The 4th Annual International Conference On Coal Gasification, Liquefaction and Conversion to Electricity

Volume 2

The 4th Annual International Conference on Coal Gasification, Liquefaction and Conversion to Electricity. Vol. 2.

THE 1977 ERDA UNDERGROUND COAL CONVERSION PROGRAM

by

Dr. Paul R. Wieber and Dr. Alpert P. Sikri

U.S. Energy Research
and Development Administration
Washington, DC 20545

To be presented at the Fourth Annual
Coal Gasification, Liquefaction and Conversion to Electricity Conference

August 2-4, 1977

Table of Contents

THE 1977 ERDA UNDERGROUND COAL CONVERSION PROGRAM

Dr. Paul R. Wieber and Dr. Albert P. Sikri
U.S. Energy Research and Development Administration
20 Massachusetts Avenue, N.W. - Room 4121
Washington, D.C. 20545

ABSTRACT

The status of the 1977 program for underground coal conversion program being conducted by the U.S. Energy Research and Development Administration (ERDA) is reviewed. The program management uses a team concept to maximize the resources of ERDA Headquarters and of the Field facilities. The program participants are listed and the accomplishments during the past year are summarized. An appraisal of the status of the technology is made, listing future priorities which the program will address. It is concluded that low-Btu gas production using the Linked Vertical Well (LVW) concept could be commercialized by 1985, steam/oxygen technology will be developed using the LVW concept, and directional drilling and hydraulic fracturing are the most promising methods to link and gasify the process wells in Eastern coals.

INTRODUCTION

The energy crisis we are encountering has come with several advance warnings. The 1973 oil embargo led to a shortage of transportation fuels. Domestic sources of oil had been unable to meet the expanding United States demand for some time, and we had relied on increased amounts of imported oil to make up the difference. When those foreign sources were withdrawn, the first shortages were felt in supplies of gasoline, diesel, and jet fuels. Then fuel oil for home heating and industrial boilers was curtailed. Industry began to shift to coal, causing temporary shortage of the low-sulfur coal needed to meet environmental standards. Another warning came during the past cold winter when a second conventional fossil fuel, natural gas, could not be provided at rates adequate to meet increased heating needs. Businesses and schools were shut down, and many states declared emergencies. Although these shortages were temporary, it has become apparent that the days of cheap, abundant supplies of these convenient fuels are over. The United States must develop other energy sources to protect its future.

The Energy Research and Development Administration (ERDA) has been given the responsibility to develop technology for new and expanded sources of energy, both nuclear and non-nuclear. Fossil energy is a major non-nuclear area. It fuels more than 90% of our current needs. Enhanced gas- and oil-recovery techniques promise to yield energy in the near-term. The Nation's coal resources could supply our needs for hundreds of years. The direct firing of coal can be used to generate electricity and supply process heat for new or retrofit installations. But the need for transportation fuels and gas for industrial and residential heat can also be met by coal through the production of synthetic fuels by liquefaction and gasification processes.

ERDA is developing underground coal conversion (UCC) processes as part of its Fossil Energy program. These concepts complement surface-based processes and use petroleum-based technology to produce gaseous and liquid fuels from coal in place with little or no mining. The reactant and product gases are carried between the surface and the coal seam by boreholes (wells) drilled into the coal seam. Using a downhole igniter, the coal is heated to a suitable reaction temperature, and the reacting fluids are forced down the injection well and through the coal seam to the production well. The products are carried to the surface where they are cleaned and processed further in surface-based plants.

The ERDA UCC program is concerned mainly with underground coal gasification (UCG). If the reactants are air and steam, the product is a low-Btu gas for on- or near-site use. If the reactants are steam and oxygen, the product is a medium-Btu gas. This gas may be transported to end-use centers which are within a few hundred miles, or it can be converted on-site to a transportable commodity such as methanol, chemicals, or synthetic natural gas. The ERDA program is exploring these and other options for using both eastern and western coals in underground processes.

The First Underground Coal Gasification Symposium was conducted by the Laramie Energy Research Center. No papers were published, but the success of the first meeting led to the establishment of the Symposium as an annual program event. The Second UCG Symposium was sponsored last summer by the Morgantown Energy Research Center, and the proceedings were published this spring.[1] We believe the Annual Symposium, with published papers and opportunities for informal discussions, provides an essential forum for a fruitful exchange of current ideas between all parties in advancing the state-of-the-technology.

Last year's overview paper by the present authors summarized the past history and promise of the technology, and the structure and status of the ERDA program.[2] The format seemed appropriate for the first published overview. This year we intend to emphasize the program's organization, accomplishments, and changes in the past year; its present status; and its future direction. We will discuss a number of issues which we believe are important in characterizing the present status of the technology and in projecting future plans for the program. Finally, we will speculate how some of the concepts being tested now in the program might be combined into some commercial process designs.

MANAGEMENT STRUCTURE OF THE UCC PROGRAM

The UCC program is in the Division of Oil, Gas, and Shale Technology (OGST), directed by Mr. Hugh D. Guthrie. OGST is one of seven Divisions under the Assistant Administrator for Fossil Energy, Dr. Philip C. White. OGST is divided into two directorates -Petroleum and Natural Gas and In Situ Technology. The In Situ Technology Directorate contains the Shale Oil Branch and the Underground Coal Gasification Branch. The authors are members of the UCG Branch. The UCC program is the only element of the Fossil Energy coal program in OGST. It is placed in OGST because petroleum technology is used in the underground part of the process, and the UCC field tests face similar problems for those of petroleum and gas field work. The surface portions of the total UCC process are similar to the corresponding chemical engineering unit operations in coal synfuel processes that are entirely surface-based. For this reason, the work in the other coal divisions is also relevant to the UCC program.

