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EVALUATING THE STATUS OF THE TEXACO GASIFIER

By
Harry Perry

Work Performed Under Contract No. AC22-80ET16056

Resources for the Future
Washington, D. C.

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The Texaco Gasifier - DOE Experience

I. Introduction

A. Status of Commercial Coal Gasification Processes

Improved methods for the gasification of coal to produce a synthesis gas or hydrogen on a continuous basis were developed during the decades of 1920 and 1930. The first commercial Winkler fluidized bed process was constructed in 1926 in Germany. By 1976, 36 Winkler gasifiers had been in operation at 16 different locations throughout the world. Six Winkler gasifiers are still in operation in different countries and are used to produce synthesis gas from coal for ammonia production.

The first fixed bed pressurized gasifier using steam and oxygen was constructed by Lurgi Kohle in 1936. A total of 65 gasifiers have been installed at 16 different locations with the largest installation being at Sasolburg, South Africa. Experimental work is continuing on Lurgi gasifiers at Westfield in Scotland and Lurgi units are still in operation in Yugoslavia and Czechoslovakia. An experimental gasifier to investigate operation at higher pressures (1500 psig compared to 450 psig) has been under test at Dorsten, FRG.

The first commercial entrained gasifier was constructed in 1952 by Koppers Totzek. This gasifier used a steam-oxygen feed with pulverized coal and operated at atmospheric pressure. Forty-nine entrained gasifiers have been constructed in 14 countries with most of the product gas being used for ammonia production.

Other types of commercial coal gasifiers have been placed in operation but they have been either much smaller or have not been as widely used as those described above. None of the large improved gasifiers have been constructed in the United States.

B. Advanced Gasifier Concepts

With the renewed interest in synthetic fuels that followed the successful production and use by the Germans of synthetic fuels produced from coal during World War II, a large number of attempts were made to further improve commercial gasification processes. The incentives for this activity were to improve process efficiency, increase feedstock flexibility and, more importantly, to reduce product costs. New processes using all three methods of contacting solids and gases (fluidized, fixed and entrained beds) were proposed and a number of laboratory and pilot plants using new processes were constructed and tested. Many of these processes have now been abandoned but a large number are still at some stage of development. Table 1 lists some of these gasification processes, their major characteristics and their current stage of development.

For most uses (medium Btu gas, synthesis gas as a chemical feedstock or for indirect liquefaction, generation of hydrogen for direct liquefaction of coal) it is advantageous to be able to operate continuously at high pressures and produce a product gas high in carbon monoxide and hydrogen. Other desirable process features are feedstock flexibility, high carbon conversion, absence of environmentally troublesome by-products, inherent safety characteristics and an

Table 1. Gasification Systems under Development.

<u>Gasifier Type</u>	<u>Scale (TPN)</u>	<u>Startup date</u>	<u>Characteristics</u>
Fixed Bed			
BGC Lurgi	10	1977	Slagging, pressurized oxygen blown
High Pressure Lurgi	6	1978	High pressure, oxygen blown
Fluid Bed			
High Temperature Winkler	1	1979	Pressurized, oxygen blown
Westinghouse	0.6	1975	Pressurized, air or oxygen blown
U-Gas	0.8	1974	Low pressure-oxygen blown
Hygas	3.0	1973	Pressurized-3 stage
Cogas	2.0	1973	Low pressure-oxygen blown
Exxon Catalytic	0.05	1979	Pressurized, catalytic
Entrained Bed			
Shell Koppers	0.3	1979	Pressurized, oxygen blown
Bigas	5.0	1976	Pressurized, 2 stage oxygen blown
Combustion Engineering	5.0	1977	Atmospheric air and oxygen blown
Texaco* (PDU)	0.6	1948	Pressurized, oxygen blown
Molten Media			
Saarburg-Otto	11.0	1979	Pressurized, air or oxygen blown
Rockwell-Molten Salt	1.0	1978	Pressurized, air blown

*Two 6 tons/hour plants are currently in existence--one at Ruhrchemie in Germany and one at TVA in the U.S. A third is being tested by Dow Chemical Company but no results are available.

advanced state of development. Pressurized entrained gasifiers have all of these desirable features. In addition, the Texaco pressurized entrained process has been used extensively in commercial operations using both gaseous and liquid feedstocks.

II. Texaco Process History

A. Natural Gas Reforming and Oil Gasification

The Texaco synthesis gas process was originally designed to produce synthesis gas from natural gas. The development work on this process started in 1945 and resulted in construction of a commercial plant by 1953. The process was then modified to handle light liquid hydrocarbons (naphtha), oil and, in recent years, vacuum residues including asphalts. A total of 76 plants located in 22 countries are now in operation using fossil fuel feedstocks other than coal. The most recently installed plants can produce more than 100 million scfd in a single train. If coal were the feedstock for a train of this size, the coal feed rate would be about 1500 tons per day.

B. Coal Gasification

In the late 1940's and early 1950's there was great interest worldwide in developing improved coal gasification processes and Texaco undertook extensive process development work at Montebello, California to adapt the high pressure Texaco natural gas and oil gasification process to the gasification of coal. This development culminated in the construction in 1956 of a 100 ton/day coal demonstration plant at the ordnance works located at Morgantown, West

Virginia. Two years of operation at this facility provided a great deal of data on the process. With the wide availability of natural gas, transported by pipeline over long distances, that occurred in the 1950's, interest in production of synthesis gas from coal declined. Interest in the process was reawakened in the late 1960's when it appeared there would be a surplus of petroleum coke and a process based on this feedstock was developed. The current energy crisis that started in 1973 has resulted in a concerted effort to adapt the Texaco process to the gasification of a wide range of coals as feedstocks for production of fuel gas, synthesis gas and hydrogen.

Tests on a pilot plant scale Texaco gasifier (15 tons/day) have been conducted at Montebello, California for a number of years. Currently there are two gasifiers of this size operating at Montebello at pressures ranging from 300 to 1200 psi. A demonstration scale pilot plant with a capacity of 150 tons/day has been operating intermittently since 1978 at Oberhausen-Holtien, West Germany. TVA has installed a 150 tons/day gasifier at its Muscle Shoals, Alabama ammonia plant and initial tests were conducted on the gasifier in the Fall of 1980.

In addition, Dow Chemical Company has a 150 ton/day demonstration plant in operation at its chemical plant in Plaquemine, Louisiana for use in powering a 15 MW gas turbine generator. No details have been released on the results of the first tests at this plant that were run in early 1981.

Two large scale projects using the Texaco coal gasification process have been proposed by W. R. Grace. The first involved the gasification of 2000 tons/day of coal to produce synthesis gas that would then be converted to 1200 tons/day of ammonia. A contract to undertake a conceptual design of a commercial plant plus a preliminary design of a demonstration plant as Phase I of this project was let in August 1977. The second project proposed to DOE in 1980 revamped the original proposal. The proposal outlined a Phase I design effort for a commercial coal to gasoline plant to be constructed at the same site as the previously proposed ammonia project. This proposal called for the processing of 29,000 tons/day of high sulfur coal to produce 16,000 tons of methanol that would be chemically converted into 50,000 barrels of gasoline per day using Mobil "M" technology.

In another project, Texaco and Southern California Edison Company jointly announced their intention to utilize the Texaco gasifier in a major demonstration project (1000 tons/day) using a coal gasification combined cycle for the generation of electricity. The Electric Power Research Institute, Bechtel and General Electric Company have joined the consortium and Pacific Gas and Electric Company has applied for approval from the California PUC to support the project.

The facility will be located at the Cool Water electric generating station of Southern California Edison Co. at Daggett, California. The Texaco gasifier would operate at 600 psi and the intermediate Btu product gas after clean up, will be burned in a combustor and expanded in a gas turbine to drive an electric generator. The hot exhaust gases from the turbine will be used to raise superheated steam that will be supplied to a steam turbine to drive another electric generator.

The Texaco gasifier was a prominent technology proposed by industry in response to the RFP solicitation under the Feasibility and Cooperative Agreement sections of both the first and second solicitations of the Department of Energy's Alternate Fuels Program, Public Law 96-126. In the first round, proposals using the Texaco process received two awards, each for over three million dollars. One of these awards was for a feasibility study of a plant capable of producing 25,000 barrels/day of methanol from 6000 tons of coal fed to the coal gasification plant. The other award was for a feasibility study of a coal gasification plant to be used in a combined cycle for the generation of electricity. In the second round of DOE solicitations, three feasibility proposals were submitted using Texaco gasification technology.

Interest in the Texaco gasification technology continues to be high as evidenced by requests for financial assistance in the 61 projects proposed to the Synthetic Fuels Corporation. The Texaco gasifier was one of the three most frequently proposed gasification technologies intended for use, with about 10 of the larger and more serious proposals indicating an interest in the Texaco gasifier.

III. Texaco Coal Gasification Process Description

The Texaco coal gasifier is basically an oxygen blown pressurized entrained flow gasifier characterized by low residence time and a water slurry feed. It is essentially a noncatalytic process involving the reaction of hydrocarbonaceous materials with oxygen and steam at high temperatures and pressure under conditions of

insufficient oxygen for complete combustion. The rapid flame-type reactions that take place with this deficiency of oxygen produce a gaseous product consisting primarily of hydrogen and carbon monoxide with lesser amounts of water vapor, carbon dioxide, hydrogen sulfide, methane, and nitrogen.

Since the temperatures are high enough to produce a slagging mode of operation, no tars, phenols, or other byproducts are formed. However, the temperature must be limited to that which the refractory-lined vessels can withstand.

The process can be operated in two basic modes: (1) direct quench with internal steam generation, and (2) gas cooler with external steam generation. The end use of the syngas determines the mode of operation and the type of downstream processing.

The direct quench mode, shown in Figure 1, is generally selected for such end uses as the production of high purity hydrogen and ammonia where it is necessary to shift the carbon monoxide using an excess of steam. The coal is ground and mixed with water to form a pumpable slurry which is fed to a specially designed burner together with the oxidant, generally high purity oxygen. The gasifier reactor consists of a steel vessel lined with refractory but containing no internal moving parts. The carbon conversion is primarily controlled by the amount of oxygen fed to the system and generally is maintained above 90 percent. The hot gas and molten slag leaving the combustion chamber are contacted with water, solidifying the slag and saturating the raw synthesis gas with steam. The solidified slag, which normally has a carbon content below 1 percent (weight), is removed through a series

of lockhoppers and taken away for disposal. The steam saturated synthesis gas still contains small amounts of particulate matter which must be removed by a final water scrubbing before the raw synthesis gas leaves the battery limits.

The various water streams containing the ash and soot removed from the synthesis gas are sent to a settler where the resulting clarified water is recovered for recycle. The settler bottoms, containing ash with significant amounts of carbon, can be discarded or recycled back to the gasifier by blending it in with the coal slurry.

The gas cooler mode of operation, shown in Figure 2, is similar in most respects to the direct quench mode except that the raw synthesis gas, after separation from the molten slag, is sent to a gas cooler where steam suitable for other processing uses is produced. The gas cooler option is generally used when there is no need for steam in the synthesis gas, such as the production of clean fuels.

Downstream gas clean up processes can be varied depending on the end use of the gas. Generally the treatment consists of particulate and acid gas removal.

IV. Texaco Gasifier Test Results

A. Published Data on Texaco Coal Gasification

According to published information¹, Texaco, Inc. has tested the following Western coals: Utah bituminous coal, Lake DeSmet

¹Texaco Coal Gasification Process; H.C. Kaufman, Staff Coordinator, Alternate Energy Dept., Texaco, Inc., Presented at Cool Water Coal Gasification Seminar, Chicago, Ill., Sept. 10, 1980.

Figure 1. TEXACO COAL GASIFICATION PROCESS DIRECT-QUENCH MODE

Figure 2. TEXACO COAL GASIFICATION PROCESS - GAS-COOLER MODE

coal, North Dakota lignites and coals from the Belle Ayr, Black Mesa and Kaiparowits mines. In addition, the following Eastern coals have been tested: Kentucky #9 (4 mines), Illinois #6 (3 mines), Girondelle (Ruhr coal) and Texas lignites. Residues from SRC-I, SRC-II, H coal and the Exxon Donor solvent direct liquefaction processes also have been gasified as well as a variety of types of cokes.

