were successful, one lasting 5-1/2 hours, the other 4-1/2 hours. To develop data for studying reaction rates within the coal bed, product gases were sampled in these tests at levels of 6, 18, and 42 inches below the top of the 7-ft coal bed.

Run HT-74 was the first hydrogasification test in which a pretreated Ohio No. 6 seam high-volatile bituminous coal was processed. The test was designed to simulate the upper, low-temperature reaction zone of a two-stage hydrogasification process, and to produce partially hydrogasified coal for a subsequent high-temperature hydrogasification test. The coal was reacted at 1300°F with a feed gas containing 45 mole percent hydrogen, 25 mole percent methane, and 30 mole percent steam. The test had to be terminated after about 2 hours and before steady-state operation was reached because of difficulties in discharging the coal.

Small pieces of caked coal lodged in the annulus between the reactor walls and the gas distributor disk, which kept coal from flowing.

The feed gas distributor described in the July 1965 Progress Report was installed in the hydrogasification reactor tube. This distributor will enable more uniform feed gas distribution for fluid-bed operations, as well as move the bottom of the coal up into the midpoint of the reactor tube, which will permit better temperature control. Operability of the gas distributor system was demonstrated in the three tests cited above.

Coal Pretreatment

Six pretreatment tests were conducted in the fluidized-bed pretreatment pilot unit. The feed was Broken Arrow mine bituminous coal from the Ohio No. 6 seam (Middle Kittanning). The objective of these tests was to study minimum pretreatment conditions and to supply the pilot hydrogasification unit with non-agglomerating char.

Nominal conditions for the six runs are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Res. Time, hr	Feed Gas Rate, SCF/hr	Oxygen Conc, %	Bed Temp, °F
FP-34	29.9	1.92	591	5.5	737
FP-34A	31.2	1.82	590	5.3	744
FP-35	49.7	1.31	654	21.0	747
FP-35A	*	*	644	21.0	749
FP-35B	*	*	570	21.0	650
FP-35C	56.3	1.94	574	21.0	634

* Not calculated because of erratic coal feeding caused by reactor plug

In the first two tests, an air and nitrogen mixture was used as the pretreatment gas. Run FP-34 had to be terminated before steady-state conditions were attained, due to solids plugging the cyclone in the product gas offtake line. Run FP-34A (made under the same conditions as FP-34) was terminated after 4 hours when the cyclone began to plug. However the test was long enough to obtain a residue char representative of steady-state conditions. Laboratory agglomeration tests showed the char to be free-flowing.

For the FP-35 series of tests, air was used as the pretreatment gas. These tests were made to investigate the oxygen breakthrough, if any, due to the higher oxygen concentration in the feed gas, under similar bed temperatures, gas and coal feed rates, and solids residence times. Considerable difficulty was encountered in trying to control the bed temperatures in the range desired (700°-750°F), due to the increased exothermic reaction contributed by the higher oxygen/coal feed ratio.

Runs FP-35, 35A, and 35B were terminated before steady-state conditions were reached, due to erratic bed temperatures and subsequent plugging of the reactor. Investigation of the reactor following these runs showed the bottom portion to be plugged with a solid coke-like formation. From these attempts it was found that the exothermic reaction would continue even with the external heat supply to the reactor turned off at 600°-650°F. During Run FP-35C, the heatup rate to the reactor was reduced in an effort to prevent plugging. By discontinuing the external heat, the bed temperatures were controlled in the 650°F range without upsetting the operation. However, analytical analysis of the residue char and mass spectroscopic analysis of the product gas gave evidence of very slight pretreatment in this temperature range. Also, laboratory agglomeration tests of the residue char showed that it was agglomerating.

In view of the results of these tests it was decided to continue pretreatment studies with air and nitrogen mixtures as the feed gas in order to investigate minimum pretreatment requirements and to prepare nonagglomerating char for the pilot hydrogasification unit.

A newly designed cyclone, which will facilitate cleaning, is being fabricated in the IGT shop to alleviate the problem of solids plugging.

Methanation

Mixing tests with standard gases were carried out and calibration curves for the CO and CO_2 analyzers were constructed. Preparation for feed gas storage and transfer was completed. The feed gases are being prepared by The Matheson Company, Inc.

The purpose of the first series of tests to be conducted in the reactor will be to establish which combinations of feed rates and basket speeds will provide perfect mixing.

Coal Characterization

Dynatech Corp. is nearing completion of the heat-of-reaction calorimeter; it will undergo shakedown operation in September.

Reflectance standards for determination of reflectance of chars and hydrogasification residues are being investigated. These products have higher reflectances than coal and the standards developed for use on coal.

Engineering Economics Studies

Process design and cost estimates for the state-of-the-art pipeline-gas-from-coal plant continued. Designs for the hydrogen and prepurification sections were completed; those for utilities and process heat recovery were partially completed. All tables for material balances and the overall flow diagram of the block flow process, with gas stream compositions, have been finalized. Drawings of other sections are in various stages of preparation.

Three patent disclosures were made during this period. The first concerns improvement in the fluidized-bed pretreatment operation. To reduce the residence time and the degree of pretreatment, while retaining the desired heat transfer characteristics of a fluidized bed, it is suggested that a two- (or more) stage fluidized bed be considered in which both stages are at the pretreatment temperature and pretreatment gas is introduced to each. Alternatively, a fluidized bed with tapered walls should reduce axial mixing of solids and reduce back mixing.

The second disclosure pertains to pretreatment of coal in a slurry form. By pumping the coal as a slurry, costly lock hoppers for solids introduction to the high-pressure gasifier can be eliminated. Preliminary experiments have shown that a free-flowing coal can be obtained by pretreating it at 1000 psig, 500°F with oxygen in a water slurry.

The third disclosure deals with a device for dewatering the coal slurry prior to its introduction into the gasifier. Reducing the amount of water added with the coal would reduce both the quenching effect on the gasifier effluent and the loss of high-availability heat. The dewatering unit consists typically of a conical section that prevents the dewatered coal from bridging. This coal can then be fed, for example, by a screw feeder into the gasifier.

As a result of an acute illness of our code welder, some delay has been encountered in modifications for converting the hydrogasifier reactor for fluidized-bed operation. Attempts were made to obtain outside help but welders with the desired capabilities are in short supply. Our welder will return to work in September. Because of the delay, we have been undertaking moving-bed runs with Ohio No. 6 coal rather than going to fluidized operation. Since Ohio No. 6 coal is to be investigated as a hydrogasifier feed, no time has been lost in the overall program.

Approved [signature] Signed [signature]
Jack Huebler, Associate Director Frank C. Schora, Manager

PROGRAM FOR DEVELOPMENT OF IGT

OCR: Contract No. 14-01-0001-381

	1964					1965												
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan

1st Year — 2nd Year

PHASE I

a. Hydrogasification

1. Establish rate-controlling areas of operation. E - 11, T - 16, DS - $[illegible], ODC - $3,500
2. Study effect of degree of pretreatment. E - 6, T - 18, DS - $17,500, ODC - $2,500
3. Study effects of variables to establish kinetics of fixed-bed system. E - 11, T - [illegible], DS - $[illegible], ODC - $[illegible]
4. Study fluidization and establish rates for fluid-bed operation. E - [illegible], T - 27, DS - $[illegible], ODC - $[illegible]
5. Study [illegible] system. E - 3, T - 6, DS - $[illegible], ODC - $[illegible]
6. Study particle size effect for both fixed and fluid-bed operation. E - 6, T - 27, DS - $[illegible], ODC - $[illegible]

b. Coal Pretreatment

1. Modify coal pretreatment unit. E - 3, T - 11, DS - $[illegible], ODC - $[illegible]
2. Study effects of pretreatment variables on char properties. E - [illegible], T - [illegible], DS - $[illegible], ODC - $[illegible]

Produce material required for hydrogasification runs

c. [illegible]