The UCC program is building on projects that were brought into ERDA from the U.S. Bureau of Mines and the Atomic Energy Commission. The current trend is toward more industrial involvement in the program, but the heavily -weighted "in-house" character of the program offered an opportunity to develop a team concept in program management. In setting up the team concept, the relationship between Headquarters (HQ) and the "in-house" Field members was clarified to avoid misunderstandings and and conflicts. As holder of the ultimate authority for conduct and content of the program, HQ selects projects; sets objectives, funding, and accomplishment milestones; and reviews the progress of the work. The Energy Research Centers and National Laboratories propose projects, prepare implementation plans for projects approved by HQ, and are responsible for the execution of those plans. The Operations Offices provide administrative and, in some cases, technical management to facilitate project execution. It was recognized that ERDA HQ and the Field teams carried skills which complemented each other and which could combine synergistically to benefit the overall program. HQ maintains a program overview and contacts with national plans and policy which gives the Field a perspective of the roles of their separate projects in the national program. The Field offices know the administrative and management procedures required to conduct business with industry. The Field research teams have acquired the detailed technical knowledge which HQ needs in developing realistic plans and goals. In addition, the information developed in each field project is applicable to all projects, and HQ is the best party to coordinate the exchange of this information between the teams on a timely basis.

The team concept has been formally implemented in the UCC program through a Management Working Group, through a Denver Project Office for Western projects, and through Technical Working Groups.

The Management Working Group consists of the HQ UCG Branch members plus one person from each of the two Energy Research Centers and the two National Laboratories which have major projects in the program, and one person from the Denver Project Office. This group is an advisory group which assumes a program (rather than a project) perspective. It meets as needed, and all members gives their best opinion on such issues as direction of the program, priority of projects within program goals, methods of improved coordination and communication, and so forth. Although these opinios are not binding on HQ, they are given the fullest consideration when HQ formulates program management decisions. The group is still in the experimental stage, but consensus indicates this has been an effective group up to now.

The Denver Project Office was formed as an extension of the San Francisco Operations Office (SAN) in response to an agreement between HQ and SAN. The agreement delegates a major role to SAN in the implementation of the UCC program in the West, including management of selected industrial projects, coordination between all western projects, and contracting for most projects in the West. The formal inclusion of an Operations Office into the UCC team brought a variety of talents into the program, and the decision by ERDA top management to implement the agreement through an office in the Rocky Mountain States points out the importance of that region's abundant coal resources to UCC technology.

Project coordination and technical information exchange is done informally, through HQ review, and by meetings of the Technical Working Groups. These groups represented one of the first attempts at team development. There are currently four groups: Geology, Site Preparation, and Field Testing; Instrumentation; Modeling and Laboratory Experimentation; and Environmental Support. The groups meet twice each year to discuss what was learned in the past six months and what is planned for the next six months. The format includes informal presentations in the morning and open discussions in the afternoon. All participants, including universities and industrial firms with contracts from the UCC program, are invited to the group meetings which are relevant to their projects. The technical group meetings not only promote information exchange between the projects, but they also offer the HQ representatives a valuable opportunity to review across-the-program status of a part of the UCC technology, such as instrumentation.

The building of a team to plan and execute the UCC program is a management goal we will continue to pursue. In particular, the activities of the Management Working Group and the Denver Office will continue to be developed in the coming year. The team concept lets the program goals become identified with the goals of each project and each member of the team. This relates the success of the program to the personal responsibilities of each team member, and the members can share in the satisfaction of each program accomplishment. We believe this is the best way to manage the UCC program.

PROGRAM CONTENT

The major processes of this program are shown in Table 1. These are Linked Vertical Wells-Air (LVW); Packed Bed Explosive Fracturing and Steam-Oxygen Gasification (PB); Longwall Generator and Eastern Coal Technology (LG); and Steeply Dipping Beds (SDB). These are supplemented by Environmental Support and Supporting Research.

The major in-house participants in the program are the Laramie Energy Research Center (LERC), the Sandia Laboratories in Albuquerque (SL), the Lawrence Livermore Laboratory (LLL), and the Morgantown Energy Research Center (MERC). These laboratories are involved in the field effort. The in-house laboratories supporting this program are the Argonne National Laboratory (ANL), the Oak Ridge National Laboratory (ORNL), and the Los Alamos Scientific Laboratory (LASL). These laboratories are providing supporting research and analyses. In addition, there are HQ R&D contracts with the University of Pittsburgh, the University of West Virginia, Booz-Allen and Hamilton, and the Stanford Research Institute. The University of Alabama and the University of Texas at Austin have UCG contracts which have been recently transferred to ERDA from the National Science Foundation. Table 2 provides a brief description of the projects, participants, functions, and Fiscal Year 1977 funding.

SUMMARY OF PAST ACCOMPLISHMENTS

This section summarizes the accomplishments since last year when the Second UCG Symposium was held at Morgantown, West Virginia.[1] Table 3 shows the significant accomplishments. These are explained in detail in the sections to follow.