The chemical properties and heat of combustion of the various pilot unit gasifier feedstocks are shown in Table 2.² The carbon content has ranged from 64 percent to nearly 90 percent and the ash content from less than 0.5 percent to nearly 28 percent. Table 3 shows the typical gasification performance for these coals when tested in the Texaco pilot plant.³ Table 4 shows the coal types that have been tested at Oberhausen-Holtent⁴ and Table 5 shows the status of the test results obtained at the demonstration plant as of the end of August 1980.⁵ Except for operating pressure and particle size distribution of the slurry, the test results have exceeded design specifications.

²Texaco Coal Gasification Technology, W. Raymond Siegart, Texaco, Conference on Synthetic Fuels: Status and Directions, San Francisco, Oct. 13-16, 1980. EPRI and Kernforschungslage, Jülich.

³Coal Gasification: for Hydrogen Manufacture, W. G. Schlingen, et al, for presentation at Joint American Chemical Society and Chemical Society of Japan Chemical Congress. April 1-6, 1979, Honolulu, Hawaii.

⁴RCH/RAG;s Version of Texaco Coal Gasification: Hydrocarbon Processing, Jan. 1981, p. 149.

⁵Raw Materials and Energy Through Coal Gasification: The Ruhrchemie/Ruhrkohle Demonstration Plant for Texaco Coal Gasification; B. Cornils, et al., Brennst-Wärme-Kraft Vol. 32, no. 10, p. 468-471, Oct. 1980.

Table 2. Properties of Pilot Unit Gasifier Feed Stocks

Weight Percent	Western Bituminous Coal	Delayed Petroleum Coke	Eastern Bituminous Coal	SRC-II Vac-Tower Residue
C	74.5	89.5	67.6	63.7
H	5.3	3.7	5.2	3.6
S	0.5	1.4	3.3	2.9
N	1.0	2.7	1.0	1.2
O	11.5	2.4	11.1	0.8
Ash	7.2	0.3	11.8	27.8
Heat Of Combustion, HHV BTU/LB Dry	12,500	14,950	12,270	11,250

Table 3. Typical Gasification Performance Summaries

<u>Feedstock</u>	<u>Western Bituminous Coal</u>	<u>Delayed Petroleum Coke</u>	<u>Eastern Bituminous Coal</u>	<u>SRC-II Vac. Tower Residue</u>
Oxidant	Oxygen	Oxygen	Oxygen	Oxygen
Slurry Medium or Moderator	Water	Water	Water	Steam
Product Gas composition, Volume Percent Dry Basis				
H ₂	35.8	34.5	35.8	34.0
CO	50.7	45.2	44.6	59.5
CO ₂	13.1	19.4	18.0	5.3
N ₂ - A	0.2	0.7	0.5	0.6
CH ₄	0.1	-	-	0.1
H ₂ O	0.1	0.2	1.0	0.5
COS	-	-	0.1	-

Table 4. Composition of Coals Tested at Oberhausen-Holten

Type	Low Volatile Bituminous Coal	High Volatile Bituminous Coal	Low Volatile Bituminous Coal	Coal Sludge*
No. Mine	1 Friedr. Heinrich Sean Girondelle V	2 Lehberg	3 Friedr. Heinrich	4,5 Prosper
Composition, % wt **				
C	85.4	80.8	81.9	60.0
H	4.0	5.0	4.7	3.8
N	1.6	1.5	1.5	1.1
S	0.8	1.1	1.1	1.4
O	2.6	5.1	4.0	5.8
Ash	5.6	6.5	6.8	27.9
Volatiles	16.0	32.1	21.7	24.2
Water content, %	ca. 8	ca. 8	ca. 8	40-55
Grain size	100% < 10 mm	ca. 8% > 10 mm	100% < 10 mm	7-35% > 315 μ m

* Typical value

** Water free

Table 5. Current (8-31-80) Test Results at Ruhrchemie/Ruhrkohle

		Results	
		according to design	current status
Temperature	(°C)	up to 1500	1350-1550
Pressure	(bar)	40	35
Coal throughput	(t/h)	6.0	2.5-6.9
Quantity of gas	(m_N^3/h)	10,000	13,000
Slurry concentration	(%)	55-60	≤ 70
Grain size distribution in slurry	(%>90 microns)	100	14-60
Amount of tested coals		-	5
ash content	(%)	-	6-30
content on volatiles	(%)	-	16-32
Total operating period	(h)	-	approx. 6500
Total amount of coal	(t)	-	approx. 36000
Total gas amount	(mio m_N^3)	-	approx. 60
Gas Composition	(Vol.%)		
CO		45-55	55
H ₂		30-40	33
CO ₂		15-20	11
CH ₄		approx.1	0.01
H ₂ S/COS			0.3
N ₂			0.6
C-Conversion (single pass)	(%)	95	> 98
Gasification efficiency			
(cold gas)	(%)	70	74
(thermal)	(%)		92

The Electric Power Research Institute (EPRI) has supported a series of tests at the Taxaco pilot plant at Montebello, California, using U.S. coals, in connection with their proposed 100 MW coal gasification combined cycle plant to be constructed at the Cool Water station of the Southern California Edison Company. The first scoping test⁶ was run in the fall of 1978 and two subsequent runs were made in the summer of 1979 using Illinois No. 6 coal. One run used pure oxygen while the second used enriched air. These studies indicated that the gasifier responded nearly instantaneously to load changes and that the product gas composition remained essentially unchanged during transients.

EPRI had a series of tests conducted on the same Illinois coal at the 150 tons/day Texaco gasifier in October of 1980 at Oberhausen-Holten.⁷ The process units evaluated during this large scale test were slurry preparation, gasification, heat recovery, particulate scrubbing and water recycle. Forty-four hundred tons of Illinois #6 coal were gasified while environmental data were gathered and dynamic experiments were conducted under a variety of operating conditions.

⁶Coal Gasification Pilot Plants, EPRI Journal, October 1980, p. 37.

⁷To be published in the EPRI Journal.

Steady state system performance was consistent and predictable. Table 6 compares typical test results from Montebello and Oberhausen. Any differences in performance figures can be attributed to differences in the heating value of the coal and in the slurry concentration. Since the Montebello pilot plant has no heat recovery system, the overall thermal efficiency is lower than at Oberhausen. General process performance at Oberhausen was as expected, after allowing for the smaller scale of the Montebello tests.

B. DOE Data on Texaco Gasification of Residuals from Coal Liquefaction

1. Introduction

Almost all direct coal liquefaction processes, which are being developed to reduce U.S. dependence on oil imports, require either hydrogen or synthesis gas (a mixture of hydrogen and carbon monoxide) as a raw material in the conversion of the coal to oil. To obtain the most favorable product yield for such processes it is desirable to produce the needed hydrogen or synthesis gas from the residuals left from the liquefaction step. These residuals, which contain the inorganic ash and a fraction of the unconverted coal, make excellent feedstocks for gasification.

The Texaco gasifier was used to perform a series of tests to determine the gasification characteristics of the residuals from three processes being studied by DOE for the direct hydrogenation of coal. Most of these residuals were materials similar to those being used in

Table 6. EPRI Test Results on Illinois #6 Coal

	<u>Montebello</u>	<u>Oberhausen</u>	
Coal feed rate (dry short tons/hr)	0.7	7	5
Coal heating value (Btu/lb dry coal)	11600	12400	12400
Slurry concentration (wt. % solids)	60	59	57
O ₂ /coal ratio (lb/lb dry coal)	.93	.93	1.03
Carbon conversion (%)	99.	95	98
Cold gas efficiency ¹ (%)	68	67	65
Overall thermal efficiency (%)	68	82	84
Raw gas composition (Vol. %)			
CO	42.2	41.2	39.8
H ₂	34.4	36.5	35.1
CO ₂	21.7	20.7	23.6
H ₂ S + COS	1.3	1.1	1.1
N ₂	.4	.5	.4

1/ HHV of clean product gas/HHV of coal feed

commercial plants that use the Texaco partial oxidation system to process heavy oil feedstocks. The major difference between the coal residuals and the heavy oil feedstocks is the much higher ash content of the residual materials.

The tests on the feedstocks were conducted at the Montebello Research Laboratory of Texaco, Incorporated. Four types of tests were performed. These include the following:

Test type of level	Description	Max. sample size	Min. no. of samples	Max. no. of samples
I	Laboratory Evaluation	20 bbls	4	25
II	Preliminary Pilot Plant Evaluation	20 bbls	0	8
III	Extended Pilot Plant Evaluation	200 bbls	0	8
IV	Sustained Pilot Plant Demonstration	300 bbls	0	4

The detailed description of the various types of pilot plant tests are outlined in Appendix A. Appendix B is a description of the Montebello Research Laboratory pilot plant.

The residues that have been tested using a level I test are shown in Table 7.⁸ From this table it is clear that the residuals of

⁸Gasification of Coal Liquefaction Residues, Allen M. Robin and Warren G. Schlinger, Texaco, Inc. The 13th Intersociety Energy Conversion Engineering Conference, Society of Automotive Engineers, 1978.

TABLE 7

**Coal Liquefaction Residues
Laboratory Evaluations Completed**

Process	H-Coal Vac. Twr. Btms.	H-Coal Vac. Twr. Btms.	H-Coal Vac. Twr. Btms.	H-Coal Settlr. Undrflw.	Synthoil Centrfg. Undrflw.	Synthoil Centrfg. Undrflw.	USS Cln.Ck. Stripper Btms.	SRC-I KerrMcGee Ash Cons.	SRC-I Filter Cake	SRC-I High Ash SRC-I	SRC-II Vac. Twr. Btms.	Exxon-EDS Vac. Twr. Btms.
Sample	1	2	3	4	5	6	7	8	9	10	11	12
Parent Coal	Ill.6	Ill.6	Wyodak	Ill.6	Ky	Ky	Ill.6	Ill.6	Ky	Ky	Ky	Ill.6
State At Ambient T	Solid	Solid	Solid	Solid	Slurry	Slurry	Semi Solid	Solid	Solid	Solid	Solid	Solid
Estimate Feed Temp, Reqd, °C	205	250	260	*	100	Ambient	80	*	*	260	290	295
Ultimate Analysis												
XC	69.73	63.99	78.06	61.38	56.19	65.24	77.35	48.44	37.00	77.56	64.90	70.74
XH	5.21	4.28	5.32	4.84	5.09	5.94	5.29	2.85	2.55	5.28	3.65	4.67
XN	0.81	1.13	0.93	0.84	0.62	0.70	0.75	1.35	0.41	1.36	1.25	1.18
XS	1.38	2.23	0.05	1.64	5.08	3.72	1.19	6.40	4.89	2.00	2.96	2.74
XAsh	19.96	25.79	10.86	28.98	32.83	22.89	12.97	40.96	53.04	10.66	25.54	16.72
XO (By Diff)	2.91	2.58	4.78	1.32	0.19	1.51	2.45	0.00	2.11	3.14	1.70	3.95
Gross Heating Value, cal/gm	7,330	6,520	7,720	6,180	6,400	7,340	7,990	5,000	3,670	7,780	6,280	7,240
Melting Range, °C		105-180		N/A	N/A	N/A	50-65	N/A	N/A	160-225	175-190	180-220

* Must be fed as a water slurry

all the direct coal hydrogenation processes that are being seriously considered for use at this time have been tested for their amenability to the production of hydrogen by partial oxidation using the Texaco process. This includes residuals from H coal, SRC-II, Exxon Donor Solvent, and several types of SRC-I residues, as well as from Synthoil and USS Clean Coke.

On the basis of these laboratory tests it was determined that all of the tested residuals were suitable for use in a commercial plant using the Texaco gasifier although three of the residuals had to be fed as a slurry instead of as a liquid.

Tests at Levels II, III and IV were performed on residual materials that appeared to warrant further investigation. These included short pilot plant tests (Type II) on H-coal syncrude bottoms (Ill. #6), SRC-II vacuum flash drum bottoms (Ky. #9/14), Exxon Donor Solvent vacuum tower bottoms (Ill. #6), and SRC-II vacuum flash drum bottoms (Powhatan II). A total of six Type II tests were run on these residuals.

A number of Type III tests were also made and typical results of four such coals are shown in Table 8.⁹ In two tests, H-coal

⁹Gasification of Coal Liquefaction Residues, Allen M. Robin and Warren G. Schlinger, Texaco, Inc. The 13th Intersociety Energy Conversion Engineering Conference, Society of Automotive Engineers, 1978.