1. [illegible]. E - 2, T - 4, DS - $[illegible], ODC - 0
2. Build and shake down lab unit. E - 3, T - [illegible], DS - $[illegible], ODC - $[illegible]
3. Lab scale catalyst evaluation. E - 3, T - [illegible], DS - $[illegible], ODC - $[illegible]
4. Study effects of gas composition. E - 5, T - 10, DS - $[illegible], ODC - $[illegible]
5. Design and construct [illegible] unit. E - [illegible], T - [illegible], DS - $[illegible], ODC - $[illegible]

d. Coal Characterization

1. Develop techniques and study [illegible] characteristics of coals, chars, and other hydrogasified residue. Determine [illegible] of reaction of coals and chars. E - 13, T - 8, DS - $[illegible], ODC - $20,500

PHASE II

a. Analysis of Experimental Data

1. Analyze and correlate data from hydrogasification, coal pretreatment, and [illegible] work, and recommend conditions for additional tests. Develop kinetic equations to use in reactor design. E - 32, T - 0, DS - $[illegible], ODC - 0

b. Process Concept Development

1. [illegible] based on present data. E - 4, T - 0, DS - $[illegible], ODC - 0
2. [illegible] and [illegible] data become available and determine where additional data are needed. Modify process concept as necessary and keep process economics updated. E - 20, T - 0, DS - $[illegible], ODC - $1,500

c. Reactor Design Studies

d. Economic Evaluation

1. Coal data [illegible]. E - 2, T - 0
2. [illegible]. E - [illegible], T - [illegible], DS - $[illegible], ODC - 0
3. [illegible] heat and material balances. E - [illegible], T - [illegible], DS - $[illegible], ODC - 0
4. Process design of various sections. E - 4, T - 0, DS - $[illegible], ODC - 0
5. Cost estimate of [illegible] plant and operating expenses. E - 3, T - 0, DS - $1,400, ODC - 0
6. Report [illegible]. E - 2, T - 0, DS - $[illegible], ODC - 0
7. Revision and updating of [illegible]. E - [illegible], T - [illegible], DS - $[illegible], ODC - 0

PHASE III

a. Preliminary Pilot Plant Design

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	[illegible]
Planned	[illegible]	21,[illegible]	21,[illegible]	21,[illegible]	21,[illegible]	22,[illegible]	24,100	24,100	24,[illegible]	21,[illegible]	21,[illegible]	21,[illegible]	[illegible]	29,[illegible]	27,[illegible]	27,[illegible]	28,100	28,100	21,[illegible]	21,[illegible]
Actual		10,000	15,000	21,300	14,500	21,000	21,100	19,[illegible]	[illegible]	[illegible]	[illegible]	24,9[illegible]	[illegible]	[illegible]						
Cumulative		10,000	25,000	46,300	[illegible]	[illegible]	[illegible]	125,700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						

Manpower shown in total man months: E - Engineers, T - Technicians

Costs shown are costs to OCR or one-half of [illegible]

HYDROGASIFICATION PROCESS

A.G.A. PB-23a

1966										1967						
Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

3rd Year

Hydrogasification of various coals, lignite, under most suitable conditions
E = 214
T = 63
DS = $27,200
ODC = $7,000

Perform any subsequent work necessary for phase III
Double check data on which pilot plant is being designed

Perform material needed for any hydrogasification runs

E = 16
T = 16
DS = $11,400
ODC = $3,250

Perform any subsequent data necessary for phase III

[illegible]

Preliminary reactor design based on [illegible] and hydrogasification results
E = [illegible]
T = [illegible]
DS = $[illegible]
ODC = 0

Revision and refinement of capital and operating costs
E = [illegible]
T = [illegible]
DS = $[illegible]
ODC = 0

Work with subcontractor on capital and operating costs for pilot plant
E = [illegible]
T = [illegible]
DS = $[illegible]
ODC = 0

E = 16
DS = $7,700
ODC = 0

Select architect-engineer subcontractor

E = [illegible]
DS = $[illegible]
ODC = 0

* $[illegible] available for architect-engineer subcontractor and engineering consultants.

21,300	21,300	21,300	21,300	21,300	15,[illegible]	15,[illegible]	15,[illegible]	21,700	21,700	21,700	21,700	21,700	21,700	21,700	21,700	21,700

[illegible] costs. DS = Direct Salaries, $
ODC = Other Direct Costs, $

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report - September 1965

to

Office of Coal Research

Contract No. 14-01-0001-381

Hydrogasification

Study of the hydrogasification of lightly pretreated bituminous coal in the balanced-pressure pilot unit continued with six tests (Runs HT-75, HT-76, HT-77, HT-78, HT-79, and HT-80). Ohio No. 6 seam bituminous coal from the Broken Arrow mine, pretreated in Runs FP-32, FP-33, and FP-34, was the feed in the first three tests. Feed for Run HT-78 was a Pittsburgh seam bituminous coal from the Ireland mine, pretreated in Run FP-37. The partially hydrogasified residue from Run HT-78 was used as the feed for Runs HT-79 and HT-80.

Run HT-75 was designed to simulate the upper, low-temperature reaction zone of a two-stage hydrogasification process, and to produce partially hydrogasified coal for a subsequent high-temperature hydrogasification test. Pretreated Ohio No. 6 seam coal was reacted at 1300°F with a feed gas containing 45 mole percent hydrogen, 25 mole percent methane, and 30 mole percent steam. The test ended before steady-state operation was reached when the coal in the reactor could not be discharged past the gas distributor disk. The annulus between the reactor walls and the gas distributor disk, through which the coal must flow, became clogged with flaked pieces of caked coal. This caked coal formed on the upper walls of the reactor tube in the previous high-temperature runs and flaked off during Run HT-75.

Runs HT-76 and HT-77 were conducted at the same conditions as HT-75, and used the same coal feed. Because of the difficulties in discharging coal past the gas distributor disk in Runs HT-74 and HT-75, the disk was not used in Runs HT-76 and HT-77. The feed gas was fed through a previously used 3/8-inch gas feed tube that extends 16-1/2 inches above the bottom of the lower furnace section. Both runs were successful. Run HT-76 lasted 4-1/2 hours and was terminated because of a gas leak that developed at the screw feeder packing gland. Run HT-77 lasted about 5 hours, and was terminated when the coal feed was exhausted. The partially hydrogasified residues from these tests will be combined for use as a feed in a later high-temperature test.

In Run HT-78, lightly pretreated Pittsburgh seam coal was hydrogasified at 1300°F with a feed gas of the same molar composition as in Runs HT-76 and HT-77. To develop hydrogasification data at low hydrogen/coal stoichiometric ratios, the test was conducted at a hydrogen/coal ratio 28% of stoichiometric. Over 125 lb of coal was processed in this test in 7 hours.

The partially hydrogasified residue of Run HT-78 was the feed for Run HT-79. Conducted at 1700°F, this test was designed to simulate the lower, high-temperature zone of a two-stage hydrogasification process. Feed gas was a hydrogen-steam mixture containing 50 mole percent steam, fed through a gas distributor disk positioned half-way up the reactor tube. The disk also supported the bottom of the coal bed. The coal bed height was 3-1/2 feet so that operating results could be compared with similar tests conducted in a 7-foot bed. The run was terminated after 50 minutes when a plug formed in the product gas line upstream of the filter. Solids lodged in the line following an uncontrollable gas surge in the reactor shortly after steam was introduced to the reactor.

Run HT-80, a repeat of HT-79, was conducted at similar conditions, using the same feed. The test was successful, and was terminated after 4-1/2 hours when the coal feed supply was exhausted.

Fabrication of the increased-capacity coal feed hopper was resumed upon the return of our code welder. Welding of the hopper and reactor head assembly are nearly completed. X-rays of the welds and stress relieving of the hopper have been scheduled.

Coal Pretreatment

Three pretreatment tests were conducted in the fluidized-bed pretreatment pilot unit. The objective of the tests was to study minimum pretreatment conditions and to supply the hydrogasification pilot unit with nonagglomerating char.

