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Hanna, Wyoming Underground Coal Gasification Data Base

Volume 1: General Information and Executive Summary

Research Report

August 1985

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
MORGANTOWN ENERGY TECHNOLOGY CENTER
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Hanna, Wyoming Underground Coal Gasification Data Base

Volume 1: General Information and Executive Summary

Research Report

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PREFACE

This report is part of a seven-volume series on the Hanna, Wyoming, underground coal gasification field tests. Volume 1 is a summary of the project and each of Volumes 2 through 6 describes a particular test. Volume 7 is a compilation of all the data for the tests in Volumes 2 through 6. The reports in this series include:

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 1: General Information and Executive Summary (DE85013695).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 2: The Hanna I Field Test (DE85013696).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 3: The Hanna II, Phase I Field Test (DE85013697).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 4: The Hanna II, Phases II and III Field Test (DE85013698).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 5: The Hanna III Field Test (DE85013699).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 6: The Hanna IVA and IVB Field Test (DE85013700).

Hanna, Wyoming Underground Coal Gasification Data Base, Volume 7: Appendices (DE85013701).

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Volume 1: General Information and Executive Summary

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GENERAL INFORMATION AND EXECUTIVE SUMMARY

I. HISTORY OF UCG LEADING TO THE HANNA TESTS

Interest in UCG research reached advanced levels immediately after World War II in the United States, United Kingdom, France, Belgium, Japan, Czechoslovakia, and Poland. The programs in the United States and the United Kingdom were by far the most extensive of these. However, neither of these programs compared in size to the effort expended by the U.S.S.R.

The Soviet field effort was initiated in 1933 at three sites. The earliest work was based on mining to create shafts within the coal seam and also included some manual crushing of the coal prior to gasification. In 1934, work at Lisichansk initiated work based on the borehole producer technique. These tests used air injection as well as cyclic air-steam injection to produce water gas.

From 1934 to 1938, efforts concentrated on the use of partial mining techniques, i.e., mining a shaft between injection and production points and gasifying along the walls of the shaft. Major efforts were made at Kuznetzk and Gorlovka. Heating values ranged from 84 to 115 Btu/scf at Kuznetzk using air. Oxygen-enriched air was also used for the first time to raise the product gas heating value. At Gorlovka, heating values as high as 168 Btu/scf were reached with the gas used to fire a boiler for several months. By October 1938, Gorlovka had produced 275 MMscf of gas with total production from all installations reaching 2.75 billion scf at an average heating value of 94 Btu/scf. About 1.1 billion scf of this total gas production was utilized for industrial purposes.

In 1938, the U.S.S.R. decided to concentrate all future efforts on shaftless techniques, i.e., coal seam preparation and gasification using only boreholes for access. Further, plans were established to construct large industrial stations to produce fuel gases for power generation, chemical works and domestic industrial purposes. In December 1940, large-scale production was initiated at Lisichansk using oxygen-enriched air producing 350 MMscf of gas in 5 months.

From 1941 to about 1946, activity in the U.S.S.R. was suspended. Expansion after 1946 was directed toward large-scale facilities to supply industrial consumers. By 1957, facilities at Lisichansk, Tula, and Yuzhno-Abinsk were producing 85 MMscfd of low-Btu gas and were operating year round for an annual production rate of 2.5 billion scf. Plans had also developed for installations as large as 1200 MWe in the Kuzbass coal fields. By the early 1960s, discoveries of large natural gas fields in Siberia, imports of natural gas from Iran, and the decision to develop large coal-fired power stations resulted in a deemphasis of UCG. Research activities were continued at three facilities, at least two of which are still operating today. During the development of UCG in the U.S.S.R., field testing was conducted on coal resources ranging from peat to anthracite at depths up to 1000 feet under adverse geologic conditions. It is estimated that up to \$10 billion was expended in the Soviet effort with a peak of 6000 technical personnel involved.

Compared to this effort, the programs in the United Kingdom and the United States have been miniscule. The initial research began in the United Kingdom in 1949 with emphasis on access only through boreholes. In 1953, this approach was modified to include partial mining to better suit the available coal resources. Interestingly, this is the reverse of the Soviet development. Work was concentrated in thin seams (less than 4 feet thick) at Newman Spinney and at Bayton. In 1955, the National Coal Board became the responsible agency for development of UCG. Plans were directed toward pilot plant operations followed by a

commercial power station with development work concentrated at Newman Spinney.

In April 1959, the gas produced from Run P.5 at Newman Spinney was used to fuel a small electric generating facility. The generation continued until August reaching a total of 3.5 million kwhr consuming 238 MMscf of 59 Btu/scf gas (average with a range of 40 to 84 Btu/scf). The coal utilization efficiency determined by later excavation was 84%. The work was terminated at this time and plans to proceed to a commercial facility were cancelled.

In late 1946, a cooperative agreement was executed between the U.S. Bureau of Mines and the Alabama Power Company to begin UCG field testing at Gorgas, AL. The coal seam was a thin (3 feet), shallow, high swelling (FSI of 9) bituminous coal which outcropped all around the test site.

The series of experiments included gasification along a mined shaft and shaftless techniques using hydraulic fracturing, reverse combustion, and electro linking to achieve communication between wells. The field test series was conducted from 1947 to 1953.

In general, the resulting gas was of low heating value and the site properties not conducive to efficient gasification operations. Economic conditions (cheap oil and gas) at the time precluded further development efforts.

Little effort was expended in the U.S. between 1959 when the Bureau of Mines terminated its UCG laboratory program and 1972 when the Hanna project was authorized. Cities Service Oil Company conducted a small field test in 1967 in Oklahoma bituminous coal using hydraulic fracturing as a seam preparation technique. No data are publicly available to determine the test results. In 1968, Gulf R & D Company conducted a small test in Kentucky in bituminous coal near the high wall

of a strip mine. Carbonization rather than gasification products were produced. Leakage to the active strip pit caused early test termination. The site was later excavated and analyzed.