TABLE 8

Gasification of Coal Liquefaction Residues
Extended Pilot Plant Evaluations
Completed at 24 Bars Pressure
Typical Material Balances

Coal Liquefaction Process Residue	H-Coal Vat. Tvr. Btms Ill, No, 6	H-Coal Vac. Tvr. Btms Wyodak	SRC-1 High Ash SRC-1 Ky	SRC-1 Filter Cake Ky
Parent Coal				
Number of Runs Completed	11	7	7	3
Total on Stream Time, Hrs.	128	74	67	17
Total Residue Gasified, Metric Tons	39	30	22	10
Avg. Run Length, Hrs.	12	11	10	6
Typical Material Balance*				
<u>INPUT</u>				
**Fuel Rate, kg/hr	296	314	315	591
Steam Rate, kg/hr	92	90	94	240*
Oxygen Rate, kg/hr	<u>240</u>	<u>269</u>	<u>276</u>	<u>376</u>
Total Input, kg/hr	628	673	685	1207
<u>*OUTPUT</u>				
Dry Product Syngas, kg/hr	535	615	621	687
Char, kg/hr	11	5	7	5
Coarse Slag, kg/hr	44	11	14	244
Fine Slag, kg/hr	4	20	13	63
Forced Water, kg/hr	<u>34</u>	<u>22</u>	<u>30</u>	<u>208</u>
Total Output, kg/hr	628	678	685	1207
<u>ANALYTICAL</u>				
Process Fuel Analysis, Wt. Pct.				
C	71.2	78.1	78.1	38.6
H	5.4	5.5	5.4	2.5
N	0.8	0.9	1.3	0.5
S	1.7	0.1	1.9	5.2
Ash	18.5	10.8	9.8	52.0
O (By Diff)	2.4	4.6	3.5	1.2
Product Gas Analysis, Vol. Pct.				
H ₂	39.33	37.91	37.03	31.06
CO	54.68	57.68	58.27	40.65
CO ₂	5.52	4.30	4.01	25.62
H ₂	0.11	0.03	0.44	0.36
H ₂ S	0.24	0.00	0.10	1.85
COS	0.02	0.00	0.04	0.13
*CH ₄	0.08	0.06	0.00	0.00
A	0.02	0.02	0.08	0.11
Carbon on Coarse Slag, Wt. Pct.	<0.5	<0.5	<0.5	<0.5
Carbon on Fine Slag, Wt. Pct.	16.3	5.2	8.6	3.1
Carbon on Char, Wt. Pct.	27.9	19.2	15.5	9.3
Percent Carbon Conversion	98.3	99.2	99.1	99.0

* All major elements plus ash are forced to yield 100 percent recoveries

** Residue plus 2 percent purge solvent

* Water rate in 71% Slurry

vacuum bottoms were used as feedstock; one of these bottom residues resulted from operation on a Ill. #6 coal and the second came from a Wyadak coal. Two tests were performed with SRC residues--one from a high ash SRC-I material and one from the filter coke. Both were residues from a Kentucky coal.

A type IV long sustained run utilizing SRC-II vacuum flash drum bottoms made from Powhatan coal was also conducted.

The results acquired during laboratory tests (Type I) on these residues were confirmed by the preliminary, extended and sustained pilot plants runs (for those coals that were tested in these modes) with respect to process variables and product quantity and quality. Long-term tests using different operating parameters under actual commercial design conditions are still needed to confirm the results.

The operating results for various residuals tested depends to some extent on their composition--ash content and chemical composition--but the variations in process parameters could be predicted within a narrow range. For example, with a residual from H-coal syncrude vacuum tower bottoms, containing approximately 25 percent ash and with a higher heating value of about 11,900 Btu per pound, the feed requirements at a gasification pressure of 350 psig were estimated to be

O ₂ /residual	pounds/pound	0.7
Steam/residual	pounds/pound	0.3

Under these conditions the product yields were calculated as:

	<u>mole %</u>
Carbon monoxide	53
Hydrogen	34
Carbon dioxide	5
Water	7
Other	1
Heating value of gas (approx)	280 Btu/cu ft
Dry Product Gas	32.2 cu ft/lb
H ₂ + CO	30.0 cu ft/lb
Unconverted Carbon	1%

Comparative estimated data for other types of residuals are shown in Table 9. Although these data are only estimates of what the results of the Texaco gasifier operation would be, actual preliminary and extended pilot plant data (Test Types II and III) have confirmed that these estimates are well within the limits of feedstock requirements and product quality and quantity actually obtained in the pilot plant runs. A typical comparison between the estimate of performance and actual data during an extended run is shown in Table 10. As the data indicate the estimated results are very close to that actually obtained in the pilot plant experiments.

Studies also were made to compare the results obtained during gasification tests of residual materials produced from different coal seams but by the same direct liquefaction process. The data from these two gasification runs are shown in Table 11. The results

Table 9. Estimate of Operation for Texaco Gasifier With Various Coal Liquefaction Residues

	H-Coal	SRC-II	EDS	Kerr-McGee
Coal ash - percent	25	25	16.7	41
O ₂ / residue lb/lb	0.71	0.77	0.79	0.84
Steam/residue lb/lb	0.3	0.3	0.5	0.8
Heating value of residue, Btu/lb	11,900	11,300	13,000	9,000
Operating pressure psi	350	350	350	350
Product Composition mole %				
CO	53	53	45	20
H ₂	34	31	34	19
CO ₂	5	7	7	20
H ₂ O	7	7	12	38
Other	1	2	2	2
Heating value of gas Btu/Scf	260	250	240	120
Dry product gas cu.ft/lb residue	32.2	31.2	36.7	23.3
H ₂ + CO cu.ft/lb residue	30.0	28.5	33.0	14.9
Unconverted carbon %	1	1	1	1

Table 10. Comparison of Estimated Operation and Pilot Plant Data for Molten SRC-II Vacuum Flash Drum Bottoms (Ky. 9 and 14 Coal Seams)

Feed Rate, pounds per hour	Estimated	Actual	1000 cu ft per pd of feed
	1000	1048 (+2%, solvent)	
Ultimate Analysis			
C	64.90	63.7	
H	3.65	3.6	
N	1.25	1.2	
S	2.96	2.9	
O	1.70	0.8	
Ash	25.54	27.8	
Higher Heating Value Btu/pound	11,301	11,250	
Pure O ₂ , pounds per hour	770	764	749
Steam, pounds per hour	300	297	290
Product Composition			
CO	53.5	59.5	
H ₂	31.0	34.0	
CO ₂	6.7	5.3	
H ₂ O	7.2	-	
Other	1.6	0.7	
Dry Product gas SCFH	31,200	31,800	30,962
H ₂ + CO SCFH	28,500	29,880	27,750
Unconverted carbon-% of carbon in feed	1	1.9	
Gasifier pressure psi	350	350	

Table 11. Comparison of Pilot Plant Data from SRC-II Vacuum Flash Bottoms from Ky. 9 and 14 Coal Seams and Powhatan Coal Seam

	Ky. 9 & 14	Powhatan
Feed Rate, pounds per hour	1048	1006
Ultimate Analysis	(+2%, solvent)	(+5%, solvent)
C	63.7	66.7
H	3.6	3.5
N	1.2	1.5
S	2.9	2.7
O	0.8	0.0
Ash	27.8	25.6
Higher heating value, Btu/pound	11,250	11,898
Pure O ₂ , pounds per hour	764	742
Steam, pounds per hour	297	397
Product Composition		
CO	59.5	53.5
H ₂	34.0	37.0
CO ₂	5.3	8.4
H ₂ O	-	-
Other	0.7	1.1
Dry product gas SCFH	31,880	33,550
H ₂ + CO SCFH	29,800	30,360
Unconverted carbon - % of carbon feed	1.9	0.3
Gasifier pressure, psig	350	350

of these tests of residuals from different coal seams give very similar oxygen and steam requirements and similar product quality and quantities.

C. DOE Data on Texaco Gasification of Coals to be used in the W. R. Grace Process

The W. R. Grace Company entered into contract with DOE for the design of a demonstration plant to produce about 1000 tons of ammonia per day using coal as the feedstock. Synthesis gas required would be produced by the gasification of coal in an entrained Texaco gasifier. Trade-off studies indicated that the gasifier should be operated at the highest pressure that the Texaco process could handle --1200 psi.

In order to determine if the coals selected for use could be successfully gasified in the Texaco gasifier, a series of tests were made in the Texaco Montebello pilot plant on coals which might be used in the demonstration plant. The major elements of these confirmation studies were to:

1. Make laboratory analysis and slurry tests of each coal to determine initial pilot plant operating conditions.
2. Establish a series of runs with varying operating conditions to establish the basis for a sustained run.
3. Demonstrate the sustained 14-30 day gasification of the design coal at 1200 psi.
4. Provide necessary design and data base for the Demonstration plant.

5. Develop necessary confirmation data to improve gasifier operations.

6. Provide mechanical configuration of gasifier.

Six West Kentucky coals were tested in a Type I test (see Appendix A). These were:

Providence No. 1 Mine of Island Creek Coal Company
 Ziegler No. 9 Mine of Ziegler Coal Company
 Colonial No. 9 Mine of Pittsburgh Midway Coal Company
 Hamilton No. 1 Island Creek Coal Company
 Mapco Doriki
 Drake No. 16

Type II tests were conducted on the first three coals in the above list. Each coal was tested in two short pilot plant runs during which four to seven tons of coal were gasified. The tests were made at two temperatures. All three coals were successfully gasified. Solids concentration in the feed coal/water slurry varied between 59 and 66 percent by weight. Gasifier temperatures ranged from 2250 to 2700°F and carbon conversions between 96.6 and 99.3 percent. Oxygen feed rates ranged from 9.7 to 10.8 SCF/pound of dry coal. ($\approx 0.7 \text{ lb } O_2/\text{lb coal}$)

Synfuels production was determined to be

Providence No. 1	32.8	SCF/pound dry coal feed
Ziegler No. 9	32.2	SCF/pound dry coal feed
Colonial No. 9	34.4	SCF/pound dry coal feed

The higher production rate for the Colonial No. 9 coal was due to its lower ash content. On the average, each pound of moisture and ash free coal produced 38.5 SCF of dry syngas. The cold gas efficiency ranged from 69 to 73 percent.

In a Type III test, 367 tons of Kentucky No. 9 coal from the Providence Mine No. 1 was gasified at 1200 psi. A total of 21 days of operating time was achieved with the longest run being 4.7 days. All the interruptions were due to mechanical equipment problems while the operation of the gasifier was generally smooth.

Carbon conversion varied between 94 and 99.8 percent and, on the average, 31.7 SCF of dry syngas (80 percent H_2 + CO) was produced per pound of dry coal. The temperature was controlled in the range of 2300 to 2800°F, the coal gas efficiency varied between 66.5 and 72 percent and oxygen requirements were 0.86 to 0.89 pounds per pound of coal.

Refractory wear was detected after 85 hours of operation so the temperature was reduced. At the end of the test the refractory had sustained only negligible surface loss but damage to the refractory of a different nature (not described in the report) was observed.

On the basis of these tests, it appears that the conditions for the successful operation of the Texaco gasifier using Kentucky No. 9 coal have been established and feedstock requirements and product quality and quantity can be predicted very closely.

V. Discussion of the Texaco Process

A. Process Parameters

From the above information it appears that Texaco has devised laboratory and small pilot plant tests that can be used to determine under what conditions a raw feedstock can be successfully gasified in their reactor. Any solid that can be ground to the particle size needed to prepare a stable water slurry should be able to be gasified in the Texaco process. In addition any material that can be pumped as a liquid at the required rates can be gasified like a petroleum feedstock.

The Texaco laboratory and pilot plant tests are able to determine feedstock requirements and to predict product yields and quality sufficiently accurately for process design needs.

B. Operating Experience

The size of the Montebello pilot plant is small enough so that extrapolation of some of the operating results to larger sizes is difficult. However, some of the operational problems experienced in the small sized plant may not occur in a larger scaled up version of the same equipment.

According to a paper presented by Texaco on October 13-16, 1980 at San Francisco¹⁰ Texaco has an ongoing development program to improve the process' performance and efficiency. It includes the following projects:

¹⁰Texaco Coal Gasification, Technology, W. Raymond Siegart, Texaco Inc., Conference on Synthetic Fuels: Status and Directions, San Francisco, October 13-16, 1980, Sponsored by EPRI and KERN FORSCHUNGSLAGE, Jülich

1. Optimizing coal/water slurry feed concentrations by improving the wet feed system.
2. Optimizing gasifier operation for high moisture content coals such as lignite.
3. Continuing a study program to increase the life of materials of construction.
4. Improving the reaction heat steam generator (syngas cooler) design to maximize the overall thermodynamic efficiency.
5. Optimizing the particle grind size as it relates to gasification efficiency and maximum slurry concentration.
6. Evaluating the economic benefit of gasifier design features.
7. Improving gasification instrumentation and control devices.
8. Determining the key scale-up parameters that must be developed to permit the successful construction of gasifier modules larger than 1,000 tons per day.