Table 1. FY 1977 Participants and Funding - Major Projects & Supporting Research

PROJECT	PARTICIPANT	FUNDING ($1,000's)
LINKED VERTICAL WELLS (ROCKY MTN. ENERGY SITE)	LARAMIE ERC	2,350
PACKED BED, STEAM-OXYGEN GASIFICATION (PUBLIC LAND)	SANDIA LABORATORIES	1,000
	LAWRENCE LIVERMORE LAB	2,750
	RESOURCE SCIENCES CONSORTIUM	0
EASTERN COALS (CONOCO SITE)	MORGANTOWN ERC	1,000
STEEPLY DIPPING BEDS	INDUSTRY	400
		7,600
KINETICS OF IN SITU REACTIONS	ARGONNE NATIONAL LAB.	150
PYROLYSIS OF LARGE BLOCKS OF COAL	OAK RIDGE NATIONAL LAB.	150
TWO STAGE CO_2-O_2 PYROLYSIS-GASIFICATION	LOS ALAMOS SCIENTIFIC LAB.	80
		380

77 31794/4 5

Table 2. FY 1977 R&D Contracts and Funding - (Headquarters)

CONTRACT TITLE	CONTRACTOR PRINCIPAL CONTACT	FUNDING ($1,000's)
GAS-LIQUID PERMEABILITY OF COALS PERTAINING TO UCG	U.O. PITTSBURGH	52
STRUCTURAL MECHANICS SIMULATION ASSOCIATED WITH UCG	WEST VIRGINIA UNIV.	52*
TECHNICAL DATA BOOK & MANAGEMENT PLANS	BOOZ ALLEN AND HAMILTON	138*
MARKET STUDY FOR LOW AND MEDIUM BTU GAS FROM UCG OF WESTERN COALS	STANFORD RESEARCH INSTITUTE	46
IN SITU COAL LIQUEFACTION	WEST VIRGINIA UNIVERSITY	70*
BLOCK SUBSIDENCE	SAI	50*
CONSULTATION	Dr. A. E. BALFOUR	20*
IN SITU GASIFICATION OF TEXAS LIGNITE	U.O. TEXAS	TRANSFERRED FROM NSF
FEASIBLE STUDIES OF IN SITU COAL GASIFICATION IN THE WARRIOR COAL FIELD	U.O. ALABAMA	TRANSFERRED FROM NSF
UNIVERSITY PROJECTS UNDER REVIEW		140*
		[illegible]

*ESTIMATED OR NOT FINAL.

77 31794/5 5

Table 3. Summary of FY 1977 Accomplishments

Linked Vertical Wells

- Hanna 2 Test Completed
- Hanna 3 Test Fielded
- Hanna 4 & 5 Plans Done

Packed Bed, Explosive Fracturing, Steam-Oxygen Gasification

- Hoe Creek 1 Test Done
- Preliminary Shaped Charges Test Done
- Steam-Oxygen and Explosive Fracture Plans Nearly Complete

Eastern Coal Technology

- Pricetown 1 LVW Test Plans Completed
- Laboratory Data Analysis Started
- Schedule for Field Site Preparations Completed

Steeply Dipping Beds

- RFP Issued

Environmental Support

- Gas Emissions Analyzed
- Ground Water Quality Measurements Done
- A Study on Cleansing Properties of Coal Started

Supporting Research

- Several Process Models Working Well With Field Data

- Lab Pyrolysis, Gasification, and Permeability Data Obtained

---

LINKED VERTICAL WELLS (LVW)

The LVW process is being developed by LERC at a site near Hanna, Wyoming. As shown in Fig. 1, this concept uses reverse combustion to link vertical wells in the coal seam. LERC is testing the concept in a 9.2-meter (30-foot)-thick subbituminous seam at 92- to 153 meter (300- to 500- foot) depths. Air is the gasifying agent with the resultant low-Btu gas applied to electrical power generation. LERC has been active in the Hanna Field since 1973.

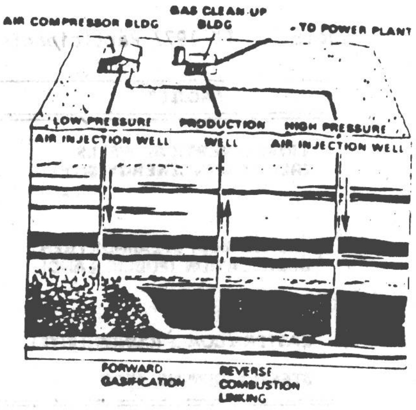


Fig. 1. Linked Vertical Wells Process

Continued analysis of the Hanna 2 field tests have verified their great success. The well patterns for Hanna 2 are included in Fig. 2. The total coal utilization from the 4-well pattern (wells 5,6,7, and 8) used for Phases 2 and 3 was 6,100 tonnes (6,700 tons), indicating a high overall areal sweep efficiency.^{3} The average heating value of Phases 2 and 3 was 146 Mega-joules per kilo-mol (MJ/k-mol) (165 Btu per standard cubic foot (Btu/Scf)) with gas production rates of 9.6 million k-mol/day (11.5 million Scf/day), consuming 109 tonnes (120 tons) of coal per day for a period of 62 days. The thermal efficiency (ratio of the total usable energy produced to the total available energy in the coal) was 82.7%. This gave an energy return ratio (the ratio of the total usable energy produced to the energy consumed in operating the process test) of 4.5. The energy produced was the equivalent of 7.5 Megawatts, assuming 33% conversion efficiency. Hanna 2 showed significant improvement over Hanna 1 in terms of energy efficiency, gas production, heating value of the gas, and tonnage of coal utilized.

Figure 3 shows the heating value, weight ratio of water produced to coal utilized, and cold gas efficiency (the ratio of the chemical energy in the product gas to the energy available in the coal) over the duration of Hanna 2, Phase 3 test.^{4,5} These data show that water intrusion has a significant effect on the process performance. As water intrusion in the coal seam increased, the heating value and the cold gas efficiency dropped. This test was run longer than optimum to obtain data for comparison with computer calculations.

