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**UNDERGROUND GASIFICATION FOR STEEPLY
DIPPING COAL BEDS**

Quarterly Progress Report, January 1—March 31, 1978

June 1978

Work Performed Under Contract No. EF-77-C-03-1472

Gulf Research & Development Company
Pittsburgh, Pennsylvania

and

TRW Energy Systems Planning Division
McLean Virginia

U. S. DEPARTMENT OF ENERGY

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1.0 ABSTRACT

Activities during this quarter focused on Phase I Final Report preparation, further site characterization activities, parametric cost analysis, and an evaluation of the technical and economic risks associated with drilling slant hole process wells. The Phase I Final Report which contains all the contract deliverables for Phase I summarizes Phase I activities. Further site characterization activities involved preparation of a detailed exploratory drilling plan and bid package as well as applying for the appropriate permits. A parametric cost analysis using a proprietary model revealed that the parameters of greatest sensitivity were product gas quality, gas leakage, and yield of product gas per unit volume of injection air. The approach to be used in evaluating slant hole process wells has been established and is presently being implemented.

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3.0 INTRODUCTION

During the last quarter of 1977 (October through December), much time was spent on site selection, environmental analysis, and test design. The North Knobs, Wyoming, site was chosen during this last quarter of 1977 and has become the subject of a comprehensive exploratory drilling plan during the present quarter (January through March, 1978). An exploratory drilling package has been prepared for bidding by various contractors. These drilling plans will allow detailed subsurface geologic and hydrologic studies to be made of the site as well as allow an evaluation of slant drilling to be made. Concurrently, permits were applied for with the state of Wyoming and the Bureau of Land Management (BLM) to allow the exploratory work to proceed.

In accordance with the schedule, the first phase of the Environmental Monitoring Plan which was developed last quarter is currently being carried out. This "equipment preparation" phase includes a thorough checkout of all circuitry, calibration, and operation for a 48-hour period to assure that equipment is functioning properly.

In addition to continuing activities begun last quarter, new activities included Phase I Final Report preparation, parametric cost analysis, and the initiation of a detailed evaluation of slant drilling.

4.0 SUMMARY OF TECHNICAL ACTIVITIES

Phase I Final Report

In accordance with DOE Contract EF-77-C-03-1472, a report describing the activities during Phase I was prepared and submitted to DOE. The preparation of this report required extensive efforts by UCG/SDB and support personnel and consumed a significant portion of their time during this quarter. The report, which contains all of the contract deliverables for Phase I, is summarized below.

The activities of Phase I have resulted in significant accomplishments. Of major importance is the selection of a test site, definition of plans for operations to be performed at the site, as well as scheduling and costing the activities of Phases II, III, and IV.

Site Characterization

The exploratory drilling program to characterize the North Knobs, Wyoming, site was updated and partially revised. A bidding package was prepared from these plans and sent to various drilling contractors. This package includes the drilling of coring, hydrology, and small diameter slant wells in order to determine subsurface geology features, fracture and permeability patterns, and slant well drilling capabilities.

Permits for exploration activities were prepared and filed with the Bureau of Land Management (BLM) and the state of Wyoming. The route for the access road has been established with concurrence of TRW, GR&DC, and BLM. An archeological survey of the site has been made. Three potential archeological sites and one historical site were defined in the site area but should not interfere with field operation.

Environmental Activities

During this quarter, work on the Baseline Environmental Monitoring task included the following:

- A thorough checkout of air monitoring instrumentation which will be used at the UCG test site was conducted.
- A sampling manifold was designed and fabricated for installation in the instrumentation trailer.
- Arrangements were made with a supplier of industrial gases in Denver to provide the necessary calibration, span, and zero gases for instrumentation checkout at the test site.

Parametric Cost Analysis

The GR&DC mathematical model was employed to perform a sensitivity analysis showing the effects of key process parameters on the anticipated sale price of gas generated by a conceptual UCG commercial plant exploiting horizontal coal seams. Because seam characteristics, drilling costs, well layout, etc., will differ between horizontal and steeply dipping beds, GR&DC intends to develop, at their own cost, a modified proprietary model for the SDB configuration. The cost analysis for horizontal beds revealed that the parameters of greatest sensitivity were product gas quality, gas leakage, and the yield of product gas per unit volume of injection air.

Program Planning

Extensive efforts were put forth in costing and planning Phases II, III, and IV activities. The formalized activity network and cost sheets which resulted were included in the Phase I Final Report.

Based upon concerns raised during the previous quarter relative to the well installation accuracy requirements, an investigation was begun to assess the technical and economic risks associated with drilling

slant hole process wells. The approach to this assessment has been developed and is presently being implemented.

The Blue Book, which will contain the formalized plans and criteria for UCG/SDB, is presently being written. A formal listing of the documents to be incorporated, and their associated review cycles, has been agreed upon.

5.0 PHASE I FINAL REPORT

In accordance with DOE Contract EF-77-C-03-1472, a report describing the activities during Phase I was prepared and submitted to DOE. The preparation of this report required extensive efforts by UCG/SDB personnel and consumed a significant portion of their time during this quarter. This report, which contains all of the contract deliverables for Phase I, is summarized below.

The activities of Phase I have resulted in significant accomplishments. Of major importance is the selection of a test site, definition of plans for operations to be performed at the site, as well as scheduling and costing the activities of Phases II, III, and IV. These accomplishments and others achieved in Phase I are tabulated below.

General

- General Technical Approach - The overall method for implementing the UCG in steeply dipping beds project was defined.
- Activity Network - A network was developed to interrelate project tasks along a time base.
- Cost Review - A detailed analysis of the projected costs through completion revealed that the original cost estimates were still valid.
- Parametric Cost Estimate - The GR&DC mathematical model was employed to perform a sensitivity analysis showing the effects of key process parameters on the anticipated sale price of gas generated by a conceptual UCG commercial plant.