Nominal conditions for the three runs are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Res Time, hr	Feed Gas Rate, SCF/hr	Oxygen Conc, %	Bed Temp, °F
FP-36	55.4	1.07	596	9.7	722
FP-37	43.0	1.26	605	9.6	744
FP-38	58.3	1.18	609	9.8	723

The feed for Runs FP-36 and FP-38 was a -16, +80 mesh Broken Arrow mine bituminous coal from the Ohio No. 6 seam (Middle Kittanning). An air-nitrogen mixture was used as the pretreatment gas. Both tests were operationally successful and were terminated voluntarily. Laboratory agglomeration tests of the residue char from FP-36 showed that it was lightly caked, indicating that pretreatment was not severe enough to ensure a free-flowing feed for the hydrogasification pilot unit. However, since the char was only lightly caked, minimum pretreatment conditions were approached. FP-38 was run under similar conditions to compare results of the residue char with that of FP-36. Laboratory agglomeration tests showed that the char was also caked. Therefore, the conditions of the two tests were inadequate for producing a free-flowing char.

Test FP-37 was run with Ireland mine bituminous coal from the Pittsburgh seam. Coal feed particle size was −16, +80 mesh. The test was conducted to supply the hydrogasification pilot unit with Ireland mine char for testing in the modified reactor. An air-nitrogen mixture was the pretreatment gas; the oxygen concentration was 9.6%. The run was successful and was terminated when sufficient char for the hydrogasification tests was obtained. Laboratory agglomeration tests showed that the char was free-flowing; this was verified by a successful run in the hydrogasification unit.

The new cyclone for the pretreatment pilot unit has been received and is in the process of being installed in the product gas offtake line.

Coal Characterization

The heat-of-reaction calorimeter is being calibrated and undergoing acceptance tests at 1500 psig and 1500°F at the Dynatech Corp. facilities in Cambridge, Mass. The calibration and testing procedure includes drop heater, alumina, and n-decane tests. The drop calorimeter is being calibrated with alumina.

The carbon monoxide alarm was installed in the laboratory. The combustible gas detector is presently being installed.

Use of strontium titanate as a reflectance standard for hydrogasification residue samples is being investigated in the petrography program. Large single crystals of this material are obtainable commercially. Petrographic examination of residues from both high- and low-temperature hydrogasification runs was started.

Flowmeters in the apparatus for determination of particle density by the Ergun gas flow method were calibrated. Determination of the particle density of sieve fractions of the feed to free-fall hydrogasification Run No. HT-60 was started.

Methanation

The continuous-flow, stirred-tank catalytic reactor was tested to establish the ranges of flow rates and catalyst basket speeds for which "perfect mixing" of the gas phase is realized.

Calibrations were prepared for the various measuring devices. Catalysts are being obtained from several suppliers in various formulations and sizes. The test program has been finalized and methanation tests are now being initiated.

State-of-the-Art Design and Evaluation

The state-of-the-art design and evaluation was completed and sent for final editing and printing.

During September, no inventions were made in the course of this work.

Approved [signature]
Jack Huebler, Associate Director

Signed [signature]
Frank C. Schora, Manager

PROGRAM FOR DEVELOPMENT OF IG

OCR: Contract No. 14-01-0001-381

1964					1965												1966
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan

1st Year — 2nd Y

PHASE I

a. Hydrogasification

1. Establish rate-controlling areas of operation. E - 13, T - 36, DS - $15,800, ODC - $5,550
2. Study effect of degree of pretreatment. E - 6, T - 18, DS - $7,500, ODC - $2,500
3. Study effects of variables to establish kinetics of fixed-bed system. E - 13, T - 36, DS - $15,800, ODC - $4,000
4. Study fluidization and establish rates for fluid-bed operation. E - 10½, T - 27, DS - $12,500, ODC - $3,000
5. Study H_2-O_2-C System. E 3, T 9, DS [illegible], ODC [illegible]
6. Study particle size effect for both fixed and fluid-bed operation. E - 9, T - 27, DS - $11,300, ODC - $2,000

b. Coal Pretreatment

1. Modify coal pretreatment unit. E - 3, T - 11, DS - $4,250, ODC - $6,000
2. Study effects of pretreatment variables on char properties. E - 4½, T 22½, DS - $13,400, ODC - $4,000

Establish pretreatment...

Produce material required for hydrogasification runs

c. Methanation

1. Review state of the art, and design lab test unit. E - 7, T - 8, DS - $3,800, ODC - 0
2. Build and shake down lab unit. E - 3, T - 4, DS - $4,150, ODC - $3,500
3. Lab scale catalyst evaluation. E - 5, T - 12, DS - $6,050, ODC - $1,250
4. Study effects of gas composition. E - 5, T - 10, DS $6,150, ODC - $1,000
5. Design and construct small pilot unit. E - 5, T - 18, DS - $8,500, ODC - $18,500

d. Coal Characterization

1. Develop techniques and study petrographic characteristics of coal, char, and spent hydrogasified residue. Determine heats of reaction of coal and chars. E 13, T 8, DS - $8,900, ODC - $20,500

Establish ... estimation of ...

PHASE II

a. Analysis of Experimental Data

1. Analyze and correlate data from hydrogasification, coal pretreatment, and methanation work, and recommend conditions for additional tests. Develop kinetic equations to use in reactor design. E - 32, T - 0, DS - $13,800, ODC - 0

b. Process Concept Development

1. Develop simple math model of process based on present data. E - 5, T - 0, DS - $2,300, ODC - 0
2. Improve and expand model when additional data becomes available and determine areas where additional data are needed. Modify process concept as necessary and keep process flowsheets updated. E - 20, T - 0, DS - $9,200, ODC - $1,500

c. Reactor Design Studies

Base ... process ...

d. Economic Evaluation

1. Cost data receipt and evaluation. E - 7, T - 0
2. Develop simple flow sheet. E - 2, T - 0, DS - $[illegible]00, ODC - 0
3. Detailed flow sheet, energy and material balances. E - 3, T - 6, DS - $1,400, ODC - 0
4. Process design of various sections. E - 4, T - 0, DS - $1,800, ODC - 0
5. Cost estimate of equipment, plant and operating expenses. E - 3, T - 0, DS - $1,400, ODC - 0
6. Report preparation. E - 2, T - 0, DS - $900, ODC - 0

Re-vision and updating of flowsheet. E - 6, T - 0, DS - $2,800, ODC - 0

PHASE III

a. Preliminary Pilot Plant Design

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Planned	855,400	23,500	23,500	23,500	23,800	22,400	24,100	24,300	24,700	23,700	23,300	23,800	30,300	29,300	27,800	27,400	28,100	28,100	23,300
Actual		10,000	15,000	23,300	14,500	23,000	21,100	19,800	28,900	23,400	30,200	24,500	22,900	28,000	21,900				
Cumulative		10,000	25,000	48,300	62,800	85,800	106,900	126,700	158,800	179,000	209,200	233,700	256,800	282,100	304,000				

Manpower shown in total man months: E - Engineers, T - Technicians

Costs shown are costs to OCR or ...

HYDROGASIFICATION PROCESS

A.G.A. PB-23a

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
	1966										1967						
						3rd Year											

7 — ...e hydrogasification of various coals, lignite, under most suitable conditions. E - 21 T - 41 DS - $27,202 ODC - $7,300

8 — Perform any support work necessary for phase III. Double check data on which pilot plant is being designed.

...perties of various coals ... $4,400

4 — Produce material needed for any hydrogasification runs

... — Run small pilot unit and develop kinetic equations for design. E - 10 T - 19 DS - $11,500 ODC - $5,250

7 — Perform any support work necessary for phase III

... correlations to enable ... for hydrogasification ... $18,200

Laboratory and Pilot Plant Phase I-A4, B4, c7 II-A2 — Engineers 24, Technicians 105 — Salaries $40,400, Other Direct Costs 11,400

2 — Perform analysis of past data and new data in any areas necessary for phase III work

1 — ...liminary reactor design based on ...