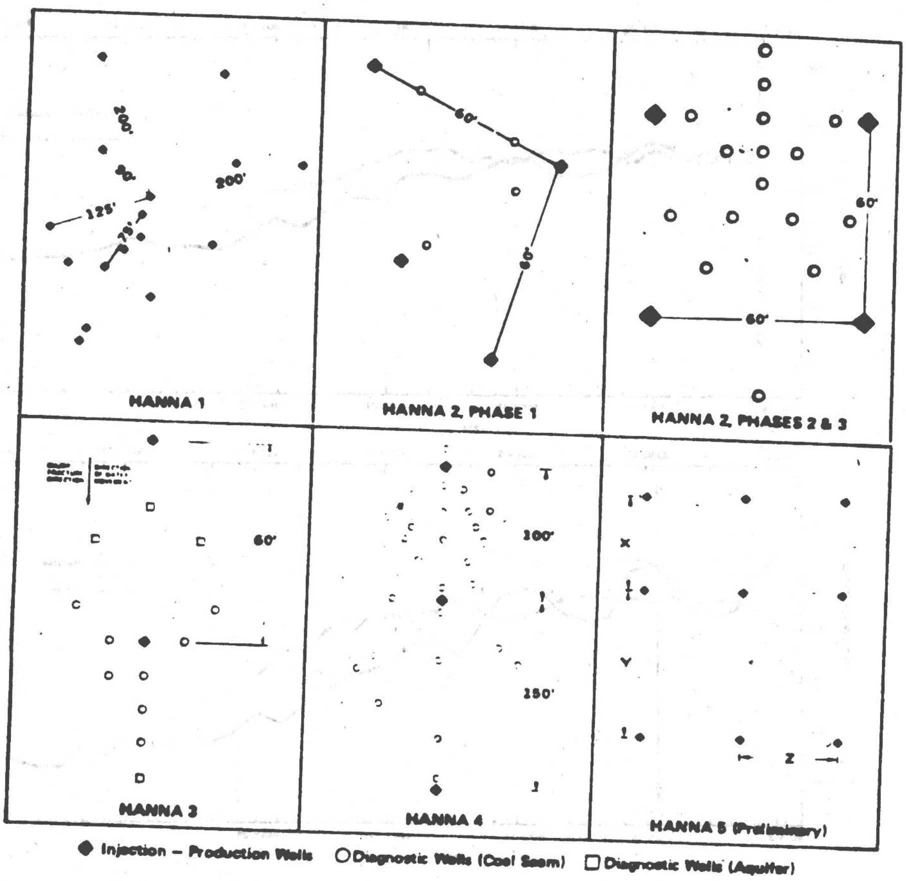


Fig. 2. Well Layouts for Hanna Tests 1 Through 5.

The mathematical modeling effort has been fairly successful in identifying physical and chemical phenomena controlling the process, interpreting of field test data, and providing potential solutions to some of the difficult process problems such as maintaining a high gas heating value.

The approximate boundaries of the final cavity (burned-out region) are shown in Fig. 4. This interpretation is based on data from Sandia's instrumentation wells (A thru M), and LERC's mathematical model predictions and material balance calculations.[3-5] The size of the cavity as the gasification progressed agrees well with the mathematical model. The plan view of the cavity for the Hanna 2, Phase 2 and 3 test is shown in Figure 5. This also is estimated from data obtained from the instrumentation wells and material balances around the wellheads. The dashed line in Fig. 4 indicates the average boundary for the bottom 3 meters (10 feet) of coal. and the solid line indicates the average boundary for the remaining 6 meters (20 feet) of the coal seam. The profiles at days 135 and 152 show that the gasification was controlled by the link established during reverse combustion. This shows that the coal was being consumed from the bottom to the top of the coal seam with high utilization and without override of the reaction zone.