The experience since 1978 at Oberhausen-Holtien with the larger 150 tons per day pilot plant has generally been good although there is reported to have been early problems with some types of refractories used in the gasifier and it was necessary to replace the first waste heat boiler that was installed. Other operating problems at Oberhausen-Holtien are reported to have been minor.

TVA started operations at their 150 tons/day Texaco unit for ammonia production but are not currently in production because of start up and operating problems. These problems have not been described in detail in any of the reports reviewed. At least one of the difficulties, however, is reported to be in the slag removal system.

Dow Chemical Co. started up a 150 tons per day Texaco unit early in 1981. Although Dow has not made any public disclosure of their experience with the unit, it was reported in mid-April that there had been problems with gasifier clogging and "the refractory-lined reactors did not always work."¹¹

Table 12 is a list of major technical uncertainties that EPRI believed remained (January 30, 1980) with respect to use of a Texaco gasifier in their Cool Water Project. Discussions with EPRI personnel indicate that they believe that the additional 1-1/2 years of experience at Oberhausen (since Table 12 was prepared) and the additional data expected to be developed at TVA and Dow will substantially reduce the technical risks in all these areas.

¹¹Coal R & D, Vol. 4, No. 7, April 15, 1981, Casey Publishing Company, 1268 National Press Building, Washington, DC 20045.

Table 12. Major Technical Uncertainties (based on experience gained at Oberhausen thru 1979)

DEVELOPMENTAL ITEMS

Gas Cooler

Ash Letdown

Integral Control/Dynamic Operation

Intermediate Btu Combustor

Refractories

OPTIONS AVAILABLE TO REDUCE RISK

Quench and/or Redundancy

Redundancy

On-Line Storage

Alternate Designs and Materials

Appendix A

Description of Montebello Pilot Plant Test Types

The Type I evaluation test is used to determine the chemical composition and physical properties of each material. On the basis of these results, the mode of feeding the material to a Texaco gasifier will be selected and the gasification conditions, yields and product gas composition will be estimated. An assessment of the suitability of the material for further testing will be made.

The Type II evaluation will consist of a preliminary pilot plant test in which approximately 20 barrels of the candidate feedstock will be gasified. This short pilot plant evaluation will confirm the operability of the process on the candidate feedstock and permit refining the estimates of preferred processing conditions, product gas yield and composition. Unexpected operating problems will be identified.

The Type III evaluation will consist of an extended series of runs in which approximately 200 barrels of the candidate feedstock will be gasified. Operating conditions will be varied to further define the optimum. Definitive heat and material balance data will be obtained. The testing will provide information which will serve as the basis for an analysis of thermal efficiency and operability of the particular liquefaction process from which the material is derived.

The Type IV evaluation will consist of a long sustained gasification run in which approximately 500 barrels of the candidate feedstock will be gasified. Operating conditions will be held substantially constant throughout the run. The demonstration will provide information which will serve as the basis for a commercial design.

Appendix B

The Montebello Research Laboratory Pilot Plant Texaco Coal Gasification Process

PILOT PLANT PROCESS FLOW

The pilot plant consists of seven sections; the residue preparation and feed system, the oxygen feed system, the steam feed system, the gasifier, the slag removal system, the char recovery and water recycle system and the syngas treatment system. The flow rate of each gaseous and liquid stream is recorded during every run.

Residue Preparation and Feed System

The residue feed is pulverized to 1/4 inch in a hammer mill, after which it is pneumatically transferred to a feed bin. From the feed bin it is charged by a screw feeder to a 1300 gallon melt tank at a rate of approximately 1000 pounds per hour, and melted at a temperature of about 500°F under a nitrogen blanket. The melt tank is agitated and a pool of molten residue is maintained in the melt tank at all times. When necessary, solvent may be added to the melt tank to reduce the viscosity of the molten residue to an acceptable level for pumping into the gasifier. From the bottom of the melt tank, the molten residue is circulated through a heat exchanger, heated to about 525°F, and then returned to the top of the melt tank. This is done to allow the hot molten residue to mix with the dry residue feed to speed the melting process.

The melted residue is intermittently screened and transferred from the melt tank to a 1000 gallon day tank which is mounted on a scale to allow monitoring the charge rate. From the bottom of the day

tank, the molten residue is circulated continuously through a line strainer past the suction of the high pressure residue charge pump and back to the top of the day tank. This is done to insure that a positive pressure is maintained at all times at the suction of the high pressure residue charge pump. The day tank is also blanketed with nitrogen during each run.

The molten residue is pumped to the gasifier under pressure at a constant rate using a positive displacement plunger pump fitted with external ball check valves. The piping between each check valve assembly and the corresponding pump cylinder is filled with a clean purge solvent. An auxiliary pump is utilized to maintain a small purge rate (+2% of residue feed rate) of fresh solvent into each connecting pipe to prevent molten residue from diffusing back to the charge pump cylinders.

Oxygen Feed System

Liquid oxygen of 99.9 percent purity is stored on site. The oxygen is pumped up to the desired pressure and vaporized before feeding to the gasifier. The flow rate of gaseous oxygen is measured with a conventional orifice, recorded, and controlled at the desired flow rate during each run. A steam heater is used to heat the oxygen to approximately 300°F prior to metering to insure a steady temperature at the orifice.

Steam Feed System

Steam is generated on site at the desired pressure using a gas fired vaporizer. The charge rate is controlled by pumping a constant weight of boiler feed water to the vaporizer using a positive displacement pump. The flow rate is determined by weighing out of the feed tank.

Pilot Plant Gasifier

Steam, molten residue and oxygen are fed at constant, predetermined flow rates to a proprietary Texaco burner from which the streams enter the gasifier at the desired pressure and mass ratio.

The pilot plant gasifier is a 5 ft diameter vessel which is divided internally into two sections. The top section is lined with a refractory material specifically designed to withstand the severe operating environment expected. In this section, the partial oxidation reactions take place. The lower section is a quench vessel. A reservoir of water is maintained in the bottom of this vessel at all times. Syngas leaving the top section of the gasifier passes through a water cooled dip tube into the water in the quench vessel. Slag, and most of the char, carried with the syngas remain in the water. The saturated syngas is removed from the gas space above the water. Water is continuously injected into the quench vessel to replace water lost by evaporation and solids removal. The gasifier is designed to operate at a maximum pressure of 80 atmospheres (1200 psig).

Slag Removal System

Molten Slag, which forms during the gasification of the residue, is carried into the quench chamber with the syngas. Upon contacting the reservoir of water in the quench chamber, the molten slag solidifies. The slag forms sand-like grains, spheres and teardrops that vary in size from a few microns up to one half inch depending on the operating conditions. Slag is removed from the bottom of the quench chamber during each run with a lockhopper system.

The slag and water which are removed through the lockhopper system are ducted to a dewatering screen where the slag is separated into coarse and fine fractions. The coarse fraction is collected and weighed as a solid with less than 10 percent moisture. The fine fraction is collected and allowed to concentrate for later weighing, sampling and disposal.

Char Recovery and Water Recycle System

During the gasification process, a small amount of char is formed which must be removed and recycled when practical. Most of this material is removed from the syngas in the water reservoir at the bottom of the quench chamber. The char is less dense than slag and tends to remain dispersed in the water.

A continuous side draw-off of char-water slurry is maintained during each run. The slurry is cooled and sent to a settling vessel where it is allowed to thicken for later removal, weighing, sampling, and disposal.

The clarified water off the top of the settling vessel is recycled to the process.

Final traces of char are removed in a scrubber in which the syngas is contacted with additional water. The dilute char-water is collected in a scrubber knockout pot from which it is continuously withdrawn and combined with the quench water-char slurry in the settling vessel.

Syngas Treatment System

The saturated syngas is removed from the gas space above the water in the gasifier quench chamber and fed through an orifice scrubber into a scrubber knockout pot. Water sprayed into the orifice scrubber removes

final traces of char from the syngas. The syngas is then cooled to condense and remove most of its water content, reduced in pressure, metered with a conventional orifice, sampled and flared. A back pressure controller on this line maintains a steady gasifier pressure at the desired level.

MEDIUM BTU FUEL GAS
CONCEPTUAL DESIGN OF 50,000 BBL PER DAY
GASOLINE PLANT

W. R. GRACE & CO.

JUNE 1981

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

OBJECTIVE / PURPOSE

- ORIGINAL AMMONIA PLANT PROJECT WAS TO DEMONSTRATE THE TECHNICAL, ECONOMIC & ENVIRONMENTAL VIABILITY OF SUBSTITUTING COAL FOR NATURAL GAS TO PRODUCE AMMONIA
- INCLUDED CONCEPTUAL DESIGN, FINAL DESIGN, CONSTRUCTION AND OPERATION, UTILIZING 1900 T/D COAL TO PRODUCE 1200 T/D OF AMMONIA
- AMMONIA PLANT PROJECT TERMINATED AT END OF CONCEPTUAL DESIGN (why)
- GASOLINE PLANT IS A CONCEPTUAL DESIGN ONLY, USING ORIGINAL SITE, AND AS MUCH OF ORIGINAL DESIGN AS PRACTICABLE.
- UTILIZING 29000 T/D OF COAL TO PRODUCE 50000 BBL/D OF 1600 GRADE GASOLINE

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT
W.R. GRACE

DOE EXPERIENCE WITH TEXACO PROCESS

- W.R. GRACE & CO - PHASE I OF CONTRACT No. 2577 - AMMONIA FROM
COAL DEMONSTRATION PLANT PROJECT
MONTEBELLO PILOT UNIT TESTS *which coals?*
- TEXACO, INC., MONTEBELLO RESEARCH LAB - CONTRACT No. 2247 - GASIFICATION
OF RESIDUAL MATERIALS FROM COAL LIQUIFICATION
MONTEBELLO PILOT UNIT TESTS *which residues?*
- W.R. GRACE & CO - COOPERATIVE AGREEMENT No. 14759 - COAL TO
METHANOL TO GASOLINE PRELIMINARY DESIGN & ASSESSMENT
NO PILOT UNIT TESTS

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT
W.R. GRACE

PROJECT PARTICIPANTS

AMMONIA PLANT

- W.R. GRACE & CO. - AGRICULTURAL CHEMICALS GROUP - INDUSTRIAL PARTNER
MEMPHIS, TN.
- EBASCO SERVICES, INC. - ARCHITECT/ENGINEER
NEW YORK, N.Y.
- HUMPHREYS & GLASSGOW - PROCESS ENGINEER
LONDON
- TEXACO DEVELOPMENT CORP. PROCESS DEVELOPER
BERKON, N.Y.