...dget and hydrogasification results. E - 6 T - 0 DS - $2,800 ODC - 0

2 — Work with subcontractor on design of reactors for hydrogasification and methanation. E - 4 T - 0 DS - $1,800 ODC - 0

4 — Revision and refinement of capital and operating costs. E - 6 T - 0 DS - $2,800 ODC - 0

6 — Work with subcontractor on capital and operating costs for pilot plant. E - 4 T - 0 DS - $4,100 ODC - 0

1 — Develop pilot plant flowsheet with heat and material balances. E - 16 T - 0 DS - $7,700 ODC - 0 — Select architect-engineer subcontractor

2 — With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.* E - 38 T - 0 DS - $16,300 ODC - 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

,300	23,300	23,300	23,300	23,300	23,300	15,800	15,800	15,800	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

E — Engineers, DS — Direct Salaries, $
T — Technicians, ODC — Other Direct Costs, $

IGT-MPR--10/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report - October 1965

to

Office of Coal Research
Contract No. 14-01-0001-381

Hydrogasification

Four hydrogasification tests (Runs HT-81, HT-82, HT-83, and HT-84) were conducted in the balanced-pressure pilot unit in a continuation of the study of the hydrogasification of lightly pretreated bituminous coals. Partially hydrogasified Ohio No. 6 seam bituminous coal (Broken Arrow mine) from Runs HT-76 and HT-77 was the feed in Run HT-81. Pittsburgh seam bituminous coal (Ireland mine), pretreated in Run FP-37, was the feed in Runs HT-82 and HT-83; that pretreated in Run FP-43 was the feed in Run HT-84.

Run HT-81 simulated the lower, high-temperature reaction zone of a two-stage hydrogasification process. Ohio No. 6 seam coal, already partially hydrogasified at 1300°F, was reacted at 1700°F with a hydrogen-steam feed gas mixture containing 50 mole percent steam. The coal was reacted in a 3-1/2-ft bed, the bottom of which was located at a gas distributor disk halfway up the reactor tube. Results of this test will be compared with those of tests conducted in a 7-ft bed to determine the effect of coal bed depth. Run HT-81 lasted 5-1/2 hours, terminating when the coal feed was spent. About 33% of the carbon in the feed was gasified.

Runs HT-82 and HT-83 were conducted at similar conditions to simulate the upper, low-temperature reaction zone of a two-stage hydrogasification process. Lightly pretreated Pittsburgh seam coal was reacted at 1300°F in a 7-ft bed with a feed gas containing 36 mole percent hydrogen, 30 mole percent methane, and 34 mole percent steam. To obtain additional hydrogasification data at low hydrogen/coal stoichiometric ratios, the tests were conducted at a hydrogen/coal ratio 12% of stoichiometric. Run HT-82 was terminated after 2-1/2 hours and before steady-state operation was reached, when coal would not discharge from the reactor. An internal leak in the bottom connection of the 3/8-inch feed gas tube allowed steam to condense in the relatively cool section above the discharge screw. The condensation wetted the coal and kept it from flowing down to the discharge screw. After the leaking connection was repaired, Run HT-83 was conducted successfully. The test lasted 5-1/2 hours and was shut down voluntarily when the coal feed supply was exhausted. Residue from this run will be used as feed for a later high-temperature test.

Run HT-84 was another low-temperature hydrogasification test with a lightly pretreated Pittsburgh seam coal. The coal was reacted at 1300°F in a 7-ft bed with a feed gas containing 45 mole percent hydrogen, 15 mole percent methane, and 30 mole percent steam. The feed gas hydrogen concentration was higher than in Run HT-83 (36 mole percent), however, the hydrogen/coal ratio was still low at 15% of stoichiometric. The test lasted 5-1/2 hours, including a 3-hour steady-state period. The test was terminated when a gas leak developed at the screw feeder packing gland which could not be repaired under test conditions.

A larger capacity residue receiver, recently fabricated in the IGT shop, was installed in the hydrogasification pilot unit. The receiver has a capacity of 14.7 cubic feet for holding the larger quantities of residues which will be produced when fluid-bed tests with high coal feed rates are initiated. Since the installation required moderate modification of the support framework and the counterbalancing system, the pilot unit was shut down for nearly 2 weeks.

Additional outdoor feed gas storage capacity — 16 high-pressure gas cylinders — has been received. These cylinders are mounted horizontally in four banks adjacent to the pilot plant. Each cylinder is 21 feet long with an internal volume of 14,171 cubic inches.

The recently fabricated 17.5-cubic foot capacity coal feed hopper was X-rayed to determine the soundness of the welds, and then stress relieved. This hopper will be installed when fabrication of the modified reactor top is completed.

Coal Pretreatment

Four pretreatment tests were conducted in the fluidized-bed pretreatment pilot unit to study minimum pretreatment conditions and to supply the hydrogasification pilot unit with non-agglomerating char.

Nominal conditions for the four runs were as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Res Time, hr	Feed Gas Rate, SCF/hr	Oxygen Conc, %	Bed Temp, °F
FP-39	46.7	1.64	663	9.3	739
FP-40	41.7	1.64	583	9.1	711
FP-41	64.8	0.80	602	9.3	733
FP-42	65.4	0.94	589	9.5	712

The feed for Runs FP-39 and FP-40 was −16, +80 mesh Broken Arrow mine bituminous coal. An air-nitrogen mixture was the pretreatment gas. The tests were conducted to provide the pilot hydrogasification unit with free-flowing Broken Arrow mine char. Both runs were made under conditions that had produced nonagglomerating char in previous experiments. Run FP-39 was operationally successful and was terminated when the coal feed supply was depleted. Laboratory agglomeration tests showed the char to be free-flowing. During Run FP-40 the desired bed temperature (750°F) could not be maintained due to erratic bed movement and subsequent plugging of the reactor. The average bed temperature during the test was 711°F. Agglomeration tests showed the char to be partially caked.

Run FP-41 was made with -16, +80 mesh Ireland mine bituminous coal as the feed. An air-nitrogen mixture was the pretreatment gas. The objective of the test was to simulate the first stage of a two-stage pretreatment process.

The coal residence time and oxygen/coal feed ratio were one-half that required to produce free-flowing char in previous Ireland mine coal pretreatment tests. Run FP-41 was terminated after 2-1/2 hours when the internal cyclone plugged and the back pressure in the reactor caused the coal in the bed to flow through the cyclone dip leg to the knockout drum. FP-42, run under the same conditions as FP-41, was successful and was terminated when enough char was produced for use as feed in the succeeding second-stage test. Agglomeration tests showed the char to be caked.

The second-stage test will be conducted with FP-42 char as feed, other operating conditions remaining the same. The combined coal residence times and oxygen/coal feed ratios of the two tests will equal that of previously conducted one-stage pretreatment tests. The primary interest in this series of tests is to study the effect of two-stage pretreatment on the volatile content of the resultant char.

Coal Characterization

Dynatech Corp. continues to have difficulties with the heat-of-reaction calorimeter. The internal high-temperature heater leads still short to the heater shields. The trouble has been traced to residual organic materials in the insulation which, under high vacuum, enter the vapor phase and crack to form carbon at the heater lead junctions. To correct this situation, Dynatech is prefiring the insulation to destroy the organic matter and installing shielded leads. Any further carbon deposition would therefore only create a short from lead shield to heater shield, which are both grounded. We believe this will solve the problem. After reassembly and performance of satisfactory n-decane hydrogenation tests, the unit will be shipped.

Reactor residue samples from hydrogasification of pretreated Ireland mine coal were examined petrographically. Significant increase in the reflectance of coal samples was observed with the degree of gasification, changing from about 1% for pretreated coal to 2.5%-5.5% for low-temperature hydrogasification residue, and to 4%-6% for high-temperature hydrogasification residue. Progress of gasification was shown by the partial disappearance of the interior vesicle wall pattern. The exterior walls appeared to have reacted less than the interior; this may be the result of low reactivity of the skin formed during pretreatment. Considerable variation among particles in degree of gasification was noted.

Particle densities were determined on each of two sieve fractions of the feed and residue from free-fall hydrogasification Run HT-60.

Methanation

Pulse tests were continued in an effort to determine the mixing characteristics of the reactor at conditions of synthesis. Several preliminary methanation runs were carried out to determine the range of operation. High conversions to methane were found for the three feed mixtures with no carbon deposition at temperatures from 700° to 800°F and at a reactor pressure of 1000 psig. Girdler G-65 catalyst was used.

Engineering Economics

Evaluation of the effect of reduced carbon conversion in the hydrogasification step on the overall process economics is proceeding. Reduced carbon conversion produces an excess of spent hydrogasification char. With the state-of-the-art design as a basis - at 53% carbon conversion - estimates are being made of the cost of pipeline gas production with carbon conversions in the hydrogasifier from 45% to 20%.