INSTRUMENTATION AND PROCESS CONTROL

Sandia Laboratories provided a major instrumentation effort on the

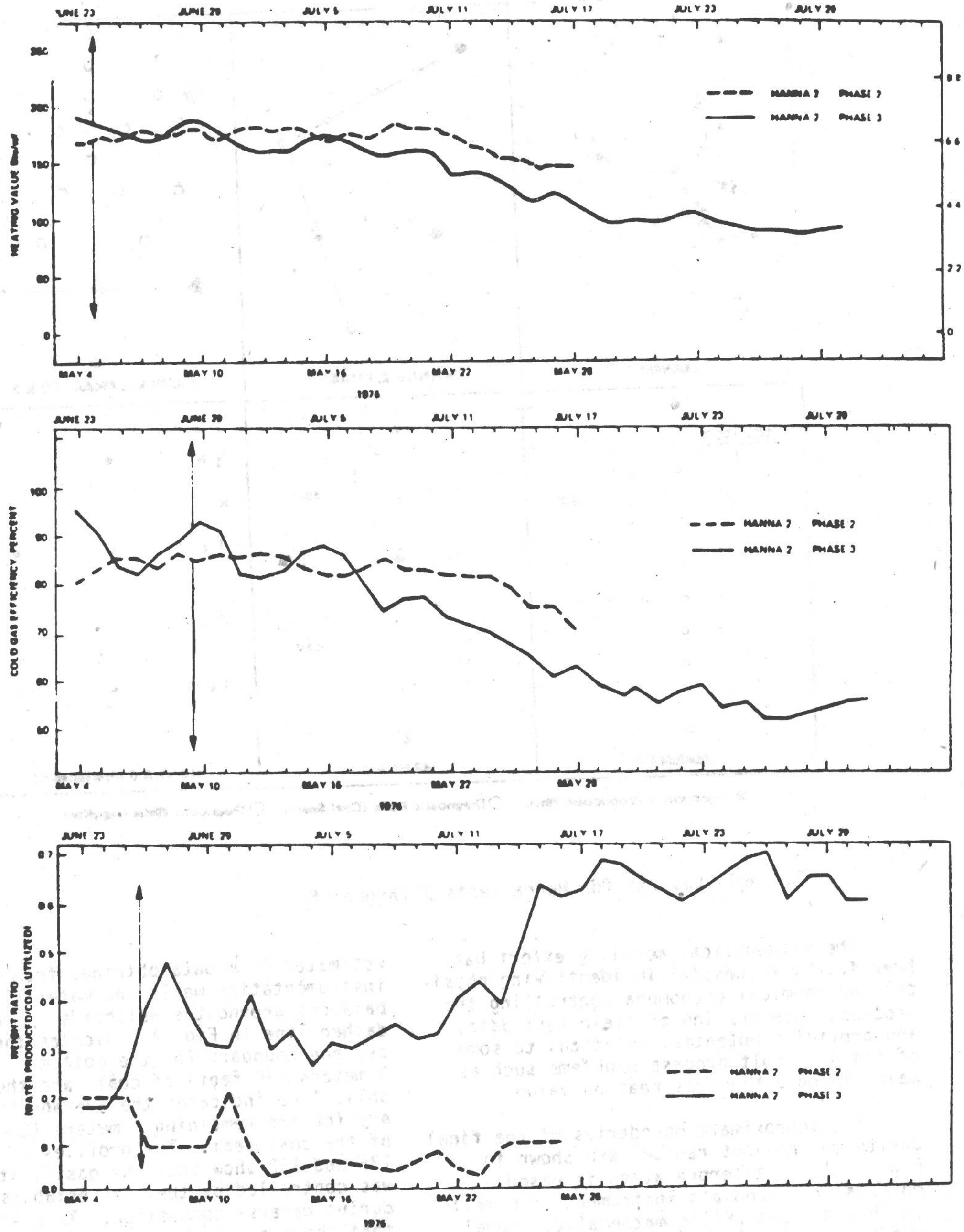


Fig. 3. Gas Quality, Water Production, and Cold Gas Efficiency Histories for the Hanna 2, Phases 2 and 3 Tests

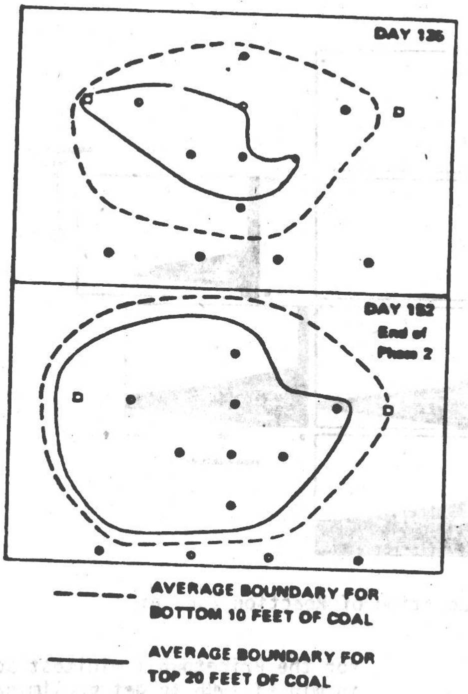


Fig. 4. Estimated Burned-Out Volumes During the Hanna 2, Phase 2 Experiment

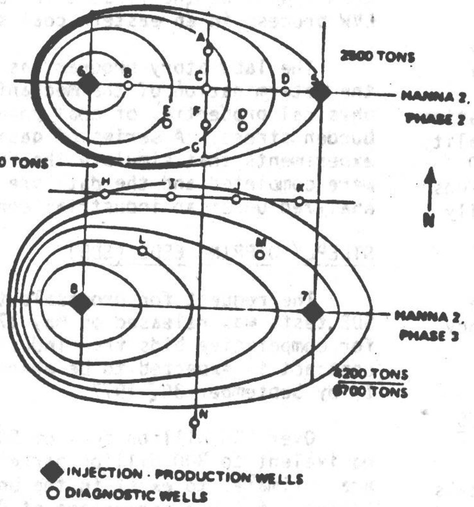


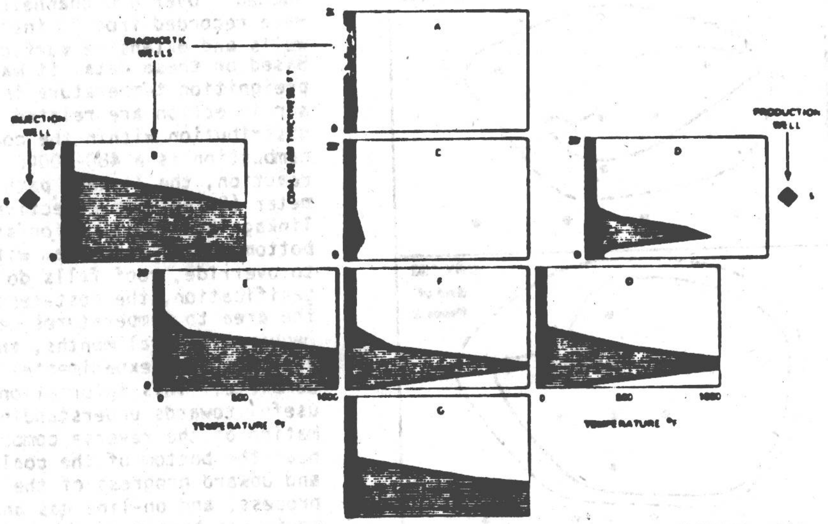
Fig. 5. Estimated Final Burned-Out Volumes for the Hanna 2, Phases 2 and 3 Experiments

Hanna 2 experiment, making this the best instrumented field test series ever conducted. Over 600 channels of information were recorded from 20 instrumentation wells and extensive surface arrays.[6] Based on these data, it was learned that preignition temperature increases during air injection are related to the air-flow distribution within the coal seam, reverse combustion is a 480-700°C (900-1300°F) reaction, the linkage path is about 1 meter (3 feet) in effective diameter, linkage and gasification start at the bottom of the coal seam with no tendency to override, roof falls do occur during gasification, the post-test cool-down of the area to temperatures below 93°C (200°F) requires several months, and coal utilization in the experimental region was complete. This information has been very useful towards understanding of the formation of the reverse combustion link near the bottom of the coal seam, outward and upward progress of the gasification process, and on-line gas analyses. A movie has been made which displays the vertical temperature distribution within the coal seam in eight of the instrumentation wells from the start of the linkage through Phase 2 of the gasification. One frame from this movie is shown in Fig. 6. These analyses are contributing significantly to the process understanding and control.