II. AREA CHARACTERISTICS

A. Basic Meteorological Data

No historical record is available from the Hanna coal gasification site. There are several climatological stations (which are part of the national network) located nearby at Elk Mountain (14 miles south), Medicine Bow (19 miles east), and Rawlins (40 miles west). All of these stations measure precipitation and temperature and the Rawlins FAA station also measured surface winds. The nearest evaporation measurements are taken at Pathfinder Dam (a large reservoir, 45 miles northwest) and at Laramie (65 miles southeast).

The climate of the Great Divide Basin region of central Wyoming is strongly influenced by the high elevation of the basin (6,000 to 7,000 ft MSL) and the presence of several large surrounding mountain ranges. In winter these mountains and other ranges further west remove moisture from air masses of maritime origin by orographic precipitation. They also block all but the strongest and deepest of the cold Arctic air masses which frequently invade the lower elevation plains of eastern Wyoming. The moderately high elevation of the land surface exposes the area to the influence of the strong winter westerlies. The stable density stratification of the winter air masses allows the topographic features to channel this generally westerly flow along the established paths of least resistance, usually down the natural hydrographic drainages. Within these drainages and where they converge, the largest wind velocities are observed, and the wintertime wind directions exhibit very little variety. The depth

of these cold, stable air masses is usually of the order of one-half to one km; the upper surface is usually well defined by a capping inversion. It is also just below this inversion where the greatest wind speeds occur. Thus boundary-layer jets are frequently observed during winter. The large amount of shear at the top of these stable air masses can produce Kelvin-Helmholtz shear instability waves (these waves may enhance vertical mixing).

Wintertime precipitation occurs primarily from large-scale traveling cyclones of Pacific maritime origin. Warm and cold fronts are usually not well enough organized in the intermountain region to produce the well-defined patterns of convergence and lifting that are needed for large amounts of frontal precipitation. Occasional snowfall results from convective instability (especially in late winter and early spring) and also from weak upper-air disturbances. Thus, the heaviest accumulations of wintertime precipitation occur in the form of perhaps ten storms, each of which lasts one to two days and deposits about four inches of snow. Accumulations of several inches usually melt or evaporate in one or two days. Locations to the west of the Great Divide Basin enjoy greater winter precipitation because they are closer to the air mass source region and because they are within the mountains where the orographic snowfall occurs. Locations to the east of the Great Divide Basin, especially near the easternmost range of mountains, also enjoy more wintertime precipitation due to the strong influence of "upslope" storms. These storms occur most often with slowly moving low-pressure systems located in southern and eastern Colorado. Their contribution is very significant for stations in eastern Wyoming; the Laramie 2N and Pole Mountain climatological stations received approximately 55 percent of their 1971 - 1972 and 1972 - 1973 winter season (September 15 to May 15) precipitation from "upslope" storms.

The summer season regional circulation is usually characterized by weak westerly flow which may be occasionally interrupted by a traveling cyclone. The majority of storm tracks are far north of Wyoming during the summer. The influence of the mountains is evidenced during summer by the mountain-valley diurnal circulations. These local circulations are upslope and up-valley during the day and downslope and down-valley at night. The circulations are driven by differential heating and cooling rates of inclined surfaces plus drainage of cooler air. The circulations are strongest near and within large mountain ranges during weak synoptic flow and they extend within about twenty miles of mountain ranges. Thus a weak mountain-valley circulation may exist in the area of the Hanna coal gasification site. This circulation has implications for the dispersion meteorology and for instrumentation placement.

Summertime precipitation in the Hanna area results almost entirely from air mass thunderstorms. Widespread areas of rain accompanying traveling cyclones or fronts are infrequent during summer. Forty to fifty thunderstorm days are expected during each summer. This precipitation falls as very heavy rainfall over relatively small areas in relatively short time spans.

In summer, the high altitude, dry air, high sun angles, and sloping terrain provide large rates of daytime heating and nighttime cooling, so that the diurnal temperature range is quite large, nearly 35°F. During winter, the reduced insolation and higher albedo (due to snow cover) limit the diurnal temperature range to about 20°F.

Temperature and precipitation data for the Rawlins FAA station are summarized in Table 1. Additional data for two other nearby stations are presented in Table 2. These three stations surround the Hanna coal gasification location and are at approximately the

Table 1. Climatological data for Rawlins, Wyoming (from Wyoming Natural Resource Board, 1966)

MEAN AND EXTREME TEMPERATURES (°F)												
Month	RAWLINS, WYOMING											
	FOR THE 34 YEAR PERIOD											
	1926-1960											
	Mean daily maximum temperature				Mean daily minimum temperature				Monthly mean temperature			
					Record highest temperature							
					Year							
					Record lowest temperature							
					Year							
Jan.	30.8	11.6	21.2	56	1953	-36	1930	0	16	31	6	Jan.
Feb.	33.6	14.0	23.8	60	1930	-32	1951	0	11	28	4	Feb.
Mar.	40.8	19.7	30.3	67	1946	-35	1943	0	7	29	2	Mar.
Apr.	53.9	28.3	41.1	77	1939	- 6	1945	0	1	21	<.5	Apr.
May	64.9	35.8	50.4	86	1954	0	1946	0	<.5	10	<.5	May
June	76.5	44.5	60.5	97	1954	21	1951	1	0	1	0	June
July	84.0	51.2	67.6	98	1954	33	1958	5	0	0	0	July
Aug.	81.6	49.4	65.5	96	1957	32	1956	1	0	<.5	0	Aug.
Sept.	70.8	40.6	55.7	88	1931	12	1926	<.5	0	4	0	Sept.
Oct.	58.1	30.9	44.5	81	1957	7	1941	0	<.5	18	0	Oct.
Nov.	42.7	20.9	31.8	68	1928	-20	1947	0	7	26	2	Nov.
Dec.	32.7	13.3	23.0	62	1939	-21	1927	0	13	30	4	Dec.
YEAR	55.9	30.0	43.0	98	July	-36	Jan.	7	55	198	18	YEAR
					1954		1930					
Mean number of days, max. temp 90° and above												
Mean number of days, max. temp 32° and below												
Mean number of days, min. temp 32° and below												
Mean number of days, min. temp 0° and below												
Month												