During October no inventions were made in the course of this work.

Approved Jack Huebler Signed

Jack Huebler, Associate Director Frank C. Schora, Manager

PROGRAM FOR DEVELOPMENT OF IG

OCR Contract No 14-01-0001-38

Schedule: 1964: Aug, Sep, Oct, Nov, Dec — 1965: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec — Jan

1st Year (Aug 1964 – Jul 1965) — 2nd Year (from Aug 1965)

PHASE I

a. Hydrogasification

1. Establish rate-controlling areas of operation — E - 13, T - 36, DS - $15,800, ODC - $5,500
2. Study effect of degree of pretreatment — E - 5, T - 15, DS - $7,500, ODC - $4,500
3. Study effects of variables to establish kinetics of fixed-bed system — E - 13, T - 36, DS - $15,600, ODC - $4,000
4. Study fluidization and establish rates for fluid-bed operation — E - 10, T - 27, DS $12,500, ODC $3,000
5. Study H₂O-CO₂-C System — E 3, T 6, DS $3800, ODC $1,000
6. Study particle size effect for both fixed and fluid-bed operation — E - 9, T - 27, DS $12,300, ODC - $2,000

b. Coal Pretreatment

1. Modify coal pretreatment unit — E - 3, T - 11, DS - $4,25[illegible], ODC - $6,00[illegible]
2. Study effects of pretreatment variables on char properties — E - 4, T - 10, DS $10,400, ODC $4,000
   - Produce material required for hydrogasification runs
   - Establish [illegible]

c. Methanation

1. Review state of the art, and design lab test unit — E - 7, T - 0, DS $3,500, ODC - 0
2. Build and shake down lab unit — E - 3, T - 6, DS - $4,[illegible], ODC - $3,500
3. Lab scale catalyst evaluation — E - 3, T - 12, DS - $6,850, ODC - $1,250
4. Study effects of gas composition — E - 5, T - 22, DS $6,250, ODC - $1,000
5. Design and construct small pilot unit — E - 5, T - 18, DS - $8,500, ODC - $18,500

d. Coal Characterization

Develop techniques and study petrographic characteristics of coal, char, and spent hydrogasified residue. Determine heats of reaction of coal and chars — E 13, T 4, DS $8,900, ODC $27,500

Establish tests and estimation of [illegible]

PHASE II

a. Analysis of Experimental Data

Analyze and correlate data from hydrogasification, coal pretreatment, and methanation work, and recommend conditions for additional tests. Develop kinetic equations to use in reactor design — E - 32, T - 0, DS $23,500, ODC - 0

b. Process Concept Development

1. Develop a preliminary math model of process based on present data — E - 5, T - 0, DS $2,300, ODC 0
2. Improve and expand model when additional data becomes available and determine areas where additional data are needed. Modify process concept as necessary, and keep process flowsheets updated — E 22, T 0, DS - $9,200, ODC - $1,500

c. Reactor Design Studies

[illegible]

d. Economic Evaluation

1. Cost data review and extension — E - 7, T - 0, DS - $3,200, ODC - 0
2. Develop simple flow sheet — E - 2, DS - $900, ODC - 0
3. Detailed flow sheet, energy and material balances — E - 3, T - 0, DS - $2,400, ODC - 0
4. Process design of various sections — E - 4, T - 0, DS - $1,600, ODC - 0
5. Cost estimate of equipment, plant and operating expenses — E 3, DS $1,400, ODC - 0
6. Report Preparation — E - 2, DS - $900, ODC - 0

Revision and updating of flowsheet — E - 5, DS - $2,600, ODC - 0

PHASE III

a. Preliminary Pilot Plant Design

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Planned	855,400	23,500	23,500	23,500	23,800	22,400	24,100	24,300	24,700	23,700	23,300	23,800	30,300	29,300	27,800	27,400	28,100	28,100	23,300
Actual		10,000	15,000	23,300	14,500	23,000	21,100	19,800	28,900	23,400	30,200	24,500	22,900	25,500	21,900	26,900			
Cumulative		10,000	25,000	48,300	62,800	85,800	106,900	126,700	155,600	179,000	209,200	233,700	256,600	282,100	304,000	330,900			

Manpower shown in total man months: E - Engineers, T - Technicians

Costs shown are costs to OCR [illegible]

HYDROGASIFICATION PROCESS

A.G.A. PB-23a

1966											1967						
Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

Year — 3rd Year

(Feb–Jul 1966) Study hydrogasification of various coals, lignite, under most suitable conditions
E - 23½
T - 63
DS - $27,000
ODC - $7,000

5 (Aug 1966–Jul 1967) Perform any support work necessary for phase III
Double check data on which pilot plant is being designed

(Feb–Jul 1966) ...nt properties of various coals
E = 5½
T = 27½
DS = $12,600
ODC = $4,500

4 (Aug 1966–Jul 1967) Produce material needed for any hydrogasification runs

(Feb–Jul 1966) Run small pilot unit and develop kinetic equations for design
E 10
T - 19
DS - $11,500
ODC $5,250

(Aug 1966–Jul 1967) Perform any support work necessary for phase III

(Feb–Jul 1966) Develop correlations to enable ... of coal for hydrogasification
E - 14
T - 11
DS - $10,200
- $500

(Aug 1966–Jul 1967) Laboratory and Pilot Plant Phase I-a8, b4, c7 II-a2 — Engineers 24, Technicians 105 — Salaries $40,400, Other Direct Costs 11,400

2 (Aug 1966–Jul 1967) Perform analysis of past data and new data in any areas necessary for phase III work

1 (Feb–Jul 1966) ... preliminary reactor design based on ... concept and hydrogasification results
E = 6
T = 0
DS = $2,400
ODC = 0

2 (Aug 1966–Jul 1967) Work with subcontractor on design of reactors for hydrogasification and methanation
E = 4
T = 0
DS = $1,600
ODC = 0

(Feb–Jul 1966) Revision and refinement of capital and operating costs
E = 6
T = 0
DS = $2,600
ODC = 0

(Aug 1966–Jul 1967) Work with subcontractor on capital and operating costs for pilot plant
E - 3
T - 0
DS $4,300
ODC - 0

(Aug–Oct 1966) Develop pilot plant flowsheet with heat and material balances
E - 19
T - 0
DS - $7,700
ODC - 0
Select architect-engineer subcontractor

2 (Nov 1966–Jul 1967) With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.*
E - 34
T - 0
DS - $16,300
ODC - 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
23,300	23,300	23,300	23,300	23,300	23,300	15,800	15,800	15,800	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

... DS Direct Salaries, $
ODC Other Direct Costs, $

IGT-MPR--11/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report - November 1965

to

Office of Coal Research

Contract No. 14-01-0001-381

Hydrogasification

Three hydrogasification tests (Runs HT-85, HT-86, and HT-87) were conducted in the balanced-pressure pilot unit in a continuation of the study of the hydrogasification of lightly pretreated bituminous coals. Lightly pretreated Pittsburgh seam bituminous coal from the Ireland mine was the feed in Run HT-85; partially hydrogasified Pittsburgh seam bituminous coal from Runs HT-82 and HT-83 was the feed in Run HT-86; and residue from Runs HT-84 and HT-85 was the feed in Run HT-87.

Run HT-85 was a low-temperature test in which pretreated Pittsburgh seam coal was reacted in a 7-foot coal bed at 1300°F with a feed gas containing 45 mole percent hydrogen, 25 mole percent methane, and 30 mole percent nitrogen. Steam, normally used in hydrogasification tests, was not used. This test was performed to determine if steam has any effect on hydrogasification results when present as a diluent in the low-temperature runs. Although there is only very little, or no net reaction of steam with carbon at low temperatures, the role of steam may not be that of a completely inert gas, since it is also a product of the reaction of feed hydrogen and the oxygen in the coal. After 6-1/4 hours of trouble-free operation, the test was terminated when the coal feed supply was used up. The partially hydrogasified residue from this test was used as a feed in a later high-temperature test.