In addition to providing diagnostic information on the chemical and physical mechanisms associated with the process, Sandia is developing remote sensing techniques using passive acoustics and induced seismic methods. These are based on detecting signal changes due to the presence of the voids in hopes of detecting the edges of the affected regions. Also, electrical techniques are being investigated, based upon the large changes in resistivity that occur during gasification. These data could provide valuable information about the movement and growth of the reaction zone.

PACKED BED, EXPLOSIVE FRACTURING, AND STEAM/OXYGEN GASIFICATION (PB)

In October, 1976, the Hoe Creek 1 test was initiated by LLL using air as the gasifying agent. This was the first ERDA test in which forward gasification was successfully conducted without establishing a linkage between the wells by means of a backward burn. Communication between the wells was established by means of a simple two-well fracturing experiment (two explosive charges were fired simultaneously at the bottom of the coal seam) which increased the preshot coal permeability from 0.3 darcy



— Fig. 6. Temperature Profiles Showing Location of Reaction Zone At Bottom of HaNna Coal Seam

to about 2-4 darcys post-shot.[7] The intent was to fracture the coal and establish communication between the injection and production wells along the entire depth of the coal seam, with higher permeability at the bottom and lower permeability at the top.

In actuality, the high permeability zone was formed near the top of the seam rather than at the bottom, which caused the reaction zone to override. Gasification proceeded for ten days producing gas quality in the range of 88-130 MJ/k-mol (100-150 Btu/Scf) and consuming 118 tonnes (130 tons) of coal. Gas quality dropped dramatically towards the end as the oxidation zone approached the production well. It is estimated that water influx into the gasification region was about 65% of the pregasification level. Thermal efficiency during the gasification was estimated to be 75%.

LONGWALL GENERATOR AND EASTERN BITUMINOUS COAL TECHNOLOGY (LG)

A process for eastern bituminous coals is being developed by MERC. A deviated well, 600 meters (2,000 feet) in length, was completed into the 1.8 meter (6-foot) thick coal seam at a depth of 260 meters (850 feet).[8] The well was turned to lie horizontally for 150 meters (500 feet) in the coal seam. Preparations are underway for the Pricetown 1 minitest sometime in mid-FY 1978 to get preliminary field data on the gasification behavior of the coal using the LVW concept. The planning phase is complete, and the field site preparations are underway. Pricetown 1 will be the first trial of the LVW process in an eastern coal seam.

The laboratory program has included the determination of the mechanical and physical properties of coal under overburden stress. A series of gasification experiments that simulate the field tests were completed and the data are being analyzed under an industrial contract.

STEEPLY DIPPING BEDS (SDB)

The request for proposals to conduct SDB tests was released on May 17, 1977, for competitive bids from industry. The contract is expected to be awarded (Phase I) by September 30, 1977.

Over 100 billion tons of SDB coal, equivalent to 300 billion barrels of oil, are estimated to exist in the United States. A large percentage of Pacific Northwest coal is steeply dipping, so commercialization of an SDB process could contribute to the future energy supply of the populous West Coast.

ENVIRONMENTAL SUPPORT AND SUPPORTING RESEARCH, (ES) AND (SR)

These categories include the environmental and general scientific and engineering studies that support the total program. The ES work is an intimate part of every major project. It has emphasized baseline studies and possible emissions to the air and to subsurface water flows. Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), the Los Alamos Scientific Laboratory (LASL), industrial firms and universities are contributing to the SR effort.

Ground-water Quality Measurements. LERC's Hanna 3 test is designed to be an "environmental burn". It is expected to provide detailed data on the effects of the process on underground water flows and composition changes. The test will use two process wells on an 18 meter (60 feet) spacing with 12 additional water-monitoring wells completed into the coal seam and the overlying aquifer, shown in Fig. 2. Water samples will be collected and analyzed before the burn and for at least 18 months after the burn to test long-term effects.

A 3-part program is being pursued by LLL on the nature and significance of the groundwater problem.[7] Their activities include a laboratory investigation of reaction products that are potential contaminants, a modeling study of the evaluation of a contaminated groundwater plume, and a groundwater sampling program at the LLL gasification site at Hoe Creek, Wyoming. Preliminary results show: the ash bed is surrounded by a ring or shell of deposited organic products after gasification; the measured pH value within the gasification zone is 10-11; the highest level of phenol concentration, approximately 100 parts per million, occurs just outside the burn zone. This is significantly lower than that in the untreated waste water from a typical surface gasification operation; laboratory evidence suggests that the cleansing properties of surrounding coal effectively confine these contaminants to an acceptably small region surrounding the burn zone.

Air Emissions. The product gas of the Hanna II test was sampled by the Radian Corporation for trace components, particulate matter, and major gaseous components.[9] This can allow assessments of the environmental impacts and surface cleanup requirements asociated with utilization of the product gas production. Very low particulate and alkali compound concentrations were found. All values were considered low and within the realm of control with existing cleanup technology.