Site

- Site Selection - A site at North Knobs, near Rawlins, Wyoming, was found to satisfy the site selection criteria set up for this project. Preliminary site characterization revealed the presence of water above the gasification region. This was one of the site selection criteria.

Operations

- Test Plan -- A plan was developed for execution of the three burns. Ranges were established for the significant process parameters.
- Facility Design -- A conceptual design for the facility was established. This design calls out the location of structures, piping, and major pieces of support equipment.
- Instrumentation -- Instrumentation needs to support the three burns were evaluated.

Support

- Site Support -- A plan was developed for support of the site operations.
- Permits -- The state and federal permits necessary for operation of the site were reviewed. No extraordinary difficulties were foreseen in obtaining these.
- Quenching -- An assessment was made of the difficulties to be encountered in extinguishing the burns. No exceptional problems are anticipated as long as the burns take place below the water table.

- Environmental Analysis -- The most likely environmental impacts of the project's operation were assessed. No major areas of concern were found. A plan was developed for environmental monitoring in Phases II and III.

A number of observations are drawn from the learning experience resulting from the Phase I activities and are listed below:

- Gasification in steeply dipping beds involves technical uncertainties not previously addressed. In order to complete this project within budget, it is mandatory that maximum use be made of the existing UCG data base developed by LLL, LERC, and Sandia.

The existing data base relates only to the subbituminous coals of semiarid Wyoming. Our site maximizes the ability to transfer the existing UCG knowledge into the SDB program.

- The planned approach to the burns forces us to face two uncertainties:
 - a) operation in a new resource (steeply dipping coal beds)
 - b) application of a high-angle slant drilling approach

In order to minimize the uncertainties involved in b), an examination of slant drilling technology is currently being undertaken. This assessment results in a recommendation to perform a slant drilling test operation early in Phase II. Such an effort is not funded under the present contract.

- It is imperative that sufficient instrumentation be emplaced in the vicinity of the burn area to allow an ongoing estimate to be made as to the location of the burn front. It is desirable to know that the burn front is developing "properly." This information is also necessary for validation of the

predictions of the process model. The complete array of UCG diagnostic instrumentation currently employed on a burn would probably be too expensive for use on a commercial operation. This project occurs during a transition period in the horizontal bed effort between an early stage of intensively instrumented burns and a second stage of development in which the burn configuration will be followed primarily from the predictions of a mathematical model. At present, neither the instrumentation nor the model has been demonstrated to yield the desired degree of predictive accuracy in horizontal beds. Steeply dipping beds present a whole new array of problems in both areas. Unfortunately, the SDB project cannot begin on the second stage of the overall instrumentation and predictive modeling development process. It is imperative that this project be highly instrumented and accompanied by a significant effort to develop an appropriate SDB process model. Each of these activities will require additional support.

- Backup sites are required to be in a high state of readiness in the event that gasification operations cannot be performed at the North Knobs site. Among the reasons for such a move would be: unfortunate hydrologic conditions, discovery of heavy fracturing in the coal seam, observation of unusually low permeability along the linkage path. Work is currently under way to locate at least two candidate backup sites.
- A characterization of the nation's steeply dipping resource should be made. This resource characterization would expand the existing work that defines the size and distribution of the SDB resource to determine the applicability of existing experience and the results of the program to that resource. The results of this study would define for potential participants the specific technical problems which might be encountered in the commercialization of a particular SDB coal.

- There is considerable commercial interest in the production of high Btu gas. This requires injection of oxygen. Development of cost factors for an oxygen burn requires that the burn extend over a significant period (as much as 80 days). The absence of these data dictates that funds should be allocated for such an exercise as part of this project.

DOE ORALS

As required by contract, the DOE oral presentations describing the status of the UCG/SDB project were given during this quarter. Eight morning presentations were given. These dealt with the following:

- schedules and budgets
- site criteria and selection
- technical approach and test plan
- drilling and permits
- facilities
- environmental activities
- program interactions and flow
- recommendations

The afternoon discussions principally dealt with DOE's request for a cost estimate of moving to the state of Washington.

6.0 SITE CHARACTERIZATION

PHASE II GEOLOGY DRILLING PLAN

SUMMARY

The Phase II geotechnical activities will collect data to define the surface and subsurface geologic character of the UCG site and facility. Activities directed towards the surface characterization will include surface geologic mapping, observation and mapping of fracture traces, trenching of the coal seams, and near-surface soil/bedrock augering. To characterize the subsurface geology and hydrology in the study areas, a drilling program will be initiated.

The drilling program will consist of drilling three types of holes. These are a) vertical core holes which will be used to obtain samples of the subsurface rock column in the UCG facility area, b) vertical hydrologic observation and water sampling wells which will be used to characterize hydrologic parameters within the rock column on the UCG facility, and c) slant hydrologic observation and water sampling wells which will be used to characterize the hydrologic parameters within the "G" coal seam on the UCG facility.

Other activities within the drilling program will include a) surveying the surface location and elevation of each drill hole, b) geophysically logging the holes, c) installing piezometers in the drill holes, d) conducting draw-down/recovery tests, and e) collecting water samples from the piezometers. These activities will be initiated after DOE approval of the drilling subcontractors is obtained, and after the necessary permits are issued. The following describes the construction plans for implementing the drilling program.

Core Holes

Four (4) vertical holes with a nominal diameter of 2-1/8" will be drilled at locations specified by the Gulf site representative (see Figure 6-1). Two of these holes will be continuously cored from the ground surface to a depth of 25' below the coal seam (one hole through the G and one through the I seams). The total depth of these holes will be about 550' each. The two other holes will each be air-drilled to a depth of about 25' above the coal seam and then cored to 25' below the coal seam. The total depth of these holes will also be 550'. One 1-1/2" diameter PVC piezometer will be installed in each hole. The maximum allowable horizontal deviation in the core holes will be 25'. The well construction criteria are summarized in Tables 6-I and 6-II, and Figure 6-2 presents a diagrammatic cross section of one of the core holes.