Table 2. Annual climatological summary for Elk Mountain and Pathfinder Dam, Wyoming
values are normals for 1941-1970

	Annual	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
<u>Avg. Temperature</u>													
Elk Mountain*	42	23	29	27	40	49	57	67	62	55	41	32	27
Pathfinder Dam	--	--	25	30	42	52	--	71	69	59	48	34	26
<u>Avg. Precipitation</u>													
Elk Mountain	12.88	.77	.83	1.22	1.59	1.59	1.59	.92	.90	1.08	1.03	.80	.56
Pathfinder Dam	9.51	.31	.40	.63	1.09	1.63	1.51	.74	.67	.79	.94	.44	.36

same elevation. The arid nature of this region is emphasized by the total annual pan evaporation of approximately 60 inches, five to six times larger than the total precipitation. Thunderstorms occur on about 50 days per year between May and September.

A historical record of several years of wind data is available for the Rawlins FAA airport, but the data have not been analyzed. Further data are available from several meteorological stations operated by the Department of Atmospheric Science, University of Wyoming.

Wind measurements were taken near the Medicine Bow airport as part of a climatological survey project of the WPA during the economic depression of the 1930's. This location is approximately 20 miles east of the coal gasification site; the terrain is similar. A summary of the annual average winds during the period 1930 to 1938 is presented in Figure 1. A running four-point center-weighted average was applied to the wind data from the sixteen compass points in order to smooth the apparent data reducer's bias toward the eight major directions. The westerly winds are dominant during all four seasons, with the greatest velocities occurring during winter and the smallest during summer. The summer season supplies the greatest contribution to the secondary peak in wind frequency from the east to southeast. The high frequency of occurrence of strong winds and low frequency of calm periods suggest that favorable dispersion conditions are common throughout the year. There are no population centers within about 20 miles downwind (east) of the coal gasification site.

B. Socioeconomic Data.

The town of Hanna originated in the late 1800's in response to demands for coal by the Union Pacific Railroad. The Hanna Basin has long been recognized as one of the richest coal areas of

Medicine Bow Winds - Annual Average 1930-1938

Figure 1. Frequency distribution of average surface winds for Medicine Bow, Wyoming

Wyoming. Coal reserves in the basin are estimated at 300 million tons. The small town of Carbon (at one time located seven miles to the south of Hanna) was originally the main mining town, which originated around 1868. Coal around Carbon was found only in thin seams and most easily recoverable reserves were exhausted by 1888. As Carbon's reserves were exhausted, mining was shifted to Dana and then eventually to Hanna, which became the chief coal-producing town for the area. Eighty-four mines have been opened in Hanna since 1868. When coal production shifted from Carbon to Hanna, so did the Union Pacific shift their mainline tracks. Moving the tracks to Hanna was advantageous for loading of coal and took advantage of more gradual grades through the mountains. The Union Pacific tracks still bisect Hanna. Just recently, a viaduct was built over the tracks to allow easy access to both sides of town.

There are three towns in the Hanna Basin: Hanna, Elmo, and Elk Mountain. Hanna and Elmo are less than two miles apart and both have experienced growth and decline as the importance of coal has risen and fallen in the United States. Elk Mountain is approximately 20 miles from Hanna and nestled at the foot of a mountain with the same name. Elk Mountain's economic base is primarily agriculture and ranching. Education levels, attitudes, incomes, and growth rates all appear significantly different from Hanna and Elmo as to classify the former as an agricultural community experiencing some energy-related growth, and the latter as booming coal towns undergoing rapid population growth. For the scope of this report Elk Mountain is not considered because of its distance from the Hanna experimental site. Of the two remaining towns in the Hanna Basin, Hanna is the largest and is receiving the majority of the growth. Very little work has been concentrated on Elmo because Hanna has more services to offer and has been gearing up to accommodate future coal-related growth.

Because of the lack of data for Elmo, because of the facilities that are available and are becoming available in Hanna, and because the experimental in situ coal gasification project is located right outside the Hanna city limits, we shall concentrate in this report on Hanna and discuss Elmo only when the two are considered together.

Hanna has always been a single-industry town. Extraction of coal has been that single industry. When the railroad first stretched across the west, Hanna and other towns were born because of their proximity to seams of coal. Hanna had a population of 1,209 as early as 1905.

When the depression came Hanna suffered, as did many other similar towns. Population declined by 29 percent from 1930 to 1940. Hanna did manage to recover economically and enjoyed a population of 1,326 by 1950.

During the 1950s when the Union Pacific shifted from coal-fired steam engines to diesel locomotives, the mines in the Hanna area closed down. Population declined 66 percent because of the railroad's decreased demand for coal. The people who remained in the area included those too old to move and those who commuted outside the area for employment. Hanna was a dying town until the 1970's and the rebirth of coal as an energy source. Since coal has reemerged as an important source of energy, so has the population of Hanna grown.

Table 3 shows the population from 1890 to 1976. The cycle of active coal production to little or no production can be easily seen. Hanna's population increased steadily from 1905 to 1930; 1940 to 1950 also saw population growth until the demand for coal by the railroad ceased. In 1970 Hanna had a population of 460

Table 3. Total Population, 1890-1980, Hanna, Wyoming

<u>Year</u>	<u>Population</u>
1890	260
1905	1,209
1912	1,347
1925	1,483
1930	1,154
1940	1,127
1950	1,326
1960	625
1970	460
1975	1,250
1976	1,500
1980	2,288

which has increased by over 300 percent to the estimated present population of 1,500.

The population situation in Hanna is dynamic. Although the exact numbers are not known, many workers are commuting to Hanna from as far away as Rawlins and surrounding areas. As housing becomes available, these workers are moving to town.

Growth in the Hanna area has been inhibited in the recent past by a ban on additional hookups to the sewage system. Workers were unable to build or move in a mobile home because of this ban. Since that time, the sewage system has been updated so as to accommodate an ever growing population.