Research and Planning. The ANL project provides kinetic data on the chemical reactions that occur during in situ gasification and to determine the important process parameters for the control of these reactions. Reaction of steam with chars prepared from Wyodak and Hanna subbituminous coals show that the Wyodak char is about twice as reactive as the Hanna char.[10] This is judged to be due to greater surface area due to larger macropores and fissures of the Wyodak char as compared to the Hanna char. Studies carried out with hydrogen and steam partial pressures similar to those expected underground indicate that steam acts as a promoter for the formation of methane from these chars. The ORNL project is collecting experimental data on the pyrolysis of large blocks of coal under simulated in situ conditions. Thermal profiles produced within the blocks during pyrolysis indicate that the volatilization of water is the heat-transfer rate-limiting mechanism, and that this water reacts with char to form hydrogen and carbon monoxide. The LASL project is studying the technical and economic feasibility of a two-stage CO_2-O_2 underground coal utilization scheme with minimal water requirements. Work on this project has just started.

The R&D contracts administered through Headquarters are with the University of Pittsburgh, the University of West Virginia, Booz-Allen & Hamilton, Inc., and Stanford Research Institute. There are several others monitored by the Energy Research Centers and National Laboratories. The University of West Virginia contract has been funded by the Headquarters, but is monitored through MERC. It focuses on the structural mechanics of the coal and rock during gasification. The University of Pittsburgh project is measuring and rationalizing the gas-liquid relative permeabilities of coals from Hanna and Hoe Creek, Wyoming and Pricetown, West Virginia. Booz-Allen & Hamilton, Inc., is providing planning support for updating and refining a four-volume report on the Five-Year Program Plan. The "Overview" is completed, the "Tech-

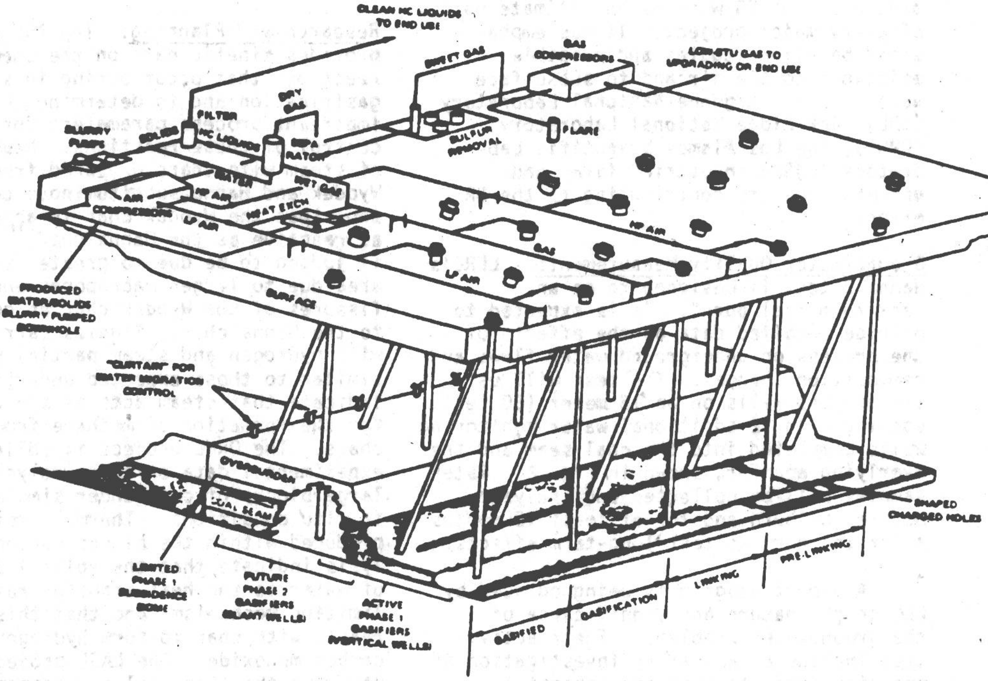


Fig. 7. A Possible Western Gasification Scheme

nical Data Book" and "Resources" volumes are almost done, and the "Management Plan" is started. Stanford Research Institute will conduct a market study for low- and medium-Btu gas produced from UCG in the Green River, Fort Union, Powder River and San Juan River regions. The contract is expected to be awarded soon.

ANALYSIS OF THE STATUS OF THE TECHNOLOGY

An appraisal of a number of issues based on the information developed or acquired by the ERDA program is presented in the following sections. We also indicate needs which must be met in the future and briefly speculate on the characteristics of future processes. The topics which will be discussed are air gasification, gasification with other reactants, linking concepts, subsidence and water control, instrumentation, environmental aspects, systems analyses and economics, resources and markets, liquefaction and advanced concepts, and the Western and Eastern Programs.

AIR GASIFICATION

The LVW-air gasification process will receive the highest priority in the next few years. The LVW concept, by virtue of its early start and the extension of previous work by the Soviets and others, is in the furthest stage of development. Work was done for forty years with air, so this gasification option has the greatest background for success and early commercialization. The successful results of LVW in Hanna 2 have been discussed earlier. Without demeaning the accomplishment, it should be recognized that this is only one fully successful test series. A high quality gas must be produced again at Hanna, at other coal sites, and at larger scales of operation. Much work remains to be done to show that the quality gas can be produced reliably, and that the concept is commercially viable. The large Soviet projects have produced average gas heating values of 93 MJ/k-mol (105 Btu/Scf) and considerably lower than the values from Hanna 2.[11] The Soviet results are consistent with those from Hanna, according to the analysis by Gunn et al.[12] They believe that different gas qualities can be related to the coal chemical and physical characteristics and to water influx through the seam. These predictions could lead to optimum site selection and process operation. For example, Hanna 3 will attempt to control gas quality by controlling the water-to-air ratio. As the seam water influx increases, the blast rate will be increased to maintain the optimum ratio for maximum gas quality as predicted by Gunn's model.