Partially hydrogasified Pittsburgh seam coal (residue of Runs HT-82 and HT-83) was used in Run HT-86 at a nominal bed temperature of 1700°F with a mixture of hydrogen and steam. The steam concentration in the feed gas was 35 mole percent, and the hydrogen/coal ratio was 28% of stoichiometric. This high-temperature test was conducted in a 3-1/2-foot coal bed and lasted 4-1/3 hours. The test was terminated when the coal feed was consumed.

Run HT-87 was also a high-temperature hydrogasification test with partially hydrogasified Pittsburgh seam bituminous coal as the feed. Residue from hydrogasification Runs HT-84 and HT-85 was made to react at 1700°F in a 3-1/2-foot bed with a mixture of hydrogen and steam. The steam concentration in the feed gas was 30 mole percent, and the hydrogen/coal ratio was about 28% of stoichiometric. The test was successful, and was terminated after 7 hours of operation.

After the completion of Run HT-87, further testing in the pilot unit was delayed until necessary equipment modifications for fluid-bed operation could be completed. These modifications allow hydrogasification operation at gas throughputs three to four times the previous rates used, with proportional increases in coal feed rates.

The present coal feed hopper was removed from the pilot unit and the recently fabricated 17.5-cubic-foot-capacity pressure vessel installed. This installation required modification of the supporting framework and servicing deckwork. Coal will be fed from this pressurized hopper to the reactor by a machined 1-7/8-inch-diameter feed screw, which replaces the original 7/8-inch-diameter screw.

A high-capacity Hills-McCanna water feed pump was installed. This pump will feed water at operating pressure to the steam generator. Piping of water lines to and from the pump is nearing completion.

U-bend return heat-exchange tubes were fabricated to handle the increased steam generating and hydrogen preheat loads associated with the higher feed gas rates expected in fluid-bed operation. The heat exchange tubes were installed in a gas-fired furnace. Piping of the tubes to the unit is nearly completed.

A large-capacity Rockwell gas meter was installed. It has a capacity up to 3000 CF/hr, and will meter product gases leaving the hydrogasification unit.

Manifolding and piping of the recently installed battery of 16 high-pressure gas storage cylinders was completed. This involved welding of short line sections and fittings. Hydrogen and hydrogen-methane feed gas mixtures will be stored in these cylinders at pressures up to 3500 psig.

Coal Pretreatment

Three pretreatment tests were conducted in the fluidized-bed pretreatment pilot unit. The objective of the tests was to study minimum pretreatment conditions and to supply the pilot hydrogasification unit with nonagglomerating char.

Nominal conditions for the three runs are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Res Time, hr	Feed Gas Rate, SCF/hr	Oxygen Conc, %	Bed Temp, °F
FP-43	36.5	1.56	608	9.6	742
FP-44	48.7	1.13	600	9.6	733
FP-45	49.6	1.30	611	9.1	728

Run FP-43 was conducted using partially pretreated char from Run FP-42 as the feed material. Run conditions were set so that the combined oxygen/coal feed ratios and residence times of tests FP-42 and FP-43 would approximate those of previously conducted one-stage pretreatment tests. The run was operationally successful and was terminated when the feed supply was depleted.

The purpose of this series of tests was to observe the effect of two-stage pretreatment (as discussed in the October 1965 Report) on the volatile content of the resultant char. Production of a high-volatile content (approx 27%-28%) nonagglomerating char was of particular interest. Laboratory agglomeration tests showed the char to be free-flowing but the volatile content (24.0%) was similar to that of previously conducted one-stage tests.

Runs FP-44 and FP-45 were conducted primarily to supply the pilot hydrogasification unit with suitable feed. A -16, +80 mesh Ireland mine coal was used as feed with an air-nitrogen mixture as the pretreatment gas.

Both tests were operationally successful. Agglomeration test results of the FP-44 char showed some of the smaller particles to be lightly caked, whereas all the char from FP-45 was lightly caked. The reason for this was the decrease in residence time in the conditions of the two tests. Although the runs were primarily conducted to produce a free-flowing char for hydrogasification tests, we were still attempting to lower the minimum requirements for pretreatment. The two chars will be stored for possible use in the fluidized-bed hydrogasification test series.

A Schutte-Koerting venturi gas scrubber has been installed in the product gas line for further cleaning of the product gas to prevent the carry-over of mist to the gas meter.

<u>Coal Characterization</u>

Testing of the heat-of-reaction calorimeter is continuing at Dynatech Corp. Leaks were found in a welded portion of the calorimeter bomb. The calorimeter was disassembled, rewelded, and examined by X-ray. The heater leads on top of the calorimeter shield again burned out. Arcing from the leads to the shield was suspected. This arcing apparently occurs because of off-gassing from the insulation within the heater shield during chamber evacuation. Under the low pressures in this system, the gases ionize, which melts the heater leads. The heating elements are being modified to eliminate this problem.

Particle density was determined on additional sieve fractions for the feed and residue from free-fall hydrogasification Run HT-60. True density by helium displacement was also determined on these samples and on the two sieve fractions whose particle densities were determined last month. Porosity calculated from these measurements ranged from 56% to 59% on the feed and 67% to 73% on the residue.

A gem-quality diamond was obtained for use as a reflectance standard in the high reflectance range. A strontium titanate single-crystal boule has been ordered for the same purpose.

Arrangements have been made for an electron microprobe examination on a cross-sectioned sample of residue from hydrogasification. This should provide information on the inherent ash of individual residue particles.

Means for improving our photomicrographic equipment is being investigated.

Methanation

Additional mixing tests were conducted to assure that complete mixing is being achieved. These mixing tests were carried out by the step input technique at various reactor shaft rotation speeds and different feed rates. The results indicate complete mixing.

Kinetic studies were performed with three different feed gases. Table 1 shows the conditions of these studies at flow rates from 5 cu ft/hr to 30 cu ft/hr.

Table 1.-METHANATION STUDIES WITH GIRDLER G-65 CATALYST

Feed Gas Compositions, %					Pressure, psig	Temp, °F	No. of Steady-State Tests
CO	H_2	CO_2	CH_4	Total			
7.2	26.9	2.45	63.45	100.00	1000	700	3
9.98	34.48	2.1	53.44	100.00	1000	700	5
2.6	13.25	1.95	82.20	100.00	1000	700	8
2.6	13.25	1.95	82.20	100.00	1000	800	3

Data obtained from these tests are being analyzed.

Engineering Economics

Evaluation of the effect of the degree of carbon conversion in the hydrogasifier on the economics of pipeline gas production is continuing. The state-of-the-art design was based on a carbon conversion of 53%. Using this design as a basis, six cases are being evaluated in the range of 20% to 45% carbon conversion.

To date, process stream quantities and compositions have been determined for all cases. Equipment for coal grinding and pretreatment, with the exception of conveyors, has been sized and costs estimated. Prepurification vessels and methanation reactors have been estimated; costs for oxygen and hydrogen production have been determined; and most of the power and steam requirements have been calculated.

During the month, no inventions were made in the performance of this work.

Approved ______________________ Signed ______________________
Jack Huebler, Associate Director Frank C. Schora, Manager

[illegible]ROGRAM FOR DEVELOPMENT OF IGT [illegible]

OCR Contract No 14-0[illegible]-0001-[illegible] A G[illegible]

Study effects of pretreatment [illegible]

E - 4

DS - $10,4[illegible]

Establish pretreat[illegible] properties [illegible]

E - 5[illegible]

DS - $12,600

ODC - $6,5[illegible]

Design and construct small [illegible] unit

E - 5

DS - $6,5[illegible]

ODC - $16,5[illegible]

Make preliminary [illegible] process concept and [illegible]

2	3	4	5	6	7
Develop simple flowsheet; E - 2, T - 3, DS - $900, ODC - 0	Calculate flowsheet energy and material balances; E 3, DS - $1,[illegible], ODC - 0	Process design of various sections; E [illegible], DS - $1,[illegible], ODC [illegible]	Cost estimate of equipment, plant and operating expenses; E 3, DS $[illegible], ODC [illegible]	Report Preparation; E - 2, T - 0, DS - $900, ODC - 0	Revision and updating of flowsheet; E - 6, T - 0, DS - $2,800, ODC - 0