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT
W.R. GRACE

PROJECT PARTICIPANTS
THE GASOLINE PLANT

- W.R. GRACE & CO, AGRICULTURAL CHEMICALS GROUP
MEMPHIS, TN
- OTHER MAJOR PARTICIPANTS:
 - TEXACO DEVELOPMENT CORPORATION.
BEACON, NEW YORK
 - TEXACO INC., HOUSTON ENGINEERING
HOUSTON, TX
 - TEXACO INC., MONTEBELLO RESEARCH LAB.
MONTEBELLO, CA
 - MOBIL RESEARCH & DEVELOPMENT CORP.
PRINCETON, N. J.
 - THE RALPH M. PARSONS CO.
PASADENA, CALIFORNIA

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT
W.R. GRACE

COST SHARING & BUY BACK ARRANGEMENTS

- AMMONIA FROM COAL FUEL GAS DEMONSTRATION PLANT
GOVERNMENT FUNDED TOTAL PHASE I - \$16.8MM
- GASOLINE PLANT COOPERATIVE AGREEMENT (what does it cover?)
GOVERNMENT WILL FUND TOTAL - \$12.6MM
- IF GASOLINE ^{PLANT} IS BUILT, GRACE WILL PAY GOVT BACK 100%
OF COOPERATIVE AGREEMENT
- TEXACO PROPRIETARY DESIGN FEE OF \$150,000 IS SHARED.
GRACE 100,000 - GOVT. 50,000

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT
W.R. GRACE

W.R. GRACE & CO
AMMONIA FROM COOL FUEL GAS DEMONSTRATION PLANT

- PHASE I CONCEPTUAL DESIGN OF DEMONSTRATION PLANT TO PRODUCE 1200TPD NH_3 FROM 1900 TPD WESTERN KENTUCKY No. 9 HIGH SULFUR COKING COOL
- GRACE NOT SELECTED TO PROCEED TO PHASE II DESIGN AND CONSTRUCTION
- ENVIRONMENTAL REPORT PREPARED
- PHASE I COMPLETED
- SLURRY FEED, OXYGEN BLOWN HIGH PRESSURE ENTRAINED BED TEXACO COAL GASIFICATION PROCESS PROPOSED FOR PROJECT
- TEST CONDUCTED AT TEXACO RESEARCH LABORATORIES USING 18 TPD 1200 PSI PILOT GASIFIER

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT

W.R. GRACE

PROCESS FLOW SHEET - AMMONIA PLANT

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

GASOLINE FROM COAL COOPERATIVE AGREEMENT

- BASED ON USING AS MUCH OF PHASE I OF THE AMMONIA FROM COAL DEMONSTRATION PLANT PROJECT AS POSSIBLE
- 50,000 BBL'S OF GASOLINE PRODUCED FROM 29,000 TPD COAL
- MOBIL RESEARCH AND DEVELOPMENT SUBCONTRACT UNDER NEGOTIATION
- ROLPH M. PARSONS SUBCONTRACT FINALIZED
- ~~ALASKA SERVICES INC. SUBCONTRACT IS NO LONGER PLANNED~~
- TECHNICAL DETAILS ON DESIGN ARE JUST BEGINNING
gasifier? naphtha?
- NO PILOT UNIT OPERATIONS PLANNED UNDER THIS EFFORT

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

FLOW SHEET - MAJOR PROCESSES

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

PROJECT SCHEDULE

PRESENT
 TIME

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

PROJECT COST SUMMARY (\$MM)

	PRIOR	FY81	FY82
EST OF GOVT COSTS			
PHASE I (COMPLETED)	16.8		
GASOLINE PLANT *		4.5	8.1
AVAIL. FUNDS			
GASOLINE PLANT	6.0	3.0†	0†

* THE CURRENT COOPERATIVE AGREEMENT WITH W.R. GRACE HAS A VALUE OF \$12.6M AND MUST BE RENEGOTIATED TO FALL WITHIN AVAILABLE FUNDS.

† FIGURES REPRESENT CURRENT DEPT REQUESTS WHICH ASSUME RECISSION OF \$3.6MM OUT OF THE \$6.0MM FY81 APPROPRIATION AND NO FUNDING IN FY82.

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

AMMONIA FROM COAL MONTIBELL PILOT TESTS

- TYPE OF TESTS CONDUCTED

TYPE I - LABORATORY SCREENING ANALYSIS AND SLURRY TESTS

TYPE II - SHORT PILOT UNIT TESTS (UP TO 1 DAY)

TYPE III - LONGER TERM SUSTAINED PILOT UNIT TESTS (14-30 DAYS)

- TYPES OF COALS TESTED

TYPE I - SIX WESTERN KENTUCKY COALS

TYPE II - THREE OF SIX WESTERN KENTUCKY COALS TESTED IN TYPE I

TYPE III - PROVIDENCE MINE NO. 1, ONE OF THREE COALS TESTED IN TYPE II

- OBJECTS OF TYPE III TEST

- ESTABLISH EQUILIBRIUM CONDITIONS

- OBTAIN ANALYTICAL DATA

- OBTAIN SLAG AND CHAR PHYSICAL PROPERTIES

- DEMONSTRATE SUSTAINED OPERATIONS WITH DESIGN COAL

- CONFIRM DESIGN BASIS

- SUCCESSFULLY MET ABOVE OBJECTIVES

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

AMMONIA FROM COAL

RESULTS OF MONTERELLO PILOT TESTS

- 367 TONS W. KENTUCKY No. 9 COAL (PROVIDENCE MINE No. 1)
- 507.7 HOURS (21 DAYS) OF ON-STREAM OPERATIONS ACCUMULATED OVER 14 RUNS AT 1200 P.S.I.
- LONGEST RUN WAS 4.7 DAYS UNINTERRUPTED
- PRODUCED 31.7 SCF DRY SYNGAS (80% $H_2 + CO$) PER POUND OF DRY COAL
- CARBON CONVERSION RANGED FROM 94.0-99.8%
- TEMPERATURE RANGED FROM 2300°-2800°F - REFRACTORY WEAR EXPERIENCED AT HIGHER TEMPERATURES.
- COAL GAS EFFICIENCY VARIED FROM 66.5 - 72.0%
- OXYGEN REQUIREMENT VARIED FROM 0.86 TO 0.89 POUNDS PER POUND OF COAL
- CONFIRMED BASIS OF DEMONSTRATION PLANT DESIGN.

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

AMMONIA FROM COAL

MONTABELLO PILOT TEST PROBLEM AREAS

- INSTRUMENTATION ?
- LINE PLUGGING ?
- REFRACTORY
- LOCK HOPPER BLOWDOWN
- LOCK HOPPER VALVES

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

GASIFICATION OF RESIDUALS FROM COAL LIQUEFACTION

OBJECTIVE

- To Confirm that various residual materials from DOE-sponsored Coal Liquefaction Projects are suitable for operability as a feedstock for production of syn gas and/or hydrogen in the Texaco Coal Gasification Process

Scope

Tests range from short screening laboratory tests to extended and sustained Pilot Unit runs. Tests conducted at the Texaco Montebello Research Laboratories. Sample ^{con. in} ~~some~~ ^{gas} ~~material~~ required for ~~long term~~ ^{sustained} tests is 500 barrels.

B-22

Purpose

High product yield obtained by gasification of residuals is important to overall economics of liquefaction processes

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

GASIFICATION OF RESIDUALS FROM COAL LIQUEFACTION MONTABELLO PILOT TESTS

- RESIDUALS FROM H-COAL, EXXON EDS, SRC I, SRC II, SYNTHAL AND U.S STEEL CLEAN COKE PROCESSES
- TESTS CONDUCTED AT FOUR LEVELS
 - TYPE I - CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES
 - TYPE II - PRELIMINARY PILOT UNIT TESTS
 - TYPE III - EXTENDED PILOT UNIT EVALUATION
 - TYPE IV - SUSTAINED PILOT UNIT DEMONSTRATION
- TEST CONDUCTED AT LOWER PRESSURE (350 PSI)

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

GASIFICATION OF RESIDUALS FROM COAL LIQUEFACTION RESULTS OF MONTEBELLO PILOT TESTS

- ALL RESIDUALS RUN IN TYPE I TEST FOUND SUITABLE FOR TEXACO GASIFIER
- SIX TYPE II TEST RUN^S ON H-COAL SYNCRUDE BOTTOMS (ILLINOIS #6) SRC II VACUUM FLASH DRUM BOTTOMS (KENTUCKY #9 & 14), EXXON EDS VACUUM TOWER BOTTOMS (ILLINOIS #6) AND SRC II VACUUM FLASH DRUM BOTTOMS (POWHATAN II)
- SEVERAL TYPE III TESTS RUN ON SIMILAR RESIDUALS TO THOSE
TESTED IN TYPE II RUNS
- ONLY ONE TYPE IV TEST RUN TO DATE - ~~ON~~ SRC II VACUUM FLASH DRUM BOTTOMS (POWHATAN II)
- CALCULATED (PREDICTED) VALUES AGREE WELL WITH ACTUAL PILOT DATA

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

TEXACO GASIFICATION PROCESS OTHER PROJECTS

- ARMY (MORGANTOWN ORDONANCE WORKS) 100 TPD - OPERATED FOR TWO YEARS ^{SUCCESSFULLY}
ON LOCAL COALS.
- RHURCHEMIE (ÜBERHAUSEN) 165 TPD - VARIETY OF COALS FROM ^{Year?}
16 - 32% VOLATILE MATTER. MOST RESULTS EXCEED DESIGN VALUES
- TVA (MUSCLE SHOALS) 160 TPD - ILLINOIS NO. 6. START-UP PHASE,
SYNTHESIS GAS FOR NH_3 PLANT
- DOW CHEMICAL (PLAQUEMINE, LA) 200 TPD AIR BLOWN - LIGNITE
AND ILLINOIS NO. 6. FEED FOR 15 MW GASTURBINE GENERATOR.

DESIGN STAGE

- EASTMAN KODAK (TENNESSEE) 1000 TPD, LOCAL COAL SYNTHESIS GAS
FEED STOCK FOR CHEMICAL MANUFACTURE
- COOLWATER (CALIFORNIA) 1000 TPD, UTAH COAL. MEDIUM BTU GAS
FOR COMBINED CYCLE electric generation

TEST UNITS

- 400 PSI AND 1200 PSI UNITS (MONTEBELLO, CA) 18 TPD, ALL COAL TYPES

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

TEXACO GASIFICATION PROCESS REPORTED OPERATING EXPERIENCE

- OBERHAUSEN-HOLTEN (RHURCHEMIE - JANUARY 1978 TO PRESENT)

GENERALLY GOOD REPORTS. INITIAL REFRACTORY, WASTE HEAT BOILER,
AND COAL GRINDING PROBLEMS NEEDED RESOLUTION. Solved?

- MUSCLE SHOALS (TVA)

START-UP PROBLEMS. HEAVY WEAR AND INSTRUMENT PROBLEMS ON DISK
MILL. SLAG REMOVAL PROBLEMS RELATED TO VIBRATING SCREEN AND
SLAG DISPOSAL TROUGH.

- OBERHAUSEN-HOLTEN (EPRI TESTS - OCTOBER 1980)

ILLINOIS NO 6 COAL EVALUATED FOR SLURRY PREPARATION, GASIFICATION,
HEAT RECOVERY, PARTICULATE SCRUBBING, AND WATER RECYCLE.
4400 TONS GASIFIED. STEADY STATE PERFORMANCE CONSISTENT
AND PREDICTABLE TO MONTEBELLO TESTS. GENERAL PROCESS
PERFORMANCE AS EXPECTED.

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT
W.R. GRACE

EPRI COOL WATER PROJECT
MAJOR TECHNICAL UNCERTAINTIES AS OF JANUARY 1980

DEVELOPMENTAL ITEMS

SYNGAS COOLER SYSTEM
ASN (SLAG) LETDOWN SYSTEM
INTEGRAL CONTROL/DYNAMIC OPERATION
INTERMEDIATE BTU COMBUSTOR
REFRATORIES

OPTIONS TO REDUCE RISK

QUENCH AND/OR REDUNDANCY
REDUNDANCY
ON LINE STORAGE ?
ALTERNATE DESIGNS AND MATERIALS
ALTERNATE DESIGNS AND MATERIALS

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

ONGOING TRXACO DEVELOPMENT OBJECTIVES

- OPTIMIZE COAL/WATER SLURRY FEED
- OPTIMIZE GASIFIER OPERATION WITH HIGH MOISTURE COALS (I.E. LIGNITE)
- INCREASE LIFE OF MATERIALS OF CONSTRUCTION
- IMPROVE SYNGAS COOLER TO GENERATE STEAM FROM WASTE HEAT
- OPTIMIZE PARTICLE SIZE RELATIVE TO MAXIMUM SLURRY CONCENTRATION
- IMPROVE GASIFIER INSTRUMENTATION AND CONTROL
- INVESTIGATE GASIFIER SCALE UP TO 1000 TPD
- CONTINUE STUDY OF GASIFIER DESIGN RELATIVE TO ECONOMIC BENEFITS

MEDIUM BTU FUEL GAS - CONCEPTUAL DESIGN OF GASOLINE PLANT W.R. GRACE

Title

- ARKANSAS POWER AND LIGHT, REDFIED, ARKANSAS - MBG, ICCG, STEAM ILLINOIS NO. 6, 7100 TPD
- CENTRAL MAINE, SEARS IS., MAINE - MBG, IGCC, KENTUCKY NO. 9, 5400 TPD
- HOUSTON NATURAL GAS / TEXACO, CONVENT, LA. - METHANOL, ILLINOIS NO. 6, 5500 TPD
- CELANESE, BISHOP, TEXAS - CHEM. GRADE METHANOL, IGCC, WESTERN BITUMINOUS, 5400 TPD
- CELANESE, CLEAR LAKE, TX - CHEM. GRADE METHANOL, WESTERN BITUMINOUS 20,000 TPD
- WYCOAL, INC, DOUGLASS, WY. - SNG, LURGI - TEXACO USING BY PRODUCT LIQUIDS
- UNION CARBIDE, TEXAS AM, TX - MBG, H_2 , SYNGAS, ILLINOIS NO. 6 8100 TPD
- EG&G, FALL RIVER, MA - MBG POWER GENERATION & METHANOL WESTERN BITUMINOUS COAL, 10,000 TPD

March 30, 1981

OPTA Environment, Health and Safety Functions

Fossil Energy Program Plans

- Provide criteria and guidance for the preparation of environmental portions of the program plans.
- Provide, as requested, advice on programs with respect to their environmental impacts
- Review for ASFE the environmental portion of the final program plans

Fossil Energy Project Plans

- Provide criteria and guidance for preparation of environmental portions of project plans
- Advise DASM on environmental adequacy of project plans prior to release of funds
- Review for the DASM the adequacy of environmental portions of the project plans in relationship to program Environmental Development Plans (EDPs)

Environmental Development Plans (EDPs)

- Monitor for ASFE the scheduling of updates of the EDPs
- Review for ASFE the joint ASFE and ASEV memo that initiates the preparation of new or updated EDPs
- Review for ASFE

Institutional Plans

- Review for DASM the environmental crosscut of the institutional plan and with the concurrence of DASM discuss the adequacy of the plan with the ETC directors.