The geologic information obtained from core examination will provide data for the local stratigraphic and structural characterization of the UCG facility. This information will be integrated with the surface geology data to produce cross sections and stratigraphic columns which will graphically show unit thickness and facies changes. Reserve estimates will be calculated from these data. In addition, interpretations about subsurface faulting and folding can be made.

The drill cores will be analyzed in the following tests: proximate analysis, ultimate analysis, ash fusion, heating value, permeability, and mineral inclusions. In addition, core from the boundary strata will be examined petrographically and tested for tensile strength and triaxial compression. These data may be used for subsidence modeling studies.

The piezometers will be used to monitor water levels throughout the drilled section of overburden.

Figure 6-1
PHASE II DRILLING PROGRAM

Table 6-I

DRILL SPECIFICATIONS FOR CORE HOLES

<u>Hole #</u>	<u>Nominal Diameter (in.)*</u>	<u>Estimated Interval (ft.)</u>		<u>Estimated Footage</u>		<u>Coal Seam Cored</u>
		<u>Air-Drilled**</u>	<u>Cored</u>	<u>Air-Drilled**</u>	<u>Cored</u>	
C-1	2-1/8	0	0-550	0	550	G, I
C-2	2-1/8	0	0-550	0	550	Wally, G
C-3	2-1/8	0-475	475-550	475	75	I
C-4	2-1/8	0-475	475-550	475	75	G
Total 2-1/8" footage				950	1250	

*Diameter of core

**Drill cuttings will be collected at 10' intervals. If ground water is encountered, it may be necessary to use water, mud or foam to maintain circulation.

Table 6-II

SPECIFICATIONS FOR PIEZOMETER INSTALLATION IN CORE HOLES

<u>Hole #</u>	<u>Piezometer Number</u>	<u>Diameter (in.)</u>	<u>Estimated Total Depth</u>	<u>Perforated Interval for Observation</u>
C-1	1	1-1/2	525'	I
C-2	1	1-1/2	525'	G
C-3	1	1-1/2	525'	I
C-4	1	1-1/2	525'	G

Figure 6 - 2
CORE HOLES

Vertical Hydrology Wells

The hydrology testing wells consist of six observation wells (H-1 through H-6) and one pump well (P-1). Figure 6-1 illustrates the location of these wells. H-1 through H-5 will have an 8" diameter and will be drilled to varying depths (25' below the G coal seam). Three 1-1/2" PVC piezometers will be installed in these holes. The piezometers will be used to monitor water levels during the draw-down/recovery testing, and throughout the life of the experiment. Casing will be set in these five observation wells from 2' above ground surface, through the soil, and 5' into bedrock.

Observation well H-6 will have a 13" diameter and will also serve as a water sampling well. H-6 will be the deepest well, and it will be drilled downdip of Burn No. 2 (Figure 6-1). Three 4" PVC piezometers will be installed in this hole. These will be used to monitor water levels and to collect water samples from the coal and the units underlying and overlying the coal. Hole H-6 will be cased similar to the other observation wells.

The pump well (P-1) will be drilled to an 8" diameter, and a 6" PVC casing will be set. This well will be used to withdraw water from the coal seam.

The maximum allowable deviation for the hydrology wells is 25' except for holes H-2, H-3, H-4, and P-1, where the maximum deviation will be 10' due to the close spacing of the holes. The well construction data are summarized in Tables 6-III and 6-IV; and Figures 6-3, 6-4, and 6-5 illustrate well construction.

Well draw-down and recovery testing will proceed after construction of the pump and observation wells. Water will be pumped from the pump hole and changes in the water levels in the observation holes will

Table 6-III
SPECIFICATIONS FOR HYDROLOGY DRILLING

<u>Hole #</u>	<u>Nominal Diameter</u>	<u>Estimated Interval</u>		<u>Estimated Footage</u>	
		<u>Air-Drilled*</u>	<u>Cored</u>	<u>Air-Drilled*</u>	<u>Cored</u>
H-1	8	0-300	0	300	0
H-2	8	0-500	0	500	0
H-3	8	0-525	0	525	0
H-4	8	0-525	0	525	0
H-5	8	0-600	0	600	0
p-1	8	0-525	0	525	0
Total 8" Footage				2950	
H-6	13	0-650	0	650	0
Total 13" Footage				650	

*Drill cuttings will be collected at 10' intervals. If ground water is encountered, it may be necessary to use water, mud or foam to maintain circulation.

Table 6-IV

SPECIFICATIONS FOR PIEZOMETER INSTALLATION IN HYDROLOGY OBSERVATION WELLS

6-9

<u>Hole #</u>	<u>Piezometer #</u>	<u>Diameter (in.)</u>	<u>Estimated Total Depth</u>	<u>Perforated Interval for Observation</u>
H-1	1	1-1/2	300	Underlying rock unit
	2	1-1/2	275	G coal seam
	3	1-1/2	250	Overlying rock unit
H-2	1	1-1/2	500	Underlying rock unit
	2	1-1/2	475	G coal seam
	3	1-1/2	450	Overlying rock unit
H-3	1	1-1/2	525	Underlying rock unit
	2	1-1/2	500	G coal seam
	3	1-1/2	475	Overlying rock unit
H-4	1	1-1/2	525	Underlying rock unit
	2	1-1/2	500	G coal seam
	3	1-1/2	475	Overlying rock unit
H-5	1	1-1/2	600	Underlying rock unit
	2	1-1/2	575	G coal seam
	3	1-1/2	550	Overlying rock unit
H-6	1	4	650	Underlying rock unit
	2	4	625	G coal seam
	3	4	600	Overlying rock unit

8" PVC casing

Figure 6 - 4
HYDROLOGIC WATER SAMPLING WELL

6" PVC pipe

450'

475'

500'

525'

8"

COAL

be recorded. Figure 6-6 illustrates the instrumentation to be used in the pump well for the draw-down recovery test. The duration of the pump testing will be defined after initial water level readings are taken in the installed piezometers.