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

[illegible]	23,500	23,000	22,400	24,100	24,300	24,700	23,700	23,300	23,600	30,300	29,300	27,600	27,400	28,100	23,100	23,300	23,300
[illegible]	23,300	14,500	23,000	21,100	19,800	28,900	23,400	30,200	24,500	22,900	25,500	21,900	26,900	27,800			
[illegible]	[illegible] 300	62,800	85,800	106,900	126,700	155,600	179,000	209,200	233,700	256,800	282,100	304,000	330,900	358,700			

Manpower shown in total man-months. E - Engineers, T - Technicians

Costs shown are costs to OCR or one-half of total costs

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…T HYDROGASIFICATION PROCESS

A.G.A. PB-23a

1966						1967											
Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

…Year ← → 3rd Year

7 Study hydrogasification of various coals, lignite, under most suitable conditions
E - 21½
T - 43
DS - $27,200
ODC - $7,300

8 Perform any support work necessary for phase III
Double check data on which pilot plant is being designed

3 …ment properties of various coals
E - 5½
T - 27½
DS - $12,600
ODC - $4,500

4 Produce material needed for any hydrogasification runs

6 Run small pilot unit and develop kinetic equations for design
E - 10
T - 19
DS - $11,500
ODC - $5,250

7 Perform any support work necessary for phase III

2 …and develop correlations to enable … of coal for hydrogasification
E - 14
T - 11
DS - $10,200
ODC - $500

Laboratory and Pilot Plant Phase I-48, 64, 67 II-42 | Engineers 24 | Technicians 105 | Salaries $40,400 | Other Direct Costs 11,400

2 Perform analysis of past data and new data in any areas necessary for phase III work

…tions

1 Make preliminary reactor design based on process concept and hydrogasification results
E - 6
T - 0
DS - $2,800
ODC - 0

2 Work with subcontractor on design of reactors for hydrogasification and methanation
E - 4
T - 0
DS - $1,800
ODC - 0

3 Revision and refinement of capital and operating costs
E - 6
T - 0
DS - $2,800
ODC - 0

4 Work with subcontractor on capital and operating costs for pilot plant
E - 9
T - 0
DS - $4,100
ODC - 0

1 Develop pilot plant flowsheet with heat and material balances
E - 14
T - 0
DS - $7,700
ODC - 0
Select architect-engineer subcontractor

2 With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.*
E - 36
T - 0
DS - $16,300
ODC - 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
23,300	23,300	23,300	23,300	23,300	23,300	15,800	15,800	15,800	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

…half of total costs. DS - Direct Salaries, $
ODC - Other Direct Costs, $

IGT-MPR-12/65

DEVELOPMENT OF IGT HYDROGASIFICATION PROCESS

Progress Report — December 1965

to

Office of Coal Research
Contract No. 14-01-0001-381

Hydrogasification

The first fluid-bed hydrogasification test (Run HT-88) was conducted in the balanced-pressure pilot unit following completion of necessary equipment modifications for fluid-bed operation. Lightly pretreated Pittsburgh seam bituminous coal from the Ireland mine was reacted in a 3-1/2-foot fluid bed at 1300°F with a feed gas containing 45 mole percent hydrogen, 25 mole percent methane, and 30 mole percent steam. In this low-temperature run, the coal feed rate was 65 lb/hr, and the hydrogen/coal ratio was 25% of the stoichiometric ratio. The test was terminated after less than 1 hour, and before steady-state operation was reached, when difficulties were encountered in discharging coal from the reactor. Compaction of the reacted coal at the annulus between the feed gas distributing disk and the reactor wall was the apparent cause of this difficulty. To remedy this situation, the feed gas distributing disk will be reduced from 3-1/2 to 3 inches in diameter, which will increase the cross-section of the annulus. Although the run was too short to yield any operational data, it did serve to check the operability of the new equipment components.

Before conducting Run HT-88, the necessary equipment modifications for fluid-bed operation were made. These consist of a 1-7/8-inch-diameter coal feed screw, feed screw housing, variable-speed drive, a reactor head assembly with an internal cyclone, gas-sampling probes, internal coal-bed thermocouples, and peripheral equipment to handle the higher gas flows.

The modified installation underwent shakedown tests, including:

- Operation and calibration of the coal feed screw at coal rates up to 100 lb/hr.
- Operation of the water feed pump and steam generator at rates up to 50 lb/hr.
- Calibration of the feed-gas orifice meter at 1200 SCF/hr against a new gas meter.
- Nitrogen flow test through the pilot unit at 5000 SCF/hr to test capacity of the feed and product gas lines and the capability of the unit back-pressure regulator to function at high gas rates.

- Nitrogen-steam flow test through the pilot unit to check capacity of the gas distributing disk and off-gas condenser at hydrogasification flow rates of 1140 SCF/hr and 23 lb/hr steam.

Coal Pretreatment

Four pretreatment tests were conducted in the fluidized-bed pretreatment pilot unit to study minimum pretreatment conditions and to supply the pilot hydrogasification unit with nonagglomerating char.

Nominal conditions for the four tests are as follows:

Run No.	Solids Rate, lb/hr	Avg Solids Res Time, hr	Feed Gas Rate, SCF/hr	Oxygen Conc, %	Bed Temp, °F
FP-46	45.3	1.10	526	[illegible].7	743
FP-47	46.0	1.51	378	3.0	741
FP-48	50.7	1.75	[illegible]	5.[illegible]	739
FP-49	[illegible]1.0	1.27	[illegible]	9.8	750

A −[illegible], +[illegible] mesh Ireland mine bituminous coal was used as feed in Run FP-46, with an air-nitrogen mixture as the pretreatment gas. The test was conducted to provide the pilot hydrogasifier with nonagglomerating feed. The run was operationally successful, and laboratory agglomeration test results showed the char to be free-flowing.

Ireland mine bituminous coal of −1/4 in. was the feed material for Run FP-47, and an air-nitrogen mixture was the pretreatment gas. The test was conducted to investigate the operability of larger sized coal particles in the pretreatment pilot unit. The test was successful and laboratory agglomeration tests showed the char to be lightly caked.

A West Virginia bituminous coal from the No. 5 Block seam was used as the feed for Runs FP-48 and FP-49. The coal is the third of seven coals selected for study under the current project. A proximate analysis of the coal is:

[illegible]	[illegible]	[illegible]	[illegible]	[illegible], Btu/lb
[illegible]	[illegible]	[illegible]	5[illegible].5	13,000

An air-nitrogen mixture was used as the pretreatment gas for both runs while the coal feed particle size was −[illegible], +[illegible] mesh. Both tests were conducted under similar conditions except for the oxygen concentration of the pretreatment gas. Run FP-48 was made with [illegible]% oxygen concentration; FP-49 was tested with [illegible]% oxygen. Laboratory agglomeration tests showed both chars to be partially caked, indicating that minimum pretreatment conditions were not attained. Further tests will be conducted to define minimum pretreatment conditions for the West Virginia coal.

Coal Characterization

Dynatech Corp. continued testing of the heat-of-reaction calorimeter. During a 4-day test, all heaters functioned properly at 1500°F. The insulation was repacked to reduce heat leaks. However, the O-ring failed at 1500°F and 1500 psia, due presumably to lack of sufficient vent holes. The calorimeter was reassembled with new O-rings and calibration has begun.

Calibration of the drop calorimeter was completed. The results are satisfactory.

Coal Petrography

Preparation of samples for a systematic examination of the coal at different stages of the hydrogasification process was started. Feed and product from pretreatment Run FP-31 and feed and residue from high-temperature hydrogasification Run HT-72 have been chosen to constitute such a series for Ireland mine coal. Mounting and polishing of selected sieve fractions of these samples has been started. Helium density and porosity will also be determined on some of these sieve fractions.

Improved sample polishing and photographic techniques were developed. Polishing of pretreated coal and hydrogasification residues is difficult because of the voids in these particles. A much better polish has been obtained by reimpregnating the mounted sample surface after rough grinding with epoxy resin under vacuum. Photomicrographic technique was reviewed with a consultant to obtain better acutance, or sharpness, and better exhibition of slight differences in sample reflectance. The latter will allow illustration of the remnants of pretreatment skin found in hydrogasification residues.