Recent age distribution data for Hanna are available from a 1975 study based on the results of a survey sent to every household in Hanna with a return rate of 66.4 percent. Table 4 shows the age distribution for heads of households divided into Oldtimers (longtime residents), Newcomers I (those who had lived in the area for less than two years prior to 1972), and Newcomers II (newcomers since 1972). The median age of heads of households for Newcomers II was 27, as compared to 25 reported for Newcomers in 1972. This trend to younger in-migrants is also reflected in the fact that 49.8 percent of the heads of households classified as longtime residents are 50 years old or older as compared to only 10.2 percent of the Newcomer I group and 9.1 percent of the Newcomer II group. Reflecting this trend toward younger heads of households is the percentage of each group under 30 years of age (Oldtimers, 22.3 percent; Newcomer I, 47.7 percent; Newcomers II, 54.5 percent).

This tendency for younger workers to move into the area is to be expected since younger, mobile in-migrants are more willing to relocate for employment than other groups.

Table 4. Age Distribution of Hanna Heads of Household by Oldtimers, Newcomers I and II

Age	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65 ⁺
Oldtimers	3.3	8.3	10.7	5.0	3.3	11.6	9.1	13.2	14.9	6.6	14.1
Newcomers I	1.6	17.1	28.7	13.2	10.1	11.6	7.8	3.1	1.6	3.1	2.4
Newcomers II	0.0	30.8	24.2	12.1	9.1	9.1	6.1	6.1	3.0	0.0	0.0

ALL VALUES IN %

Educational levels in the Hanna Basin are higher than average for Carbon County or the United States: 26.4 percent of residents in Hanna have had some college education as compared to 13.0 percent for Carbon County and 13.1 percent for the United States. Table 5 shows the educational attainments for Hanna, Carbon County, and the United States. Table 6 shows educational attainments of Hanna residents broken into Oldtimers, Newcomers I, and Newcomers II. The table shows no significant differences between these groups when age was controlled.

Family size for Hanna (3.37 persons) is larger than for both Carbon County (3.01) and the United States (3.02). Given this larger average family size, we can expect a slightly faster natural population increase in addition to population increases due to in-migration created by labor demands.

Unlike Wyoming, which has traditionally had an agricultural base, Hanna has traditionally had an economy based on coal production. Characteristic of single-industry communities, the total economic history of Hanna is reflected by the history of coal. In the early 1900s, coal was extremely important for the coal-fired steam engines of the Union Pacific. Coal production dropped off during the depression and stopped altogether when the railroad completed its conversion to diesel locomotives. Coal did not become important again economically until the 1970's with the push by eastern utilities to switch to low sulfur western coal. Regardless of the future of coal in the United States, Hanna could remain a single-industry town. Also located within the Hanna area are large deposits of uranium which could prove valuable in the not too distant future depending largely on federal nuclear energy policy.

In a single-industry community, employment is a direct reflection of the demand for the particular item being produced. Demand for

Table 5. Educational Attainment, Hanna, Carbon County, and the U.S.

<u>Education Completed</u>	<u>Hanna</u>	<u>Carbon County</u>	<u>U.S.</u>
0-8 years	4.8	22.3	23.4
9-11 years	15.0	18.9	15.7
High School	44.3	37.6	32.7
Some College	26.4	13.0	13.3
College Graduate	9.6	8.0	15.1
ALL VALUES IN %			

Table 6. Educational Attainments of Hanna Residents, 30 or under

<u>Education Completed</u>	<u>Newcomer II</u>	<u>Newcomer I</u>	<u>Oldtimer</u>
0-8 years	0.0	0.0	0.0
9-11 years	13.3	8.1	0.0
High School	50.0	48.6	50.0
Some College	26.7	21.6	25.0
College Graduate	6.7	16.2	12.5
Vo-Tech Graduate	3.3	5.4	12.5

ALL VALUES IN %

coal has fluctuated in the United States during this century. The railroad was the primary use of coal from Hanna until 1950. When the railroad shifted from coal to oil, employment dropped drastically and Hanna's population declined to 460 before a new market was created for western coal.

Although employment has risen and fallen with the demand for coal the town cannot currently provide enough housing for all the individuals working in the area. Many find it necessary to commute from Rawlins, Saratoga, Medicine Bow, or Laramie. The coal-dependent labor market is such at present as to demand the in-migration or commuting of workers to the Hanna area mines.

Table 7 shows 1975 - 1990 employment estimates for Hanna. Also important in the employment area will be the increase in service employment. At present, much of the service employment or population-dependent employment is being created in Rawlins instead of Hanna. This is a situation that is expected to change as Hanna is able to provide needed facilities (water and sewage treatment) and growth levels off. The present basic to nonbasic employment ratio is .22. That is, for every basic job created, .22 nonbasic jobs are created. In contrast to this extremely low ratio is the "average" basic/nonbasic multiplier of 1.0--one basic job creates one nonbasic or service job. As the employment situation stabilizes in Hanna, we can expect the ratio of basic to nonbasic employment to increase. The net result of this increase will mean increased goods and services for the population in the Hanna areas.

Annual family income in Hanna is considerably above the national average and significantly higher than average in Carbon County. Table 8 shows the distribution of income levels in Hanna, Carbon County, and the United States. The fact that 77.7 percent of Hanna workers earn \$10,000 or more annually as compared to 38.6

Table 7. Employment Estimates, Hanna, 1975-1990

	<u>1975</u>	<u>1980</u>	<u>1985</u>	<u>1990</u>
<u>Low Estimate</u>				
Basic Jobs				
Mining	788	1,685	1,690	1,690
Union Pacific	15	15	15	15
Contract Construction (Mining or Union Pacific related)	80	80	40	40
Total Basic Jobs	883	1,775	1,745	1,745
Local Service Jobs ¹	95	340	560	730
TOTAL	978	2,115	2,305	2,475
<u>Moderate Estimate</u>				
Basic Jobs	883	1,685	1,690	1,690
Local Service Jobs ²	95	385	665	950
TOTAL	978	2,070	2,355	2,640
<u>High Estimate</u>				
Basic Jobs	883	1,685	1,690	1,690
Local Service Jobs ³	95	510	1,040	1,540
TOTAL	978	2,265	2,785	3,385

¹The basic/nonbasic multiplier is assumed to increase from .25 in 1975 to .4 by 1980, .5 by 1985, and .6 by 1990. The ratio is based on the basic employees who will be living in Hanna.