Slant Hydrology Wells

Three slant wells will be drilled down dip within the bottom third of the G coal seam for a slant length of 675'. Figure 6-1 illustrates the location of these wells. Two of the holes (S-1 and S-3) will be drilled to a 2-1/8" diameter and one 1-1/2" piezometer will be installed in each hole. Well S-2 will have a 6" diameter and one 4" piezometer will be installed. Tables 6-V and 6-VI summarize the slant well drilling specifications. Figure 6-7 illustrates the well construction for the slant wells.

The hydrologic tests will provide the following information:

- (a) the extent of hydraulic connection between aquifers;
- (b) the direction of preferred flow in the aquifer above the production zone under stress;
- (c) the hydraulic connection between monitor wells and the aquifer to be used to quench the burn;
- (d) information on the transmissivities of the aquifers;
- (e) the quality and quantity of aquifer waters;
- (f) the connection between the aquifers and surface sources.

A map of the local potentiometric surfaces of overlying, underlying, and coal aquifers will be constructed on which the following data will be plotted: a) the wells used to obtain head levels, b) the surface elevation of the wells, and c) the perforation interval.

Water samples will be shipped to Harmarville for chemical analyses.

Figure 6-6
INSTRUMENTATION FOR DRAWDOWN TESTING
(PUMP WELL)

Table 6-V

SPECIFICATIONS FOR SLANT WELL DRILLING

<u>Hole #</u>	<u>Hole Diameter</u>	<u>Slant Length Air-Drilled*</u>	<u>Angle to Horizontal</u>
S-1	3"	675	65° <u>±</u>
S-2	6"**)	675	65° <u>±</u>
S-3	3"	675	65° <u>±</u>
Total Slant Footage		2025	

*Drilling cuttings will be collected at 10' intervals. If ground water is encountered, it may be necessary to use water, mud or foam to maintain circulation.

**)If not feasible, hole diameter will be 3".

Table 6-VI

SPECIFICATIONS FOR PIEZOMETER INSTALLATION IN SLANT WELLS

<u>Hole #</u>	<u>Number of Piezometers</u>	<u>Diameter</u>	<u>Total Depth (ft.)</u>	<u>Perforated Interval for Observation</u>
S-1	1	1-1/2	675	G coal seam
S-2	1	4*	675	G coal seam
S-3	1	1-1/2	675	G coal seam

*If hole is drilled to 3" diameter, then a 1-1/2" piezometer will be installed.

Figure 6-7

HYDROLOGY SLANT WELLS

Geophysical Logging

Each hole will be geophysically logged after it is drilled and before the piezometers are installed. The following logs will be taken:

Gamma ray

Temperature

Density

Drift survey

Resistivity

The logs will be compared to the cores obtained and further characterize the subsurface dip integrity of the coal seam and overburden character beneath the UCG facility.

PERMIT SUPPORT

Permitting requirements in the state of Wyoming by local, state, and federal agencies were surveyed in greater detail, and a preliminary list of permits was formulated. This list must be resurveyed and will be subject to revision.

The permits required for the construction and operation of the North Knobs site fall into two categories:

- Permits required for 1978 geological/hydrological testing and site access
- Permits required for facility construction and operation

Permits falling in the first category will be needed in April 1978.

Permits for Geological/Hydrological Testing and Site Access

These permits will allow site access and on-site geologic and hydrologic activities to proceed. The following permits are required:

- License to explore for minerals by dozing--
Wyoming DEQ Land Division (includes \$20 000 reclamation bond)
- Permit to appropriate ground water -- Wyoming State Engineer
(one permit for each drill hole)
- Temporary tram road -- BLM

After filing with the state of Wyoming DEQ for the minerals exploration and ground water permits, GR&DC and TRW personnel met with a BLM representative in Rawlins on March 16 to discuss routing of the access road into the test site. After a discussion of the various routing alternatives, an on-site tour of the access route alternatives

was conducted. The BLM representative determined that the least objectionable route is NE along an existing jeep trail in Section 14 to an intersection with the Section 11 south boundary near the SE corner. An application for a temporary access road permit along this route has been submitted. Later, an application for a permanent road right-of-way will be submitted. Roadway survey and profile drawings have been contracted for. Design and eventual construction of the access road will proceed upon receipt of the survey, the road profile data, and permit approval.

In light of recent permitting requirements, an archeological survey of the site was made. Three potential archeological sites and one historical site were identified near the site area but should not interfere with field operations.

Permits Required for Facility Construction and Operation

The permits outlined below may be required before any site construction activities can be started. Since these permits will require from four to six months of agency review time, they must be submitted by October 1, 1978, to preclude project delays. Some permits also require baseline data for up to 1 year prior to application.

- Permit to Mine
- Water Quality Permit--WY DEQ
- Air Quality Permit--WY DEQ
- Permit to Appropriate Groundwater--WY State Engineer
- Permit to Construct a Water Well--WY State Engineer
- Permit to Construct a Reservoir--WY State Engineer
- Right of Way Permit--BLM
- Carbon County Building Permits
- Construction Permit--WY DEQ

A consultant experienced in Wyoming permitting operations has been retained to assist in determining all the required permits, their

data requirements, and submitting the permit applications. Data collection planned for the SDB project will be reviewed and provisions to obtain missing data will be made. The consultant will then provide assistance in assembling the data into the formats required by the permits, and formulating responses to the regulatory reviewer's questions.