- Monitor the implementation of the institutional environmental program

Program Reviews by ASFE and DAS

- As requested, participate in program reviews for adequacy of environmental plans

Focal Point for FE Environmental Program Information, Strategy and Policy

- Prepare for ASFE responses to requests for information on FE's environmental program
- Assess and develop consistent overall FE and ES&H policy and strategy
- Coordinate and concur in ASFE responses on environmental matters received from Congress, other federal agencies and other offices within DOE
- Acts as program manager for studies of generic FE environmental issues.

NEPA

- The primary responsibility for decisions with respect to what type of NEPA actions are required is with the DAS with final approval of ASFE and transmitted to ASEV. OPTA will provide review and concurrence of proposed action for ASFE
- If an EA or EIS is required, it will be prepared by the DAS for approval and transmittal to ASEV and GC. OPTA will provide review and concurrence of the proposed action for ASFE.

OS&H Program

- OPTA will provide oversight of the adequacy of implementation of the DOE OS&H program. Periodic reports on the status of OS&H programs will be made to ASFE
- OPTA is notified of all accidents of ASFE installations and represents ASFE in accident investigations.

SARS

- OPTA has the responsibility for developing guidance in preparation of SAR's
- OPTA has the responsibility for the oversight of the implementation of SARS.

Report on the Technical Status
of the U-Gas Process

Table of Contents

- A. Introduction
- B. Process Description
- C. Pilot Plant Tests - Ending with Test 156 (1974 to March 1979)
 - 1. Test runs 1 to 67
 - 2. Test runs 101 to 104
 - 3. Test runs 105 to 111
 - 4. Test runs 112 to 117
 - 5. Test runs 118 to 133
- D. Evaluation of Data Through Test 133
- E. Pilot Plant Test Runs 150 to 156 (April 1979 to December 1979)
- F. Comparison of Test Runs 150 to 156 with Previous Data
- G. Transition Period - December 1979 to July 1980
 - 1. Tests 157-159 April to June 1980
 - 2. Test 160 - July 1980
- H. Pilot Plant Test Runs 201-205 - September 1980 to February 1981
 - 1. Tests 201 to 205
 - 2. Evaluation of series 200 tests
- I. Evaluation of Overall Pilot Plant Operations
- J. Conclusions and Recommendations

Report on the Technical Status of the U-Gas ProcessA. Introduction

The U-Gas Process, a fluidized bed gasifier under development by the Institute of Gas Technology (IGT) for the production of medium-Btu gas (MBG), has been under test in a 1 ton of coal per hour pilot plant that was put into operation in 1974. This test program was conducted under the joint sponsorship of the Energy Research and Development Administration (later transferred to the Department of Energy) and the American Gas Association. Since 1977, IGT has been participating in a DOE funded program to prepare a detailed design of a demonstration plant to produce fuel gas for industrial use in the Memphis, Tennessee area.

The Memphis Light, Gas and Water Division (MLGW) supplies electricity, gas and water to consumers in Shelby County, Tennessee. Curtailment by its natural gas supplier, Texas Gas Transmission Corporation, led MLGW to becoming the prime contractor in 1977 to prepare a preliminary design of a demonstration plant to produce fuel gas from coal with the goal of assuring an adequate industrial fuel supply.

Planning and design are expected to be complete by early 1982 and site preparation should be started in May of 1981. The objective of this report is to review the adequacy of the technical data base on which the design has been predicted and evaluate the technical

risks associated with proceeding with the construction of the demonstration plant. The data used in this evaluation are the results obtained from the pilot plant from 1974 to December of 1979 and the results of tests conducted in modified pilot plant from August 1980 to January 1981.

B. Process Description

The process and the pilot plant have undergone a series of modifications over nearly seven years of operations. These changes were based on the operating experience gained during the pilot plant tests.

At present the pilot plant gasifier consists of a single stage fluidized bed that can be operated at pressures up to 55-60 psig. The gasifier is refractory lined and has a diameter of 3 feet. Oxygen and steam are fed into the bottom of the gasifier while fresh coal is fed directly into the fluid bed. The gas produced leaves the top of the gasifier after passing through an internal cyclone which removes some of the particulates and returns them to the fluid bed. After cooling the gas passes through 2 external cyclones. The fines removed in the first of the two external cyclones is to be recycled to the gasifier.

Ash is removed from the bed as agglomerates formed by the sticking together of the ash particles remaining after the coal is converted to gas. These heavy particles sink to the bottom of the bed where they are removed through a venturi throat.

It is claimed that the U-gas process can handle any type of coal. A number of successful tests have been conducted on Western Kentucky

No. 9 coal, a mildly coking bituminous coal, without the need for coal pretreatment. Operating temperatures have been varied between 1800° and 2000° F and the gas quality has been in the range of 275 to 285 Btu per cu. ft. The raw gas produced in the demonstration plant would be purified and compressed to pressures required by the MBG distribution system.

C. Pilot Plant Tests - ending with test 156 (1974 to Dec. 1979).

Table 1 is a summary of the U-gas pilot plant tests from the initiation of the pilot plant operations until the end of 1979.

The feedstocks used for each of the eight periods and the objectives of each set of tests are shown. These eight periods can be divided into three phases:

Phase 1 - Proving process feasibility (67 tests)

Phase 2 - Coal trail tests (17 tests)

Phase 3 - Gathering a data base for demo plant design (23 tests)

1. Test runs 1 to 67

These tests were made in order to shakedown the equipment, prove process feasibility and test a highly reactive, small-sized feed (char from the COED process). As a result of these 67 tests IGT reported that the process could be operated successfully to produce a MBG while agglomerating the ash and removing agglomerates from the fluid bed with a minimum of unreacted carbon.

On the basis of these results (concluded in June 1976) it was decided that the process was sufficiently promising so that tests on coking and noncoking coals should be undertaken. To facilitate

these tests with coal required modification of the pilot plant so that extended runs could be made. Modifications included changes to improve reliability of operations and to operate with coal as the feedstock.

2. Test runs 101 to 104

These tests were made with coke in order to test the operational reliability of the pilot plant, as modified. The results of these tests were

Test 101 - total of 60 hours of operation of which
20 hours was with metallurgical coke

- test concluded due to blockage of venturi ash-discharge

Test 102 - total of 133 hours of operation of which 100
hours was with metallurgical coal

- test concluded due to failure of screw feeder

Test 103 - total of 148 hours of operation of which 118
hours was with metallurgical coal

- test voluntarily terminated

Test 104 - no data obtained

- blockage of L valve feeder

In one or more of these 4 tests

1. Ash agglomerates were continuously produced and discharged
2. Reinjection of fines from external cyclone was accomplished

3. Test runs 105-112

These tests were made to determine how the gasifier would operate on a coal char and to continue to shake down the modified pilot plant. The results of the tests were:

- Test 105 - operations had to be changed from coal char to coke several time during the run
 - test concluded when ash discharge ceased
- Test 106 - total of 90 hours of operation of which 30 hours were with Montana coal
 - test concluded due to blockage of feeder
- Test 107 - presence of tramp material blocked feeder
 - test concluded due to appearance of sinter
- Test 108 - total test time of 58 hours
 - ash agglomerates not formed during coal feed period
 - test terminated due to electric malfunction of feeder scale system
- Test 109-110 - both tests terminated because of bed defluidization
- Test 111 - total test time of 81 hours with 16 hours of fine injection
 - test terminated because of poor fine controllability
 - 92% carbon conversion but with no ash agglomeration

In these tests on Montana Sub-bituminous coal, the following information was developed

1. Bed temperatures were reduced from those obtained with metallurgical coke.
2. Ash agglomeration of the lower bed temperature could not be achieved.
3. Operational problems forced termination of most of the tests.
4. There was no evidence that condensibles were evolved with product gas.

4. Test runs 112 - 117

These tests were made to determine the operability of the pilot plant using an Illinois No. 6 washed coal. The results of these tests were:

- Test 112 - no evidence of bed defluidization or tar accumulation
 - test terminated with development of sinter which prevented ash discharge
- Test 113 - defluidization occurred at reactor wall
 - greater turbulence needed to ensure ash agglomeration
- Test 114 - defluidization occurred in the reactor (venturi area)
 - solid discharge rate reduced to zero and terminated run
- Test 115 - evidence of defluidization occurred as run terminated

In these tests (runs 112-115) it was demonstrated that

1. Continuous in bed feeding of a washed bituminous coking coal could be sustained.
2. No organic condensibles were deposited in the system.
3. Continuous ash agglomeration could not be achieved,
4. Tests had to be terminated because of slag and sinter formation.

- Test 116 - total test time of 60 hours of which 12 hours was with coal feed
 - ash accumulation caused termination of test because of lack of solids discharge

- Test 117 - only 4 hours of coal feed due to operating problems
 - bed level of the reactor could not be maintained

These two tests added little additional information to the data base for the design of the demonstration plant.

5. Test runs 118 - 133

A total of 16 tests on the U-gas pilot plan were conducted between January 1968 and February 1979 to gather data for the design of the U-gas Memphis demonstration plant. All tests were conducted with Western Kentucky No. 9 coal. The results of these tests were:

- Test 118 - total test run of 60 hours including 10 hours of continuous coal feed (ROM-W. Ky #9)
 - test terminated due to lack of coal supply
- Test 119 - 168 hours of operation but with only 2 hours of coal (ROM - W. Ky #9)
 - test terminated due to screw feeder problems
- Test 120 - 107 hours of operation but with only 1 hour of coal feed (ROM - W. Ky #9)
 - test terminated due to malfunctioning of the trickle valve seal
- Test 121 - 23 hours of operation with 4 hours of coal feed (ROM - W. Ky. #9)
 - test terminated due to defluidization of reactor
- Test 122 - 92 hours of operation with 54 hours of continuous coal feed (ROM - W. Ky #9)
 - test terminated due to failure of automatic vent valve.

Between test 122 and 123 the gasifier was modified to permit pressure operations. This included a reduction in the gasifier diameter from 4 feet to 3 feet.

- Test 123 - 70 hours of operation with 38 hours of coal feed (ROM - W. Ky #9)
 - test terminated due to excess carryover of fines

Test 124 - 305 hours of operation with 168 hours with coal feed (ROM - W. Ky #9)
- test terminated voluntarily

Test 125 - 143 hours of operation with coal feed of only 1 hour
- test terminated due to bed defluidization

Tests 126 to 128 were conducted to demonstrate that the pilot plant was suitable for 50 psig operation while achieving coke gasification and ash agglomeration. Coke breeze was used as the solid feedstock.

Test 126 - 79 hours of total operation - no coal feed
- test terminated due to bed defluidization

Test 127 - 166 hours of operation at 4 set points
- test terminated because of hole in second stage cyclone

Test 128 - 172 hours of operation at 6 set points
- test terminated when the air compressor failed

Tests 129 to 133 were conducted using washed W. Kentucky #9 coal at slightly elevated pressures.