²The multiplier is assumed to increase from .25 in 1975 to .4 by 1980, .55 by 1985, and .65 by 1990.

³The multiplier is assumed to increase from .25 in 1975 to .5 by 1980, .75 by 1985 and 1.0 by 1990.

Table 8. Annual Family Incomes for Hanna, Carbon County, and U.S.

<u>Income</u>	<u>Hanna</u>	<u>Carbon County</u>	<u>U.S.</u>
Less than \$4,000	6.1	14.4	17.6
\$4,000 - 6,999	6.7	20.0	15.4
\$7,000 - 9,999	9.5	27.1	14.6
\$10,000 - 14,999	49.7	27.9	22.6
\$15,000 - 24,999	24.6	8.7	22.1
\$25,000 or greater	3.4	2.0	7.8

ALL VALUES IN %

percent of Carbon County and 52.5 percent for the United States is due to the wages paid by the coal companies. Wages must be sufficiently high to attract workers from outside the area and to compensate them for the living conditions many must endure.

III. SITE SELECTION HISTORY.

When the Hanna project was authorized by the United States Bureau of Mines in 1972, contact was made with Rocky Mountain Energy Company, the minerals subsidiary of Union Pacific Corp. to determine the availability of suitable sites in the Laramie area. The basic site characteristics were a subbituminous coal seam about 20 feet thick at a depth of 400 feet which was isolated from past or proposed mining activities and located near utilities, access roads, and a community for lodging.

Given the criteria, Rocky Mountain Energy Company recommended 3 sites in the Hanna area. The site consisting of the SW $\frac{1}{4}$ of Section 29 (the SE $\frac{1}{4}$ of Section 30 was added in 1976), Township 22N, Range 81W was selected as being the most suitable because it was far closer to existing utility lines, improved roads (U.S. Highway 30), and the town of Hanna. The other two sites contained suitable coal but would have required sizable expenditures to extend power and telephone lines and a year-round access road to the sites. Additionally Rocky Mountain Energy Company did not own the surface rights to the other two sites which could have been a complicating factor in leasing the sites.

The geologic information available for the chosen site consisted of logs from six holes drilled by the Union Pacific in 1929, data from five measured sections at the exposed outcrop of the Hanna No. 1 seam, and an unpublished U.S. Geological Survey map by J.S. Adair. This map (Figure 2) shows an asymmetric syncline plunging to the northeast which is faulted by several northwest-southeast trending faults ranging from 4 to 174 feet in displacement. These faults are, for the most part,

southward projections of faults encountered during underground mining activities north of the site. The drillers logs of the six holes showed clean coal ranging from 12 to 20 feet in thickness in the 30 feet aggregate thickness of the Hanna No. 1 seam. The remaining interval was carbonaceous shale or bony coal.

Based on this information, the site was certainly suitable. The location of the first test was then set in an area within the ring formed by the six previously drilled holes where the depth to the coal could be expected to be about 400 feet.

IV. SITE CHARACTERISTICS.

Three Upper Cretaceous-Tertiary formations deposited during structural evolution of the Hanna Basin are recognized in the region. These include the Upper Cretaceous Medicine Bow, Paleocene Ferris, and Paleocene-Eocene Hanna Formations (Figure 3). Aggregate thickness of these deposits is approximately 21,000 m. Each of these units was deposited in the intermontane subsiding Hanna Basin in continental environments including alluvial fan, lacustrine, fluvial, and swamp settings. Coal beds are common in all three lithologic units and many have been extensively exploited by both underground and strip mining.

The Hanna Formation was named from exposures north and west of Hanna, Wyoming. The formation contains interbedded conglomerate, sandstone, shale, and coal, and ranges in thickness from 2100 m in the Hanna Basin to less than 150 m in the Laramie Basin. The greater thickness of Hanna strata in the Hanna Basin likely reflects more continuous deposition during late Cretaceous through early Eocene time.

Conglomerates are typically comprised of detritus derived from erosion of local highlands, including granite, quartzite, chert, and Mesozoic rock fragments. Massive Hanna conglomerates frequently grade into thick cross-bedded coarse-grained feldspathic sandstones which often form

MODIFIED FROM DOBBIN (1929)

Figure 3. Upper Cretaceous and lower Tertiary stratigraphy of the Hanna Basin.

ledges. Thinner, finer-grained, less-resistant sandstones are also present. Hanna sandstones are usually broadly lenticular. Shale units contain abundant plant remains, freshwater gastropods, bivalves, and ostracodes, and vertebrate bone fragments.

Paleocurrent analysis of Hanna fluvial sandstones reveals that the Granite Mountains to the north provided most detritus during Hanna deposition, with the Freezeout Mountains serving as a less important source. The Medicine Bow Mountains to the south provided little clastic material.

The Hanna Formation at the Hanna UCG site may be grouped into three broad lithologic units (Fig. 4) on the basis of sedimentary structures, grain size, texture, and faunal content. These lithologic variants have been informally designated Units A, B and C with A being oldest.

Unit A:

Unit A is found directly above the Hanna No. 1 coal seam and consists of siltstones and fine-grained sandstones with lesser amounts of claystones. The unit contains numerous coarsening up sequences. The typical sequence starts with claystone at the base and coarsens upward to siltstone and then fine-grained sandstone overlain by claystone of the next sequence. Primary sedimentary structures found in the sandstones and siltstones are ripple drift cross-stratification (often burrowed) and high angle foreset beds (often contorted by slumping). The claystones are finely laminated and often contain bands of siderite. Bioturbation is common through the claystones and some gastropod shells have been found.

Unit B:

This unit consists primarily of olive gray to olive black mudstones and carbonaceous shales. Finely laminated claystones similar to those in

**Lithology
and
Structures**

**Lithologic Units
and Interpretations**

Figure 4. Subdivision of the Overburden of the Hanna No. 1 Coal Bed at the Hanna UCG Site into Three Gross Units.