7.0 ENVIRONMENTAL ACTIVITIES

During this quarter, work on the Baseline Environmental Monitoring task included the following:

1. A thorough check-out of air monitoring instrumentation which will be used at the UCG test site was conducted. The instruments were operated in the laboratory for one week to assure that each was functioning properly. As of the date of this report, each of the instruments functioned according to specifications. The calibration source for two of the instruments was found to be defective and will be replaced.

2. A sampling manifold was designed and fabricated for installation in the instrumentation trailer.

3. Arrangements were made with a supplier of industrial gases in Denver to provide the necessary calibration, span, and zero gases for instrumentation check-out at the test site.

8.0 PARAMETRIC COST ANALYSIS

Introduction

An analysis of the UCG process parameters has been obtained with the Gulf Economic Model for UCG. Although the model was developed for horizontal beds, the significance of parameters studied should be similar.

The underground coal gasification process embodies many variables which affect not only the process operating characteristics but also the process economics. In general, these variables can be grouped into physical properties of the coal seam, independent operational variables and dependent production variables. It is important to know the effect of each of these variables on economics in order to indicate where experimental work will be most fruitful.

An evaluation of process economics requires that cost studies be made on a system which would be representative of a commercial installation. Gulf Research & Development Company developed such a conceptual design for horizontal coal seams, and, in order to facilitate the lengthy economic calculations, also developed a computerized mathematical model. This proprietary model and its use for parametric studies related to our DOE contract are discussed further in the Phase I Final Report.

It must be emphasized that the conceptual design and computer program were developed for horizontal coal seams. Because seam characteristics, drilling costs, well layout, and field piping will differ between horizontal and steeply dipping beds, GR&DC intends to develop at their own cost a modified proprietary model for the SDB configuration. GR&DC expects that the absolute value of the economics will be different for a steeply dipping bed plant; however, for many or most of the variables, the effect of changes in their values will be similar, regardless of seam orientation.

The studies which are in the final report are for a plant producing 152×10^3 GJ/d (144×10^9 Btu/day) of low-heating-value gas from a horizontal seam of subbituminous coal located in the western United

States. The gasifying medium was air. This size plant furnishes sufficient gas to generate approximately 600 MW of electric power.

Parameters Studies

Sixteen different cases were run in which individual parameters were varied and four cases were run in which two or more parameters were varied together. The base values of the parameters which were held constant as they were varied one by one are shown in Table 8-I and the ranges through which they were varied are shown in Table 8-II. Table 8-II also contains the calculated price for LHV gas with equity financing over the range of the various parameters.

From Table 8-II it may be seen that many parameters were varied over a range of 100% or more; and to reduce the results to a more comparable basis, the effects were calculated for a 50% increase in parameter value at its mid-range. The effect of this increase on the price of LHV gas is shown in Table 8-III.

Table 8-III shows that the most effective way to reduce the cost of gas from UCG is to increase its heating value. This decreases the plant size, number of wells, fuel requirements, and coal consumption. For the heating value effect, all of the combustible gases were assumed to increase together in the same proportion. Runs were also made in which methane only and hydrogen only were increased. When either of these alone increased by 50%, the product gas heating value increased by about 15%. Gas prices decreased, but to a lesser extent than when heating value increased 50%.

The next most effective ways to reduce gas cost are to increase product gas recovery and air utilization, i.e., to minimize leakage. To express the numbers from Table 8-III in another way, each 2% decrease in

Table 8-I

BASE PARAMETER VALUES FOR PARAMETRIC COST ANALYSIS

<u>Parameter</u>	<u>Base Value</u>
<u>Coal Data</u>	
Seam depth, m (ft)	183 (600)
Seam thickness, m (ft)	9.1 (30)
Density, t/ha-m (T/acre-ft)	13 970 (1900)
Heat content, kJ/kg (Btu/lb)	18 600 (8000)
<u>Operational</u>	
Well spacing, ha (acres)	0.81 (2)
Aspect ratio ^(a)	1
Production rate/well, m ³ /d (10 ⁶ scf/d)	141 580 (5)
Injection air rate, m ³ t/coal (scf/T)	1605 (51 430)
Injection air pressure, kPa (psig)	790 (100)
Production wellhead pressure, kPa (psig)	445 (50)
Sales gas delivery pressure, kPa (psig)	1310 (175)
Water/O ₂ consumption ratio, weight	1.5
<u>Production</u>	
Gas production rate, m ³ /t coal (scf/T)	2620 (84 000)
Gas composition, mol % H ₂	18.0
CO	18.0
CH ₄	5.0
C ₂ H ₆	0.5
CO ₂	10.0
H ₂ S	0.1
N ₂ + Ar	48.4
Gas heating value, kJ/m ³ (Btu/scf)	6560 (176)
Sweep efficiency, %	100
Air utilization, %	100
Gas recovery, %	100

(a) Aspect ratio - distance between production rows divided by distance between wells in row.