A sample of residue from a free-fall hydrogasification run (HT-39), in which raw (not pretreated) coal had been fed, was prepared for petrographic examination. Observations on this sample will be reported next month, particularly on absence of the effect of the pretreatment skin on reactivity.

A prism has been cut from a strontium titanate single-crystal boule for use as a high-reflectance standard. Polishing of the surfaces is not yet completed.

Methanation

Methanation studies continued with Girdler G-65 and Harshaw Ni-0104T nickel catalysts. For comparable space velocities the Harshaw catalyst gave conversions equal to those obtained with the Girdler catalyst operating at approximately a 100°F higher temperature. The lower limit of activity for Ni-0104T is about 450°F, compared to 600°F for G-65. The activity of the Ni-0104T was more steady during its time on-stream than was the G-65 catalyst.

Catalyst screening tests are continuing and will include studies of a nickel catalyst from Catalyst & Chemicals, Inc., and a 0.5% ruthenium on alumina catalyst from Engelhard Industries, Inc.

Engineering Economics

Evaluation of the effect of the degree of carbon conversion in the hydrogasifier on the economics of pipeline gas production is largely completed. Results will be presented in a memorandum to A.G.A.-OCR.

Approved ____________ Signed ____________

Jack Huebler, Associate Director Frank Schora, Manager

PROGRAM FOR DEVELOPMENT OF IGT

OCR: Contract No 14-01-0001-381

1964 — 1965 — Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb

1st Year — 2nd Year

PHASE I

A. Hydrogasification

1. Establish rate-controlling areas of operation. E - 13, T - 16, DS - $15,800, ODC - $5,500
2. Study effect of degree of pretreatment. E - [illegible], T - [illegible], DS - $7,500, ODC - $2,500
3. Study effects of variables to establish kinetics of fixed-bed system. E - [illegible], T - [illegible], DS - [illegible], ODC - [illegible]
4. Study fluidization and establish rates for fluid-bed operation. E - [illegible], T - 27, DS - $12,500, ODC - $3,000
5. Study H2O-CO-C System. DS $[illegible], ODC $[illegible]
6. Study particle size effect for both fixed and fluid-bed operation. E - [illegible], T - 27, DS - $[illegible],300, ODC - $2,000
7. Study hyd[illegible]

B. Coal Pretreatment

1. Modify coal pretreatment unit. E - [illegible], T - [illegible], DS - $4,2[illegible], ODC - $6,0[illegible]
2. Study effects of pretreatment variables on char properties. E - 4[illegible], T - [illegible], DS - $10,400, ODC - $4,000
3. Produce material required for hydrogasification runs
4. Establish [illegible]. E - 5[illegible], T - 27[illegible], DS - $12,[illegible], ODC - $[illegible]

C. Methanation

1. Review state of the art, and design lab test unit. E - [illegible], T - [illegible], DS - $3,800, ODC - 0
2. Build and shake down lab unit. E - 3, T - 4, DS - $4,150, ODC - $2,500
3. Lab scale catalyst evaluation. E - 5, T - 12, DS - $6,850, ODC - $1,250
4. Study effects of gas composition. E - 5, T - 20, DS - $6,150, ODC - $2,000
5. Design and construct small pilot unit. E - 5, T - 18, DS - $8,500, ODC - $28,500

D. Coal Characterization

1. Develop techniques and study petrographic characteristics of coal, char, and spent hydrogasification residue. Determine heats of reaction of coal and chars. E - 13, T - [illegible], DS - $8,900, ODC - $20,500
2. Establish tests and develop corr[illegible] estimation of [illegible] of coals for [illegible]. E - 14, T - [illegible], DS - $10,[illegible], ODC - $[illegible]

PHASE II

A. Analysis of Experimental Data

Analyze and correlate data from hydrogasification, coal pretreatment, and methanation work, and recommend conditions for additional studies. Develop kinetic equations to use in reactor design. E - 32, T - 0, DS - $23,800, ODC - 0

B. Process Concept Development

1. Develop simple math model of process based on present data. E - [illegible], T - 0, DS - $2,300, ODC - 0
2. Improve and expand model when additional data becomes available and determine areas where additional data are needed. Modify process concept as necessary and keep process flowsheets updated. E - 20, T - [illegible], DS - $9,200, ODC - $1,500

C. Reactor Design Studies

Based [illegible] process concept [illegible]

D. Economic Evaluation

1. Cost data review and extension. E - 7, T - 0
2. Develop simple flow sheet. E - 2, T - 0, DS - $500, ODC - [illegible]; DS - $3,2[illegible], ODC - 0
3. Detailed flow sheet, energy and material balances. E - [illegible], T - [illegible], DS - $1,400, ODC - [illegible]
4. Process design of various sections. E - [illegible], T - [illegible], DS - $1,800, ODC - [illegible]
5. Cost estimate of equipment, plant and operating expenses. E - 3, T - [illegible], DS - $1,400, ODC - 0
6. Report preparation. E - [illegible], T - 0, DS - $400, ODC - 0
7. Revision and updating of flowsheet. E - [illegible], T - [illegible], DS - $2,800, ODC - 0

PHASE III

A. Preliminary Pilot Plant Design

TOTAL COSTS TO OCR (INCLUDES OVERHEAD AND FEE)

	TOTAL	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Planned	855,400	23,500	23,500	23,500	23,800	22,400	24,100	24,300	24,700	23,700	23,300	23,800	30,300	29,300	27,800	27,400	28,100	28,100	23,300	23,300
Actual		10,000	15,000	23,300	14,500	23,000	21,100	19,800	28,900	23,400	30,200	24,500	22,900	25,500	21,900	26,900	27,800	22,300		
Cumulative		10,000	25,000	48,300	62,300	85,800	106,900	126,700	155,600	179,000	209,200	233,700	256,600	282,100	304,000	330,900	358,700	381,000		

Manpower shown in total man months: E - Engineers, T - Technicians

Costs shown are costs to OCR or one-half of total co[illegible]

† HYDROGASIFICATION PROCESS

31 A.G.A PB 23a

1966											1967						
Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

Year ← → Year

5 — Study hydrogasification of various coals, lignite, under most suitable conditions. E = 25½, T = 63, DS = $27,200, ODC = $7,000 → **5** — Perform any support work necessary for phase III. Double check data on which pilot plant is being designed.

4 — [illegible] properties of various coals. E = 5½, T = 27½, DS = $12,600, ODC = $4,500 → **4** — Produce material needed for any hydrogasification runs.

7 — Run small pilot unit and develop kinetic equations for design. E = 10, T = 19, DS = $11,500, ODC = $5,250 → **7** — Perform any support work necessary for phase III.

2 — And develop correlations to enable [illegible] of coals for hydrogasification. E = 14, T = 11, DS = $20,200, ODC = $300

Laboratory and Pilot Plant		Engineers	24	Salaries	$40,400
Phase I-48, 54, 57	II-42	Technicians	105	Other Direct Costs	11,400

2 — Perform analysis of past data and new data in any areas necessary for phase III work.

1 — [empty box]

1 — Make preliminary reactor design based on process concept and hydrogasification results. E = 6, T = 3, DS = $2,800, ODC = 0 → **2** — Work with subcontractor on design of reactors for hydrogasification and methanation. E = 4, T = 0, DS = $2,800, ODC = 0

4 — Revision and refinement of capital and operating costs. E = 6, T = 0, DS = $2,800, ODC = 0 → **4** — Work with subcontractor on capital and operating costs for pilot plant. E = 9, T = 0, DS = $4,200, ODC = 0

1 — Develop pilot plant flowsheet with heat and material balances. E = 14, T = 0, DS = $7,700, ODC = 0. Select architect-engineer subcontractor → **2** — With assistance of subcontractor work on phase III as outlined in Contract No. 14-01-0001-381.* E = 34, T = 0, DS = $16,300, ODC = 0

* $85,500 available for architect-engineer subcontractor and engineering consultants.

Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
23,300	23,300	23,300	23,300	23,300	23,300	15,800	15,800	15,800	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700	23,700

[illegible] of total costs. DS – Direct Salaries, $
ODC – Other Direct Costs, $

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