Unit A are occasionally found. Most of the primary bedding has been destroyed by rooting and there is an abundance of organic partings and occasional coal lenses. Interspersed throughout the finer-grained rocks are isolated fine-grained to very fine-grained sandstone bodies.

The lenticular sandstone bodies show a fining upward trend in grain size from fine-grained to very fine-grained sandstone near the top. There is also a vertical decrease in the size of sedimentary structures from trough cross-bedding to ripple cross-stratification and the upper contacts are gradational with overlying shales. The basal contacts are erosional and usually overlain by clay clast conglomerate.

The very fine-grained sandstone bodies are tabular in cross-section and are rarely over 1.5 m (5 ft.) thick. They display a vertical increase in grain size from muddy siltstone to very fine-grained sandstone. Sedimentary structures are mostly ripple drift cross-stratification with occasional occurrences of trough cross-stratification. The lower contacts are gradational with underlying mudstones and shales. The upper contacts are sharp with the overlying shales and show evidence of rooting.

Unit C:

This unit truncates Unit B and consists of coarse-grained to fine-grained sandstones with conglomeratic beds. Some minor amount of shale is found within the unit. There are numerous thin (.15 to .9m) fining upward sequences bounded by erosional contacts. The predominant sedimentary structures are high angle (up to 25 degrees) planar cross-stratification and rough cross-stratification. The conglomerate beds are composed of quartzite pebbles, clay clasts, and carbonized material in a sandstone matrix.

Interpretations of the environments of deposition for the above lithofacies are given and illustrated in Figure 4. Three basic

depositional environments are evidenced in the overburden: lake, meandering river and flood plain, and braided river.

The Hanna No. 1 coal seam consists of deposits of a poorly drained swamp in the flood plain of a fluvial system. The high ash content of the Hanna No. 1 coal seam suggests a large amount of clastic material that probably came from fluvial sources.

The olive gray, finely laminated claystones interbedded throughout Unit A were probably deposited in a lacustrine environment. This is suggested by the dark highly organic and laminated nature of the claystones and the shells of freshwater molluscs that have been found in some cores.

The climbing ripple-stratified sandstones and siltstones were deposited in a lacustrine delta. As the delta prograded into the lake, sandstones were deposited in high angle foreset beds. Evidently, the delta filling was not continuous because of the interfingering of deltaic sandstones and lacustrine claystones. During periods of rapid deposition from heavy runoff or floods, the ripple drift or climbing ripple stratification was formed. During normal flow, the lacustrine processes and deposition of laminated clays occurred. The interbedding could also have been formed by delta lobe switching.

Unit B was probably deposited by a meandering river and flood plain system following lake infilling and abandonment of the lacustrine delta of Unit A. Quiet water environments would have formed the carbonaceous shales, mudstones, and claystones of Unit B.

The dark olive gray organic mudstones and carbonaceous shales were deposited in poorly drained swamps similar to the formation of the Hanna No. 1 coal seam. Overbank flooding was probably common because of the abundance of clastic materials that occur within the deposits. The lighter colored gray mudstones that occur in Unit B were probably

deposited in well drained swamps that occur along the margins of channel sandstones because most of the organic would have oxidized when drained by the fluvial system.

The claystones identical to those found in Unit A are interpreted as lake deposits. These would have been small lakes associated with the meandering river system.

The lenticular sandstone bodies were probably deposited as point bars in the meandering river system. The point bar deposits are characterized by a vertical sequence of features produced by lateral migration of the bar. First, a basal erosional contact overlain by clay clast lag and fine-grained through cross-bedded sandstones representing deposition in the lower point bar. Second, the lower point bar grades into very fine-grained planar and ripple cross-stratified sandstones representing the upper point bar deposits. Third, the point bars are overlain by rooted siltstones and mudstones of the levee or abandoned channel fill.

The thin, tabular, very fine-grained sandstones (less than 1.5 m) were deposited by crevasse splays that were formed during times of flooding when levees were breached, allowing sediment laden water to invade the floodplain. The combination of rapid sedimentation and slow water currents resulted in the deposition of climbing ripples.

The medium to coarse-grained sandstones and conglomerates of Unit C were deposited in a braided river system. Four distinguishing features indicate a braided river environment: (1) few stratification types, (2) rare ripple cross-lamination, (3) high sand, and (4) thin fining-upward cycles. There is evidence to indicate the presence of transverse bars (thick, fine to medium grained sandstone sequences with high angle planar stratification), longitudinal bars (clast supported conglomerates with crude horizontal bedding), and interbar channels (fining upward trough cross-bedded sandstones containing erosional basal contacts with clay clast lags).

Hutchinson et al performed a multi-well pump test at the Hanna III site prior to gasification. McKee et al further analyzed the data using the Papadopoulos method. An average permeability of 9.2 md. was found with the axis of major permeability lying in a 51° east of north direction. The major and minor transmissivities were found to be 1.16 gpd/ft (17 md. permeability) and .34 gpd/ft (5 md. permeability), respectively.

Both constant rate and fixed volume injection tests were conducted in the fall of 1980 using newly completed and existing wells (Figure 5). Fixed volume (slug) tests were performed on 15 wells (3 in the upper overburden aquifer, 3 in the lower overburden aquifer, and 9 in the Hanna No. 1 Coal aquifer). Three injection tests were performed: one single-well injection test in the coal aquifer with a monitoring well in the upper overburden aquifer, and two two-well injection tests in the coal aquifer.