Table 8-II

SUMMARY OF PARAMETER VARIATIONS AND THEIR EFFECT ON UCG ECONOMICS

PARAMETER STUDIED	Range of Parameter		Sales Gas Price, \$/GJ(\$/10 ⁶ Btu)	
	Low	High	At Low Range	At High Range
<u>COAL SEAM</u>				
Depth, m (ft)	91 (300)	233 (764)	1.70 (1.79)	1.80 (1.90)
Seam thickness, m (ft)	1.5 (5)	10.4 (34)	2.30 (2.43)	1.74 (1.84)
Coal density, t/ha-m (T/acre-ft)	13 970 (1900)	27 480 (3737)	1.76 (1.86)	1.71 (1.80)
<u>OPERATIONAL</u>				
Well spacing, ha (acres)	0.28 (0.7)	1.58 (3.9)	1.72 (1.82)	1.90 (2.00)
Aspect ratio (Note a)	0.2	8.9	2.45 (2.59)	1.53 (1.61)
Production rate/well, m ³ /d (10 ⁶ scf/d)	65 103 (2.3)	274 670 (9.7)	2.80 (2.95)	1.53 (1.61)
Air rate, m ³ /t coal (scf/T coal)	1055 (33 800)	1915 (61 430)	1.50 (1.58)	2.04 (2.15)
Air pressure, kPa (psig)	480 (55)	1480 (200)	1.65 (1.74)	1.91 (2.02)
Production wellhead pressure kPa (psig)	240 (20)	745 (93)	2.78 (2.93)	1.35 (1.42)
<u>PRODUCTION</u>				
Gas rate, m ³ /t coal (scf/T coal)	1875 (60 000)	3230 (103 500)	2.27 (2.39)	1.56 (1.65)
CH ₄ in product gas, mol %	2.1	7.0	2.55 (2.69)	1.46 (1.54)
H ₂ in product gas, mol %	12.6	21.3	2.14 (2.26)	1.59 (1.68)
Gas heating value, kJ/m ³ (Btu/scf)	4580 (123)	8380 (225)	4.10 (4.33)	1.18 (1.25)
Sweep efficiency (coal usage), %	25	97	2.20 (2.32)	1.76 (1.86)
Air utilization, %	40	98	3.86 (4.07)	1.78 (1.88)
Gas recovery, %	40	98	4.42 (4.66)	1.78 (1.85)
<u>COMBINED PARAMETERS</u>				
Air rate, m ³ /t coal (scf/T coal)	1070 (34 290)	1850 (59 140)	{ 1.85 (1.95)	1.73 (1.83)
Gas rate, m ³ /t coal (scf/T coal)	1870 (60 000)	3230 (103 500)		
Air pressure, kPa (psig)	410 (45)	1010 (132)	{ 2.50 (2.64)	1.30 (1.37)
Production pressure, kPa (psig)	240 (20)	840 (107)		
Depth, m (ft)	76 (250)	182 (598)	{ 2.92 (3.08)	1.15 (1.21)
Air pressure, kPa (psig)	370 (39)	1310 (175)		
Production pressure, kPa (psig)	200 (14)	1135 (150)		
Depth, m (ft)	76 (250)	182 (598)	{ 3.12 (3.29)	2.20 (2.32)
Air Pressure, kPa (psig)	370 (39)	1310 (175)		
Production pressure, kPa (psig)	200 (14)	1135 (150)		
Air leakage, %	5	30		
Gas leakage, %	5	30		

Note a: Aspect ratio = distance between production rows divided by distance between wells in row.

Table 8-III

EFFECT OF 50% INCREASE IN PARAMETER
VALUE ON LHV GAS SALES PRICE

<u>Parameter</u>	<u>Change in Sales Gas Price, %</u>
Product gas heating value	-54.0
Product gas recovery	-30.4
Air utilization	-26.8
Gas production/t coal	-24.2
Injection air/t coal	+23.5
Methane content of gas	-20.7
Hydrogen content of gas	-20.6
Production wellhead pressure	-16.9
Production rate/well	-9.5
Sweep efficiency	-4.9
Aspect ratio	-4.7
Well spacing	+3.8
Injection air pressure	+3.8
Coal seam thickness	-3.5
Coal seam depth	+2.1
Coal concentration/unit surface area	-1.6

either air or gas leakage (or 1% in both) reduces sales gas price by 1%. Decreased leakage reduces cost because of reduced plant size, number of wells, fuel requirements, and coal consumption.

Gas production per ton of coal and air injection per ton of coal have opposite effects on gas price as they are increased. Since they will probably increase together rather than individually, the net effect of increased air injection and gas production is likely to be small.

Increased production wellhead pressure has a beneficial effect on gas price because the conceptual plant design requires that the production gas be compressed to 1135 kPa (150 psig) before it goes to the main plant, and the high costs of field compressors and their operation can be reduced at high wellhead pressure. Increasing wellhead pressure by increasing air injection pressure is cheaper than the cost of compressing production gas, because the air volume is only about 57% as great as the volume of product gas.

Increased production rate per well reduces the number of wells and the amount of field piping required. The total plant investment and the sales gas price are thereby reduced.

The remaining parameters have only moderate effects on gas price in this study. This arises because their effects are largely related to well costs and field piping, and these constitute a minor portion of the plant investment and operating costs in the conceptual plant.

In addition to the relationship of gas production and air injection mentioned above, other parameters are related in various fashions. Outlet and inlet pressure, well depth and pressure, and depth, pressure, and leakage are three sets of variables which have been

examined together in this study. In the first two of these three, the effect of outlet pressure dominates the combined effects so that the effect of wellhead pressure alone accounts for most of the change in gas price. When gas leakage increases with increasing pressure, the effect of pressure dominates at low pressures and low leakage rates, whereas the effect of leakage dominates at high pressures and high leakage rates. For the magnitude of the relationships chosen for this study, an optimum pressure was obtained.

Discussion

The effects calculated in this study were determined by the values assigned to all the variables, and the interactions which could be investigated are almost limitless. One parameter which has not been varied is the pressure at which the sales gas is delivered. If this pressure could be lessened, it is possible that the other pressure parameters will be less important.

This study does not take into account relations between operational and product parameters. The development of process models which is contemplated in the DOE contract should help correct this deficiency. The ease of using the economics model will enable the process models to be tested as the experimental investigations proceed.