It is expected that near-optimum well spacings will be determined by experiments such as Hanna 4, and calculations using two-dimensional models that are being developed. This will optimize coal use and the underground reactor efficiency. The question of subsidence effects on process efficiency have not yet been addressed in the ERDA program because the scale of the experiments has been too small. The Hanna 5 test will supply our first extensive data. This is also the last test planned before going to a pilot-scale project. Scaleup of the process for greater production and longevity will give the engineering data needed to determine commercial potential. Equally important is the verification of the process performance for similar coals at several different site locations. The development of a characteristic test for the process must be done. This could be a simple 2-hole test for the LVW process, but if subsidence is a critical item, a 4-spot square pattern might be needed to affect a wide area of coal.

The air can be partially enriched by oxygen to raise the product gas quality, giving a product which can be transported farther and is easier to use. The reduced volume flow for fixed-Btu production allows smaller equipment to be used, offsetting some of the costs of oxygen enrichment. Although this option is of interest, it has a lower priority than the main development sequence for air gasification.

GASIFICATION USING COMBINATIONS OF OXYGEN, STEAM, CO_2 OR HYDROGEN

UCG using gaseous reactants with no nitrogen gives a medium-Btu product which can be upgraded by further surface processing to a synthesis gas or a synthetic natural gas (SNG). Some possible injection combinations are pure oxygen, steam (or water) with oxygen, carbon dioxide with oxygen, and hydrogen.

Gasification with pure oxygen is possible, but carries disadvantages. High pressure pure oxygen can cause combustibles to explode, so an extremely clean handling system is needed. It is possible to ignite the metal casing in the hot coal seam, and the destruction of the casing would result as the reaction propagated up toward the surface. Another problem is the excessive local heating and clogging of the coal subjected to a stream of pure oxygen. The addition of a water spray to the oxygen could alleviate some of these problems and make steam in-situ. However, the water could also segregate at the bottom of the seam and quench part of the reaction zone.

It is more advantageous to gasify with a mixture of steam and oxygen. The steam reduces the partial pressure of oxygen, lowering the safety and handling problems, cooling the casing while also preventing hot spots in the coal. The steam also acts as a source of hydrogen in a chain of reactions, and it is easily removed from the product stream. The steam/oxygen ratio is not restricted by reactor cooling problems, so the operators are free to optimize this ratio. Steam/oxygen gasification also has negative aspects. The costs of oxygen and of generating the steam are added, partially offset by cheaper, smaller gas handling equipment. The steam could condense in the seam before reaching the reaction zone. Underground leakage becomes more serious when costly oxygen is lost.

Stephens has analyzed the Soviet-bloc oxygen enrichment tests, including one with pure oxygen.[13] The results are abstracted on a nitrogen-free basis in Table 4. The highest gas quality was 235 MJ/k-mol (267 Btu/Scf) for the pure oxygen run. No major operational problems were reported, although seams that performed poorly with air did also

Table 4. Enriched Oxygen Data Adjusted to a Nitrogen and Water-Free Basis

Station	Composition, Vol %					Heating Value, Btu/Scf
	CH_4	H_2	CO	C_nH_m	CO_2, O_2 H_2S	
Gorlovskaya	3.9	40.7	27.0	-	25.4	228 (259)
Lisichansk	3.9	25.6	12.4	0.3	56.2	148 (168)
Podmoskovnaya #VNII	2.3	41.8	18.3	0.5	37.2	200 (227)
Podmoskovnaya	2.1	41.5	18.5	0.5	37.3	191 (216)
Mars Mine, Poland*	6.3	37.0	25.8	-	29.5	235 (267)
Gorgas, Alabama	4.1	24.5	21.2	0.3	48.0	172 (195)

*100% oxygen injection

with enriched oxygen. Thus, the steam/oxygen system appears to be technically feasible, and it will receive a higher priority in the ERDA program.

It has been suggested that carbon dioxide could replace steam as a diluant for injection with oxygen. The higher concentration of CO_2 could encourage the production of carbon monoxide by the Boudart reaction. The injection of hot CO_2 to precondition and pyrolyze the coal seam is also being explored by LASL. Certainly it will be more costly to remove the CO_2 than water vapor from the product stream. But in areas where water is scarce and the coal seams are also very low in water, this option may be worth exploring.

The injection of hydrogen for in situ hydrogenation has been suggested, and it may be tested in the Belgian-German program. The hydrogen is relatively quite expensive and leakage would be economically unacceptable. A plant would be needed to generate the hydrogen in a commercial operation, and this could be a major undertaking in itself, compounded by the remote site locations in the United States. Hydrogen injection has a low priority in the ERDA program for these reasons at the present time.

LINKING CONCEPTS

The difference between various concepts can be reduced to the means used to link the process wells through the coal seam, the mode of gasification, and the application to a particular resource. The most significant differences lie in the linking method, where the coal seam is prepared for subsequent gasification by developing preferred paths of flow for the reactants. The various approaches to linking will be discussed here.

The LVW and Soviet processes use reverse combustion to link the wells. Air is forced through the coal seam toward an ignited zone, and that zone is drawn toward the source of oxygen. The hot porous path that results is a low resistance, non-plugging path that controls the gasification propagation. Although reverse linking is subject to variances in the natural permeability of the seam, such as major cracks, it has proved reliable in the ERDA tests thus far. When linking parallel paths, it is possible to strike a link diagonally to another well, thus circumventing part of the coal. This should not be critical to the operation of a large plant, although it would affect the local