Fixed volume injection tests are applicable to fully penetrating wells in confined aquifers of low permeability as at Hanna. Such tests can be performed without pumps and provide an estimate of transmissivity at a reasonable expense. However, the storage coefficient determined by this method is of questionable reliability. Injection tests were performed rather than pump tests because of problems in maintaining low pump rates in the low transmissivity coal seam aquifer. Water was injected at constant rates during the injection tests by using a 1-hp stainless steel submersible pump in a stocktank with a stainless steel flow regulator. The regulator is accurate to $\pm 1.5\%$ of setting. Flow was repeatedly checked manually by measuring the time required to fill a five-gallon container. A fiberglass tape with .01 foot increments and an acoustic sounding device were used to measure water level decline during slug tests while pressure transducers (sensitive to changes of 0.01 psi) were used to measure buildup during injection tests. The transducers were connected to a digital switching box. The pressure in each well was obtained by turning the switch to the appropriate transducer and recording the reading. With this arrangement, reliable

Figure 5. Locations of Existing UCG Process Wells and New Hydrology Wells

data could be obtained early in time when buildup changes were rapid. Initial water levels were checked with a fiberglass tape. Since water levels increased rapidly during the early part of the injection tests, pressure readings were initially taken at short intervals. The time between readings increased as the tests progressed. The collected injection data were plotted and analyzed in the field during each test. The preliminary analysis provided the basis for determining the length of each test.

The Theis method was used to analyze buildup data in observation wells of the injection tests. The method of Agarwal et al was used to analyze the injection well data. This method yields a fairly accurate determination of transmissivity by considering well bore storage (due to finite well diameter) and skin effects. Table 9 summarizes the results of all fixed volume and constant rate injection tests performed. In addition, averages and minimum and maximum values are presented for the transmissivities of the three aquifers.

The quarterly collection of water surface elevation data for both new and existing wells commenced in August of 1980. Groundwater flow velocities for each aquifer were obtained using water surface elevation data (March 1981) from selected wells in each aquifer (Table 10) and fitting the elevation data to a plane using a least squares computer program. The average, minimum, and maximum transmissivity values from Table 9 were used, giving three flow velocities for each aquifer.

V. PERMITTING

Upon initiation of the Hanna project in 1972, no requirement for permit acquisition was recognized by the Federal government for its projects. An Environmental Impact Assessment was completed by field personnel for review by headquarters personnel of the U.S. Bureau of Mines. In 1972 the headquarters review resulted in a negative declaration for the Hanna

Table 9. Aquifer Test Results from Hanna UCG Site

<u>SLUG TESTS</u>	<u>Well #</u>	<u>T(gpd/ft)</u>	<u>k(md)</u>	<u>S</u>
Hanna No. 1 Coal Aquifer	CB0142	6.40	16.0	---
	CB0143	0.71	1.4	---
	CB0145	0.57	1.4	---
	CB0146	4.50	9.7	---
	CB0147	0.33	0.8	---
	CB0150	0.28	0.6	---
	CB0152	2.37	5.4	---
	CB0153	0.14	0.4	---
	CB0154	27.50	58.0	---
Lower Overburden Aquifer	OVB135	1.64	3.1	---
	OVB139	0.49	0.6	---
	OVB140	11.99	10.0	---
Upper Overburden Aquifer	OVB136	20.78	8.7	---
	OVB138	18.34	14.0	---
	OVB141	57.02	17.7	---
<u>INJECTION TESTS</u>				
1-well Injection	CB0154	23.40	49.0	---
2-well Injection Observation	CB0142	3.90	9.9	---
	CB0155	19.60	43.9	1.6×10^{-4}
2-well Injection Observation	11A	14.30	31.0	---
	10	6.60	14.3	1.1×10^{-4}
<hr/>				
	<u>Average Trans.</u>	<u>Min. Trans.</u>	<u>Max. Trans.</u>	
	<u>(gpd/ft)</u>	<u>(gpd/ft)</u>	<u>(gpd/ft)</u>	
Coal	7.44	0.14	27.50	
Lower Overburden Aquifer	4.71	0.49	11.99	
Upper Overburden Aquifer	32.04	18.34	57.02	

Table 10. Wells and Water Surface Elevations
Used to Determine Groundwater Flow

	<u>Well</u>	<u>Elevation (ft)</u> *
Hanna No. 1 Coal Aquifer	CB0143	6842.8
	CB0149	6874.4
	CB0152	6902.8
	CB0154	6834.3
	CB0155	6837.0
	CH3	6858.1
Lower Overburden Aquifer	OVB135	6924.3
	OVB139	6891.5
	OVB140	6831.9
Upper Overburden Aquifer	OVB136	6814.6
	OVB137	6823.1
	OVB138	6866.2
	OVB141	6816.7

Groundwater Flow Velocities for Hanna UCG Site Aquifers

	<u>Flow Rate</u> <u>(ft/yr)</u>	<u>Direction</u>
Hanna No. 1 Coal Aquifer	11.90 (Avg.)	N16.59°W
	0.23 (Low)	
	44.10 (High)	
Lower Overburden Aquifer	3.17 (Avg.)	S87.55°E
	0.33 (Low)	
	8.06 (High)	
Upper Overburden Aquifer	1.63 (Avg.)	N3.82°W
	0.93 (Low)	
	2.90 (High)	

* Referenced to Sea Level.

project, i.e., no significant impacts were identified for a project of the scope envisioned.

Until late 1977 the Federal government maintained its position that no permit acquisition was required for federally funded projects. Then an agreement was signed stating that all State permitting requirements must be complied with by all Federal projects -- both existing and new. Because the Hanna project had been in existence for over 5 years at the time, the permits for the project were grandfathered according to agreements reached between the Laramie Energy Technology Center and the Wyoming Department of Environmental Quality (DEQ). The information submitted to the Wyoming DEQ was of a form judged necessary to meet the State's requirements for an R&D License.

The complete file of material submitted to DEQ as part of the permit application is included in the appendix to this report in microfiche form. In addition, the groundwater monitoring data are also included in the appendix for all wells sampled on a quarterly basis. The data are complete through the last quarter for which data were made available to the contractor.

VI. EXECUTIVE SUMMARY

A summary of all the Hanna tests is provided in this section. Additional details are available in the individual reports on each of the field tests.

HANNA I

Hanna I represented the first field test in the reinitiation of United States research on underground coal gasification. Its primary goal was to determine if thick Western subbituminous coal seams offered distinct technical advantages over the thin Eastern seams gasified during the test program at Gorgas, AL, in the 1940's and 1950's.