One definite limitation in this study is that it applies only to horizontal coal seams. In order to apply such a study to steeply dipping beds, it will be necessary to develop a conceptual plant and mathematical model for that configuration. Many of the parameters would be expected to have similar effects for either horizontal or steeply dipping beds. However, because well costs are greater in steeply dipping beds and because field piping may involve greater costs as the wells are spaced in a single row along the seam, some of the parameters may have

increased effects in the SDB process. Some parameters which should be particularly examined in the steeply dipping bed model are well depth, seam thickness (as it affects drilling costs), well spacing, production rate per well, and sweep efficiency. The whole concept of optimizing the positioning of wells, field piping, and gas handling plants must be carefully considered as this new model is developed.

9.0 PROGRAM PLANNING

PHASE I FINAL REPORT

Extensive efforts were put forth in costing and planning Phases II, III, and IV activities. The formalized activity network which resulted was included in the Phase I Final Report. This effort involved several iterations of the network activity initiated last quarter to assure integrated planning at the subtask level and to achieve a viable schedule. Coordination meetings were held to effect interaction between task leaders and resolve omissions, duplications, and unrealistic time spans. Major emphasis was given to identifying and scheduling appropriate data flow between interdependent tasks/subtasks.

BLUE BOOK PREPARATION

The Blue Book which will contain the formalized plans and criteria for UCG/SDB is presently being written. A formal document review cycle has also been established to evaluate the resulting documents. The Blue Book will contain the following:

1. Test Plan
2. Systems Descriptions for the Process Concept
3. Geotechnical Characterization Plan
4. Environmental Criteria
5. Instrumentation and Data Acquisition
 Systems Criteria
6. Facilities Acceptance Criteria
7. Slant Drilling Criteria Plan
8. Permeability Test Facilities Acceptance
 Criteria
9. Burn No. 1 Test Facilities Acceptance
 Criteria
10. Burn No. 2 Test Facilities Acceptance
 Criteria
11. Burn No. 3 Test Facilities Acceptance
 Criteria
12. Site Operation Plan
13. Preparation of the Safety Criteria
14. Site Restoration Criteria

PROCESS WELL DESIGN AND DRILLING

Drilling Assessment

Based upon concerns raised during the previous quarter relative to the well installation accuracy requirements, an investigation was begun to assess the technical and economic risks associated with drilling slant-hole process wells.

Figure 9-1 reflects the approach to this assessment including key activities.

Beginning with activity (A), Establish Well Requirements, the process well requirements are defined. In addition, hole placement tolerances are also determined.

Once well requirements are established, preliminary well system design (B) is accomplished. That is, the well is designed to the extent of determining casing diameters, slotted liner placement, number of wells, module drilling schedule, whether air or mud will be the drilling fluid, and other critical design features.

Following the preliminary well activity (B), an extensive investigation (C) is made to determine available drilling options and techniques which will satisfy the well placement requirements. Based on literature reviews, contacts with drillers, consultants, directional drilling tool manufacturers, and visits to on-going drilling sites, a catalog of options and techniques is compiled.

Once the available options and techniques are identified, criteria for selecting the best option are established (D). This is done by addressing the various risk potentials, technical capacity of the drilling equipment and tools, cost implications, and project schedule impact.

FIGURE 9-1

THE APPROACH TO ASSESS THE ECONOMIC AND TECHNICAL RISKS
ASSOCIATED WITH SLANT HOLE DRILLING ON THE
UCG (SDB) PROJECT

Once the options are identified and the criteria for selection determined, the options are evaluated (E). This evaluation establishes, by use of a weighting scheme, a ranking of those options which will have minimal risks relative to the successful accomplishment of the project objectives.

Moving to the final evaluation step, a cost trade-off (F) is performed to assess the cost versus the ranking of the well installation options ranked in activity (E). This evaluation is not a cost/effectiveness analysis but a cost-ranking of the weighted options which when coupled with professional judgment, allows one or more options to be recommended.

The last step (G) in the approach methodology consists of preparing recommendations relative to:

- i) Well Design (sketches, specifications, etc.)
- ii) Well Drilling Procedure
- iii) Well Survey Procedure
- iv) Composition of the Well Installation Contractor Team

Progress to Date

At this point in the assessment, the process well configuration and placement requirements have been determined (see Figures 9-2 and 9-3), and portions of the Well Design have been established based upon a preliminary design analysis (see Table 9-I). It must be noted here that the Phase I cost estimate for the well drilling was based on the data presented by GR&DC in the Blue Book of design criteria dated October 24, 1977, and subsequently revised November 30, 1977. The well depths for each burn now being discussed and presented here in Figure 9-3 are greater than the Blue Book values. Consequently, the costs for drilling the wells will be greater than originally estimated. In addition, if these new well depths become official criteria, the Phase I cost estimate for the test facility may no longer be valid. The deeper well depth will require

Figure 9-2 Process Well Design Criteria

(NOTE: The * indicates well depths different from the baseline given in the GR&DC "blue book dated 10/24/77 and revised 11/30/77. These depths, if they become official criteria, will increase the costs of the wells and the test site facility as estimated during Phase I of this project.)

Figure 9-3 Process Well Depth Criteria

(NOTE: The * indicates well depths different from the baseline given in the GR&DC "blue book" dated 10/24/77 and revised 11/30/77. These depths, if they become official criteria, will increase the costs of the wells and the test site facility as estimated during Phase I of this project.)

PROCESS WELL DESIGN DATA

1. <u>DIAMETERS</u>	<u>PRODUCT WELL</u>	<u>INJECT AIR WELL</u>
(a) Hole	12-1/4"	12-1/4"
(b) Casing - Surface	13-3/8" OD	13-3/8" OD
- Intermediate	8-5/8" OD	8-5/8" OD*
- Slotted Liner	7" ID	7" ID

2. <u>CASING & LINER DEPTHS:</u>	<u>BURN #1</u>		<u>BURN #2</u>		<u>BURN #3</u>	
	<u>PRODUCT</u>	<u>INJECT</u>	<u>PRODUCT</u>	<u>INJECT*</u>	<u>PRODUCT</u>	<u>INJECT*</u>
(a) Casing - - - -	250 ft	500 ft	250 ft	1. 640 ft 2. 560 ft	250 ft	1. 700 ft 2. 600 ft
(b) Liner - - - -	100 ft	-	200 ft	-	270 ft	-

*NOTE - Burn #2 & #3 will have spare inject wells.