Test 129 - 66 hours of operation with washed coal fed for 8 hours
- test terminated due to plugging of scrubber

Test 130 - 178 hours of operation with 106 hours of coal feed. Ash balanced operation maintained for 72 hours. Three of planned set points were achieved
- test terminated due to failure of operation of internal cyclone

Test 131 - 196 hours of operation with 104 hours of coal feed. Ash balanced operation maintained for 68 hours
- test terminated because of hole in second stage cyclone

Test 132 - 174 hours of operation with 54 hours of coal feed. Ash balanced operation over 68 hours
- test terminated due to malfunctioning of internal cyclone

Test 133 - 193 hours of operation with coal feed for 138 hours at 42 psig. Ash balanced operation over the run
- test terminated voluntarily

These test runs were longer than those previously able to be obtained with coal feed and represented limited operational experience at pressures up to 42 psig.

D. Evaluation of Data Through Test 133

In March 1980, UOP/SDC was requested by DOE to evaluate the U-gas pilot plant test results through run 133. They were provided reports on the tests through November 1979 and a number of monthly report data summaries for specific runs. In addition a meeting was held with IGT at IGT and one with Foster Wheeler. Subsequently a second meeting with IGT was held at the U.O.P. offices.

This same basic information has now been reviewed independently and the conclusions reached by UOP/SDC appear to be correct. This summary evaluation of the data base was that it could (ref. 9):

"Summary: With the understanding that our review has been limited to the data, information and time sequence referenced in Table 1, the data presented to us:

1. Demonstrate the ability of the gasifier to process washed Kentucky coal without pretreatment.
2. Demonstrate suppression of tars and oils to non-problem levels.
3. Leaves open the question of adequate demonstration of operation in an ash-balanced mode without formation of ash deposits.
4. Leaves open the question of adequate demonstration of collection and reinjection of fines to extinction.
5. Leaves open the question of adequate demonstration of proposed demo plant yields, oxygen, and steam rates."

The UOP/SDC report did not address the important question about whether the process can be operated successfully and reliably for long periods. Even toward the end of the test program most runs were terminated involuntarily because of some equipment or process malfunction. Clinkers were found in many different parts of the reactor indicating that control over the process was imperfect.

An evaluation of U-gas process was made by DOE personnel in January of 1980. They concluded

1. That U-gas had demonstrated the ability to process run of mine or washed coking bituminous coal and coke.
2. A very successful pilot plant test run was conducted continuously at 42 psig for 158 hours of operation, gasifying 102 tons of coal. Ash balanced operation was achieved with 95% carbon utilization.
3. The effect of ash level and fines on the operation in an ash agglomerating mode was still uncertain.
4. The effect of high pressure on the process was not known and it would require a new type of feeder to determine the effect of pressure on throughput, feed requirements and quality of the product.
5. Other uncertainties are scale up of gasifier bottom for ash agglomerate removal and the limits of the coal types that can be used without pretreatment.
6. Adequate demonstration of collection and reinjection of fines to extinction had not been achieved.
7. The anticipated yields and oxygen and steam requirements to be used as the basis for design of the demonstration plant had not been demonstrated in the pilot plant.

8. An ash balanced mode operation without the formation of ash deposits had not been demonstrated.

In order to minimize the risks caused by the above uncertainties a number of design changes were to be made for the demonstration plant.

These included provisions for a coal pretreater (should direct feeding of an untreated coal prove infeasible), for sufficient flexibility in the shell diameter and height to accommodate changes in redesign of gasifier bottom section, for ash removal on either a continuous or a batch basis and for simplification of the waste water treatment system.

A number of other design changes were incorporated to assure design output despite design uncertainties. On the basis of these changes the DOE personnel assessed the process risk for U-gas gasification to be judged low to moderate and the risk of acceptable performance to be moderate.

Tests 150 to 156 were conducted to obtain additional data for pilot plant design using both ROM and washed W. Kentucky #9 coal.

E. Pilot Plant Test Runs 150-156

- Test 150 - 87 total operating hours of which 24 hours were conducted with washed coal feed. Twelve hours of balanced ash agglomerate was achieved.
- test terminated by process upsets, including sintering.

Test 151 - 86 total operating hours of which 21 hours were with washed coal

- test terminated because of low inventory of dried coal

Test 152 - 78 total operating hours of which 10 hours were with washed coal and 34 with ROM coal (W. Ky #9)

- test terminated due to bed defluidization because of clinkering on the grid

Test 153 - 49 total operating hours of which 18 hours were with washed coal and 2 hours were with ROM coal (W. Ky #9)

- test terminated due to bed defluidization because of clinkering on the grid

Test 154 - 50 total operating hours of which 20 hours were with ROM coal (W. Ky #9)

- test terminated due to plugging of the venturi

Test 155 - 77 total operating hours of which 40 hours were with ROM coal (W. Ky #9)

- test terminated due to obstruction of venturi by an accumulation of loose solids and sinters

Test 156 - 59 operating hours of which 22 hours were with ROM coal (W. Ky #9)

- test terminated due to blockage of internal cyclone by fine particulates

F. Comparison of Test Runs 150 to 156 with Previous Data

Test 150 to 156 followed the same pattern as the previous tests both with respect to the five conclusions reached by UOP/SDC and those reached by DOE and the experience with maintaining operability. Those tests did, however, demonstrate that run-of-mine West Kentucky No. 9 coal can also be used successfully in the gasifier without pretreatment.

G. Transition Period, December 1979 to July 1980

After test 156 there was a transitional period from December 1979 to March 1980 when tests were resumed. During this period the pilot plant was modified to (1) eliminate erosion and minimize ash accumulation problems in the internal cyclone by increasing its size, (2) raising the second stage cycle to provide extra dipleg height to improve fines recycle operation. Also, all the mechanical equipment was checked and general maintenance performed.

1. Tests 157 to 159

These tests were conducted on a washed Pittsburgh seam coal in order to test a highly coking eastern bituminous coal. No pre-treatment was necessary and the coal was fed directly into the fluid bed with no tars or other condensables deposited in the system.

Ash agglomeration was achieved in all these tests and in the final two tests second stage cyclone fines were recycled; in the final test (159) for 44 hours.

2. Test run 160

A blend of Ky No. 9 and 11 was successfully gasified with agglomerate produced under ash balanced conditions.

H. Pilot Plant Test Runs 201 to 205 - September 1980 to January 1981

1. Test runs 201-205

Test 201

- 118 hours with 69 hours of washed W. Ky #9 coal; 76 hours of balanced ash agglomeration
- internal cyclone filled with char and ash solids that blocked dipleg; some ash accumulation in cyclone

Test 202

- approximately 38 hours of balanced operation at set point one ($p = 55$ psig with no fines recycles) and 27 hours of balanced operation at set point 2 (fines recycle, balanced ash operation)
- test terminated - feed nozzle blocked

Test 203

- 42 hours of ash balanced operation with W. Ky #9 washed coal, recycle of fine for 24 hours, with interruptions
- ash accumulation in cyclone terminated run

Test 204

- total 113 hours with recirculation of fines for 18 hours. Set point not achieved
- test terminated because internal cyclone not functioning

Test 205

- Run in February 1971 for a total of 211 hours of operation of which 136 hours were with coal. The major purpose of determining if a cooled cyclone surface will prevent ash deposition
- Test terminated voluntarily with no buildup of ash or water cooled surfaces

2. Evaluation of series 200 tests

Except for test 205, these tests were generally not as successful as some of the previous tests, from an operational standpoint. Some experience was gained with gasification of washed W. Kentucky #9 coal but operating problems made it difficult to draw conclusions about much of the test results. The problems identified in Section D above remain not completely resolved.

I. Evaluation of Overall Pilot Plant Operations

In March 1981 (Reference 2) IGT concluded that the pilot plant tests demonstrated the following:

"Very successful results were obtained from the gasification tests conducted under this AAG program.

1. The modified AAG pilot plant readily accepted raw subbituminous, then successively washed and ROM bituminous coal feed without fluidization or tar deposition problems.
2. Each feedstock, including coke, achieved conversion efficiencies (coal to gas) of at least 70%.
3. Achieving coal conversion efficiencies over 90% required that the first two stages of cyclone fines be recirculated back to the reactor.

4. Continuous and stable gasification of Montana subbituminous coal at ≈ 2 ft/s superficial velocity was achieved in the AAG reactor. However, its high coal reactivity produced a high-quality gas (253 Btu/SCF) that precluded achieving operating temperatures sufficiently high ($+1800^{\circ}\text{F}$) for ash agglomerate formation.
5. Fluidization stability with raw bituminous coal feed at 2 to 3 ft/s superficial velocity was marginal. An operational change to a near 4 ft/s produced fluidized bed stability, confirming that there was no need for pretreatment before AAG processing.
6. Fluidization bed temperatures necessary to achieve ash agglomeration of washed Illinois No. 6 bituminous coal were demonstrated ($\approx 1850^{\circ}\text{F}$).
7. Stable fluidization and ash-balanced conditions for ash agglomeration of washed and ROM western Kentucky No. 9, washed Pittsburgh seam and western Kentucky Nos. 9 and 11 mixed bituminous coals were confirmed.
8. Gasifying bituminous coal with ash agglomeration by steam-oxygen mode produced fuel gas having heating values averaging 270 Btu/SCF.
9. A tabulation and graphical illustration of the performance of the important equipment components of this AAG pilot plant is included in this report. It reveals that 42% of the problems encountered with equipment are traceable to changes in process operating conditions for which the equipment was not designed. Those components that had a significant number of equipment-related failures (4+) were thermocouples, the internal cyclone, and the coal feed system. However, these components were expected to furnish significant materials and mechanical problems because of the extreme environment and service conditions inherent in coal gasification process."

Of these nine conclusions only the claims about successful fluidization and fines recirculation can be challenged. For conclusions one and seven, in a number of tests the bed defluidized because of blockage of gas flow due to clinker formation or refractory spalling. For conclusion three, fines recirculation was not able to be maintained for a large number of runs although a total of 150 hours of successful fines recycling was achieved.

In addition to the positive conclusions described in the IGT report a number of unresolved problems still need to be settled.

These include

- 1) Ash deposition problems, particularly in the cyclone during ash balanced agglomeration conditions. This may be able to be overcome by water cooling of the primary cyclone based on the experience of run 205 and that of Westinghouse in the operation of their cyclone collector.

- 2) Additional information is needed so that a scale-up of the bottom part of the gasifier, where ash is agglomerated and removed, can be accomplished with minimum risk.

- 3) Additional data is needed on how multiple inlet feeds will behave for coking coals in a large gasifier and where in the gasifier bed the fresh coal should be injected and in what manner.

- 4) Additional data is needed on reliable operation at balanced conditions of fines recycle.

- 5) Demonstration of feed requirements and product quality used in demonstration plant design.

J. Conclusions and Recommendations

To date it has been demonstrated in a series of runs at steady state conditions in this pilot plant

- 1) that Western Kentucky No. 9 coal (either run-of-mine or washed) can be gasified without pretreatment,
- 2) that other coking bituminous coal may also be able to be gasified without pretreatment,
- 3) pretreatment is not required to achieve satisfactory ash agglomeration.
- 4) balanced ash agglomeration with satisfactory removal of the agglomerates has been achieved. Stable operation of ash agglomeration is possible during periods of short upset,
- 5) solutions appear to have been found for prevention of clinkering and sintering by alternative venturi design, modification in the oxygen feed system and increasing the superficial velocity of the gas,
- 6) under certain circumstances fines recycle has been achieved with stable operation and fluidization,
- 7) the process can be operated at pressures up to 60 psig without adversely affecting other process parameters,
- 8) A wide range of operating conditions can be used while maintaining system operability. These variables include bed-ash content, turndown to one-third full capacity and variable bed height,
- 9) in a single test water cooling of the cyclone appears to prevent ash deposition on the cooled surfaces. This confirms the experience of Westinghouse with ash deposition prevention in their fluidized bed gasifier.

Although all of the above process variables have been demonstrated in one or more tests, they have not always been reproducible nor have they necessarily been accomplished simultaneously -- both are requirements for successful operation of a demonstration plant. The last test (No. 205) had the most extended operating period ever achieved, probably due to the expanded maintenance procedures that were used. If this type of operation can be repeated in future tests it will be possible to confirm the operability of the process with respect to the following parameters:

- 1) That fines recycle can be achieved on a routine and reliable basis,
- 2) that water cooling of the cyclone will reduce ash deposition to levels that will allow for long periods of continuous operation,
- 3) the effect of water cooling of the cyclones on process efficiency and materials requirements,
- 4) minimum and maximum fluidization velocities as a function of operability, entrainment and bed depth,
- 5) operation of gasifier at demonstration design conditions (except for pressure) for oxygen, steam and coal bed requirements and gas quality.