Hanna I was a distinct success in achieving its objectives. Given the extremely limited budget and the need to use staff from other projects on a temporary basis to get the test up and running, the results obtained augured well for the technology. The results are summarized in Table 11.

HANNA II, PHASE I

Hanna II, Phase I was designed to determine the need to align the well pattern along the major in situ permeability direction, to operate a gasification test over a closer well spacing (52.5 feet), to increase air injection rates to achieve more efficient gasification conditions, and to use downhole instrumentation to monitor the progress of the gasification zone.

The test results were significantly better than those obtained during Hanna I. The first use of an on-site mini-computer allowed real-time display of data for process assessment and control. The results are summarized in Table 12.

HANNA II, PHASES II & III

These two gasification tests represent the most successful in situ coal gasification operations ever in the United States in terms of gas quality and sweep efficiency. They also were highly instrumented yielding for the first time documented information on the growth of the gasification zone versus time.

The two phases consisted of sequential gasification tests between two parallel 2-well pairs at 60 feet spacing. The results substantiated the need to conduct larger tests at commercial well spacings to expedite commercialization and technology transfer. The results are shown in Table 13.

Table 11. Hanna I Results Summary

Test Period	March 1973 - Feb. 1974
Test Duration (Months)	12
Average Injection Rate (MMscfd) *	1.07
Average Production Rate " *	1.60
Average Injection Pressure (Psig) *	35
Average Production Pressure (Psig) *	8
Average Heating Value (Btu/scf) *	126
Thermal Efficiency (%) *	60
Average Dry Gas Composition (Mole %): *	
<u>Component</u>	
H ₂	15.96
CO	6.33
CO ₂	19.22
CH ₄	3.91
N ₂	53.18
Ar	0.76
H ₂ S	0.07
C ₂ - C ₄ 's	0.57
Total Coal Gasified (Tons)	4,000

*For the period 9/16/73 - 2/28/74

Table 12. Hanna II, Phase I Results Summary

Test Period	April - July 1975
Gasification Test Duration (Days)	38
Average Injection Rate (MMscfd)	1.9
Average Production Rate (MMscfd)	2.7
Average Injection Pressure (Psig)	28
Average Production Pressure (Psig)	9
Average Heating Value (Btu/scf)	152
Average Dry Gas Composition (Mole %):	
<u>Component</u>	
H ₂	17.3
CO	14.7
CO ₂	12.4
CH ₄	3.3
N ₂	51.0
Ar	0.6
H ₂ S	0.1
C ₂ - C ₄ 's	0.6
Thermal Efficiency (%)	83
Total Coal Gasified (Tons)	1260

Table 13. Hanna II, Phases II & III Results Summary

	<u>Phase II</u>	<u>Phase III</u>
Test Period	April - May 1976	June - August 1976
Gasification Test Duration (Days)	28	40
Average Injection Rate (MMscfd)	4.4 (5.0 Max)	5.4 (6.5 Max)
Average Production Rate (MMscfd)	7.4 (8.5 Max)	9.2 (12 Max)
Average Injection Pressure (Psig)	72	75
Average Production Pressure (Psig)	33	34
Average Heating Value (Btu/scf)	175	138
Average Dry Gas Composition (Mole %):		
<u>Component</u>		
H ₂	17.19	14.13
CO	15.79	13.32
CO ₂	12.12	14.17
CH ₄	5.40	3.73
N ₂	48.33	53.47
Ar	0.53	0.60
H ₂ S	0.10	0.10
C ₂ - C ₄ 's	0.56	0.48
Thermal Efficiency (%)	89	76
Total Coal Gasified (Tons)	2520	4200

HANNA III

The primary purpose of Hanna III was to provide a field test devoted to determining the impacts of underground coal gasification on groundwater quality which is the major environmental concern associated with the process. Additionally, the test was utilized to assess process control techniques and to obtain additional data for improvement of a predictive process mathematical model.

The test provides the only data on the effects of too little groundwater influx thus providing too little hydrogen for the gasification reaction and for temperature modification. Groundwater monitoring is still ongoing. The results are summarized in Table 14.

HANNA IVA AND IVB

Hanna IV was the first test incorporating commercial well spacings (100 and 150 feet) to obtain design data for technology development. The data to be obtained were intended to serve as the design basis for a follow on pilot plant.

The test was conducted in two phases due to the occurrence of faulting through the well pattern causing operational difficulties which were not successfully remedied. The results of the two operations are summarized in Table 15.

Table 14. Hanna III Results Summary

Test Period	June - July 1977
Gasification Test Duration (Days)	39
Average Injection Rate (MMscfd)	4.0
Average Production Rate (MMscfd)	6.5
Average Injection Pressure (Psig)	48
Average Production Pressure (Psig)	26
Average Heating Value (Btu/scf)	138
Average Dry Gas Composition (Mole %):	
<u>Component</u>	
H ₂	13.47
CO	15.16
CO ₂	13.79
CH ₄	3.51
N ₂	52.90
Ar	0.59
H ₂ S	0.10
C ₂ - C ₄ 's	
Thermal Efficiency (%)	76
Total Coal Gasified (Tons)	2850

Table 15. Hanna IVA and IVB Results Summary

	<u>Hanna IVA</u>	<u>Hanna IVB</u>
Test Period	Jan. - June 1978	April - Sept. 1979
Gasification Test Duration (Days)	52	25
Average Injection Rate (MMscfd)	4.0	2.3
Average Production Rate (MMscfd)	6.2	3.8
Average Injection Pressure (Psig)	80	94
Average Production Pressure (Psig)	68	57
Average Heating Value (Btu/scf)	105	135
Average Dry Gas Composition (Mole %):		
	<u>Component</u>	
	H ₂	11.75 16.27
	CO	9.29 10.27
	CO ₂	15.71 15.63
	CH ₄	2.96 4.18
	N ₂	59.22 52.52
	Ar	0.73 0.59
	H ₂ S	- -
	C ₂ - C ₄ 's	0.25 0.39
Thermal Efficiency(%)	75	89
Total Coal Gasified (Tons)	3470	1120