3. WELL DEGREE OF STRAIGHTNESS - Adequate for normal casing pipe.
4. CASING SPECIFICATIONS - Material - TBD
Length of Sections - TBD
Type of Joint - TBD
5. CASING CENTRALIZERS - Skids or standoffs to be welded to casing.
6. CASING CEMENT TYPE - TBD
7. WELL HEAD DESIGN - TBD
8. SLOTTED LINER SPECIFICATION - Material - TBD
Slot Design - TBD
9. ACCEPTANCE TESTS - TBD
10. ABANDONMENT PROCEDURES - TBD

* maximum casing diameter is shown here, the actual casing may be smaller

TABLE 9-I

a re-evaluation of the air compressor and piping capability to provide an adequate flow of air at the pressures and rates required. It may also be necessary to modify the facility plot plan to accommodate these potential changes.

Based on the well requirements and design information, initial hole drill rig options were identified (see Table 9-II). This table of optional drilling rig configurations will be expanded as the information collected during the data collection activity are analyzed. For example, several directional drillers have recommended, for the purpose of assuring hole direction accuracy, that a pilot hole be drilled first and then the hole reamed out to the 12-1/4" diameter. Therefore, the final rig configuration may have to be one which is capable of both bit sizes and torque/hp requirement.

The data collection activity was primarily conducted during the period March 6-15 and while not 100% complete, has produced valuable insight into directional drilling techniques. Knowledgeable individuals contacted during this period are included in Table 9-III. Concurrent with the collection of technical information, cost data were also accrued which will be useful in validating earlier drill program cost estimates.

Predicated on the information gleaned from the various directional drilling professionals contacted and the information derived from the various documents and reports reviewed, our conclusions at this point are:

- Slant hole drilling rigs, in the capacity required, are available without modifications.
- Installation of the well holes will require the application of controlled directional drilling technology. This technology has already been proven.

QUALIFIERS DRILL RIG OPTIONS	REQUIRES ASSEMBLY OF VARIOUS MECHANICAL COMPONENTS	RIG MUST CAN MEET X. HOLE REQUIREMENTS	RIG MUST HEIGHT LIMITATION	REQUIRES MAST ANCHORING SYSTEM	HOLE DEVIATION CONTROL	RIG TORQUE/HP APPROPRIATE FOR DEPTH	REQUIRES 1 OR 2 DRILL RIGS
DOWN THE HOLE DRILL MOTOR W/SLANT DRILL RIG	NO	YES	NOT A PROBLEM	NO	INTEGRAL WITH DRILL MECHANISM	NOT A PROBLEM	ONE
DIAMOND CORE W/SLANT ROTARY RIGS • PILOT HOLE RIG • HOLE ENLARGE- MENT RIG	NO	YES	NOT A PROBLEM	POSSIBLE REQUIREMENT	RETRIEVAL CASING WEDGE	NOT A PROBLEM	TWO
SLANT ROTARY/ PERCUSSION COMBINATION RIG	NO	YES	NOT A PROBLEM	POSSIBLE REQUIREMENT	RETRIEVAL WHIP STOCK	NOT A PROBLEM	ONE
TOP DRIVE TRIPOD RIG	YES (KEY COM- PONENTS MUST BE MATCHED)	YES	NOT A PROBLEM	NO	RETRIEVAL WHIP STOCK	NOT A PROBLEM	ONE
BLAST HOLE RIG	NO	CAN BE MODIFIED	POSSIBLE PROBLEM	POSSIBLE REQUIREMENT	RETRIEVAL WHIP STOCK	NOT A PROBLEM	ONE

Note: This assessment is incomplete as of this date

TABLE 9-II

UCG/SDB 12" DIAMETER WELL HOLE DRILLING OPTIONS

NAME	COMPANY	SPECIALTY
TOM BEARD	CONSULTANT	GEOLOGY/HYDROLOGY
GORDON VENEKLASSEN	SAN MATEO RESOURCES, INC.	DIRECTIONAL DRILLING/ GEOLOGY
JOHN WORKMAN	DYNA-DRILL CO.	DOWN HOLE DRILLING MOTORS
BILL HAMBY	SPERRY-SUN, INC.	SURVEY AND GUIDANCE TOOLS
DAVE NEWELL	ENERGY CONSULTANT ASSOC.	WELL DESIGN, EMPLACEMENT & COMPLETION MANAGEMENT
JIM DERNER	ARROW DRILLING CO.	SLANT DRILLING CONTRACTOR
AL KNODEL	EASTMAN WHIPSTOCK, INC.	SURVEY & GUIDANCE TOOL RENTAL
WAYNE CRAIG	CHRISTENSEN DIAMOND PRODUCTS, INC.	DIRECTIONAL DRILLER & DIAMOND BIT DISTRIBUTOR
RAY O'CONNELL	DIRECTIONAL INVESTMENT GUIDANCE, INC.	DIRECTIONAL DRILLER, SURVEY & TOOL RENTAL
FRED STAGG	DRILCO, INC.	SUPPLIER OF DRILL STRING DIRECTIONAL CONTROL DEVICES

TABLE 9-III
INDIVIDUALS CONTACTED DURING THE INFORMATION
AND DATA COLLECTION EFFORT (MARCH 6-15)

- It is anticipated that a directional drilling supervisor will be required on the site to assist in managing the drilling contractor.
- The size of the process well drilling targets is such that, in order to hit them, a well drilling service company specializing in the rental and application of directional control instrument will be required.