Other problems to which the pilot plant can help to contribute information for the demonstration plant design are the handling of ash slurries, materials of construction and design of lock hopper valves. The pilot plant cannot provide information about the effect of increasing the pressure from 55 to 60 psig (pilot plant) to 90 psig (demonstration plant).

The most difficult design problem is the scale up of the ash agglomerating section of the gasifier. At present the question of whether one venturi or three venturies would involve less technical risk, is under consideration. Data from cold model tests, consultation with fluidization experts and mathematical modeling of mixing patterns are all being used to reach a decision on this problem. Detailed designs of both options will probably be made.

To reduce other technical risks, the following design basis is being used:

- 1) Residence time of solids in the demonstration plant twice that of the pilot plant.
- 2) Extra gasifier length so that a deeper fluid bed can be used if needed.
- 3) The use of three gasifiers and one spare to ensure greater reliability of operation.
- 4) Provision to remove oil and tar from the system although none has been produced in pilot plant.
- 5) Provision to use bed withdrawal in place of ash agglomeration should ash agglomeration prove impossible in the large gasifier. This will result in reduced gasification efficiency but the penalty is not excessive.
- 6) Should gas quality be lower than specified, means of upgrading the gas to specifications by CO_2 removal is being provided.

7) Provision has been made for injecting fresh coal at four different bed heights and for six spare feed inlets..

This review of the U-gas process indicates that some additional data are required to reduce technical risks of building the demonstration plant.. Therefore, the pilot plant should be operated during the period required for detailed design to develop the information required. When the additional information is successfully obtained, if long term reliable operation has been feasible and if a conservative backup design basis is used (for the seven areas above) then construction of the demonstration units would involve low to moderate risks.

Table 1. SUMMARY OF PHASE I PILOT PLANT TESTS

TEST RUN	PERIOD	FEED	FUNCTION
1-9	1974	Metallurgical Coke	Equipment Shakedown
10-53	1974	Metallurgical Coke	Process Feasibility
54-67	1975	COED Char	Test High Reactive, Small Size Feed
101-104	1977	Metallurgical Coke	Shakedown of Modified Pilot Plant
105-111	1977	Montana Subbituminous	Test Highly Reactive Feedstock
112-117	1977	Illinois No. 6	Coal Trial Runs
118-133	1978-1979	W. Kentucky No. 9 (ROM)	Demonstration Plant Design Data
150-156	1979	W. Kentucky No. 9 (ROM and Washed)	Demonstration Plant Design Data

References

1. Industrial Fuel Gas Demonstration Plant Program, Technical Support Report: Pilot Plant and Support Studies. Prepared under Contract ET-77-C-01-2582, November 1979.
2. Draft report on "Operation of the Ash-Agglomerating Gasifier." For Periods July 1976 through December 1977 and April 1979 through July 1980, March 1981.
3. Review by IGT of the Ash Agglomerating Gasifier Pilot Plant, Morgantown Energy Technology Center, October 16, 1979.
4. Evaluation Panel Report, Fuel Gas Industrial Demonstration Program, January 30, 1980.
5. Institute of Gas Technology - Gascope, Spring 1979, No. 45.
6. Fossil Energy Technology Fact Sheet, Memphis Demonstration Plant, June 1980.
7. Preliminary Report - Technical Evaluation and Comparison of U-Gas and Westinghouse Gasification Processes, by C.F. Braun Corp., October 1979.
8. Westinghouse Coal Conversion Program, Westinghouse U-Gas Comparison, October 30, 1979.
9. Review of U-Gas Pilot Plant Program, Memorandum to C.W. Pace from UOP-SDC, January 14, 1980.
10. The IGT Low Btu Gas Process - Design and Economics, by J.G. Patel and others; Paper presented at Symposium on Comparative Economics for Synfuels Processing, American Chem. Society, April 4-6, 1976.
11. Letter to Mr. Laza (DOE) from J. G. Patel (IGT) December 31, 1980 enclosing report on "Ash Deposits in Pilot Plant Cyclone."

PILOT PLANT OPERATION HAS DEMONSTRATED

- WESTERN KY NO. 9 COAL (WASHED AND RUN-OF-MINE) CAN BE GASIFIED WITHOUT PRETREATMENT
- BALANCED ASH AGGLOMERATION AND SATISFACTORY REMOVAL OF AGGOMERATES
- CLINKERING AND SINTERING CAN BE CONTROLLED
- FINES RECYCLE HAS BEEN ACHIEVED IN SOME TESTS
- OPERATION AT 60 PSIG PRESSURE
- ASH DEPOSITION HAS BEEN PREVENTED BY WATER COOLING IN ONE TEST
- WIDE RANGE OF OPERATING CONDITIONS CAN BE USED

ADDITIONAL PILOT PLANT DATA IS REQUIRED ON

- FINES RECYCLE ON A ROUTINE BASIS
- WATER COOLING OF THE CYCLONES TO CONTROL ASH DEPOSITION
- MINIMUM FLUIDIZING VELOCITIES AND BED DEPTHS
- OPERATION OF PILOT PLANT AT DEMONSTRATION PLANT DESIGN CONDITIONS

OTHER DESIGN UNCERTAINTIES

- EFFECT OF HIGHER PRESSURE 90 vs 55-60 PSIG
- SCALE UP OF ASH AGGLOMERATING SECTION

TECHNICAL RISK REDUCTION THROUGH CONSERVATIVE DESIGN

- RESIDENCE TIME TWICE AS LONG AS IN PILOT PLANT
- EXTRA GASIFIER LENGTH
- USE OF THREE GASIFIERS AND ONE SPARE
- PROVISION TO REMOVE OIL AND TAR
- PROVISION FOR BED WITHDRAWAL IN PLACE OF ASH AGGLOMERATION
- PROVISION FOR FEEDING AT FOUR DIFFERENT BED LEVELS
- PROVISION FOR CO₂ REMOVAL TO MAINTAIN GAS QUALITY

CONCLUSIONS

- CONTINUE TO OPERATE PILOT PLANT AND OBTAIN REQUIRED DATA
- DEMONSTRATE OPERABILITY WITH HIGH RELIABILITY OF PILOT PLANT FOR EXTENDED PERIODS
- USE CONSERVATIVE DESIGN BASIS

THEN

- CONSTRUCTION OF DEMONSTRATION PLANT WOULD INVOLVE LOW TO MODERATE RISKS

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FOSSIL ENERGY R&D PROGRAM DEVELOPMENT ACTIVITIES

Presented by Fossil Energy

December 1980

PURPOSE OF THE BRIEFING

- **What is the Status of Fossil Energy Technology with Regard to Its Readiness for Commercialization?**
- **What Information about Industry's View of the Technology Status Can Be Gained from the Industry's Responses to the Three Solicitations and from Announced Industry Plans?**
- **What Are the Critical Generic R&D Needs to Reduce Technology and Environmental Risks and Decrease the Need for Federal Subsidies?**
- **What Impacts Will the Functioning of the Synthetic Fuels Corporation, Other Incentives, and Industry Activity Have on Ongoing Fossil Energy R&D?**

- **What Has DOE/FE Been Doing to Answer These Questions?**

- **Draft Technology Assessment Report Has Been Prepared.**
- **Industry Review Is about to Be Requested.**
- **Program Priorities Being Reexamined.**
- **Budget Implications Being Reviewed.**

PURPOSE OF TECHNOLOGY ASSESSMENT

- **Identify the Technical Readiness of Fossil Energy Technologies Which Are**
 - Ready for Immediate Deployment.
 - Under Development and Could Be Deployed by the Late 1980's.
 - Necessary to Support Deployment of These Technologies or Represent Advances and Could Be Deployed in the 1990's.
 - Currently Being Considered by Industry.
 - Response to Alternative Fuels Solicitation
 - Announced Plans
- **Identify the Highest Priority R&D Tasks Required to Reduce Technical Risks and Remove Uncertainties.**

TECHNOLOGY ASSESSMENT NOT LIMITED BY

- **Capital Costs**
- **Cost of Product**
- **Process Efficiency**
- **Infrastructure Constraints**
- **Institutional and/or Regulatory Barriers**
- **Availability of Other Needed Resources**
- **Socioeconomic Impacts**

FOSSIL RESOURCE BASE

(Estimated)

Western Oil Shale	600 Billion Barrels (25 Gallons/Ton or More) 1200 Billion Barrels (15-25 Gallons/Ton)
Eastern Oil Shale	1000 Billion Barrels (10-25 Gallons/Ton)
Heavy Oil	74 Billion Barrels
Light Oil	230 Billion Barrels
Tar Sands	30-45 Billion Barrels
Coal	1600 Billion Barrels Oil Equivalent
Devonian Shale — Gas	28-280 Billion Barrels Oil Equivalent
Tight Gas Formations	56-140 Billion Barrels Oil Equivalent
*Conventional Oil	150 Billion Barrels
*Conventional Gas	130 Billion Barrels Oil Equivalent

***Mean Resources — USGS**

CATEGORIES OF TECHNOLOGY

● First Wave Technologies

- Ready for Immediate Deployment**
- Have Improvement Opportunities**
 - Environment**
 - Efficiencies**
 - Costs**
 - Extension to Wider Range of U.S. Resource Base**
- Need Supporting and Environmental R&D**

● Second Wave Technologies

- Expected to Yield Commercial Product by Late 1980's**
- Offer Substantial Benefits over First Wave**
- Need Further Development Including Environmental**

● Supporting Fossil Energy Technologies

- Necessary for Successful Deployment of First and Second Wave Technologies**

● Advanced Fossil Energy Technologies

- Limited Contribution Likely in Shortrun, or**
- Deployment Likely to Occur after 1992**
- Important to Longer Range Goals**

FIRST WAVE TECHNOLOGIES

Liquids

- **Oil Shale — Surface Retorting**
- **Indirect Liquefaction — Fischer-Tropsch; Methanol Methanol/Gasoline**
- **Enhanced Oil Recovery — Heavy Oils**
- **Enhanced Oil Recovery — Light Oils**

Gases

- **Surface Coal Gasification**
- **Tight Blanket Gas Formations**
- **Devonian Shale**

Direct Utilization

- **Pulverized Coal Firing/Improved Flue Gas Scrubbing**
- **Coal-Oil Mixtures**
- **Small Industrial AFB**
- **Synthetic Fuels — Low, Medium-BTU Gas, and Synthetic Liquids**

SECOND WAVE TECHNOLOGIES

Liquids

- **Oil Shale**
 - Modified In-Situ, Advanced Mining and Retorting
- **Direct Coal Liquefaction**
 - SRC-I and II, EDS, H-Coal
- **Indirect Liquefaction**
 - Advanced Fischer-Tropsch and Alternative Synthesis Processes
- **Enhanced Oil Recovery**
 - Downhole Steam Generation for Heavy Oil
 - Chemical and Gas Flooding for Light Oil
- **Tar Sands**
 - Surface Mining and Recovery
 - In-Situ Recovery

Gases

- **Surface Coal Gasification**
 - Improved Entrained, Moving and Fluidized-Bed Gasifiers
- **Western Tight Gas**
 - Stimulation of Lenticular Formation

SECOND WAVE TECHNOLOGIES (CONCLUDED)

Direct Utilization

- **Direct Coal Firing**

- Dry and Regenerable Scrubbers
- Atmospheric Fluidized-Bed Combustion (Large Industrial, Utility)

- **Combined Cycles**

- Gasifier Combined Cycle Systems
- Pressurized Fluidized-Bed Combined Cycle Systems

- **Coal-Based Mixtures**

- Coal-Oil Mixtures Extension
- Coal-Water Mixtures
- Coal-Synfuels Mixtures

INDUSTRIAL RESPONSE TO DOE SOLICITATIONS

Technology	1st Round Responses		2nd Round Responses		Incentives Responses
	FS	CA	FS	CA	
Liquids					
Coal					2
Shale					6
Tar Sands					3
COM					2
Peat					1
Gases					
Coal					
SNG					1
Low/Med BTU					
Underground Coal Gasification					
Unconventional					
Tight Sands					
Devonian					
Coal-Bed Methane					
Peat					

GENERIC R&D NEEDS

- **Resource Characterization and Extraction**
- **Environmental**
- **Process Scaleup, Control**
- **Upgrading and Product Testing**
- **Components and Materials**
- **Process Operability and Reliability**

IMPACT ON FOSSIL ENERGY R&D

- **Industry Is Expected to:**

- Focus in the Short Term, on Development of Information for Design and Construction Purposes.
- Decrease Emphasis on Developing New Processes.
- Subsequently Shift R&D to Overcome Startup and Operational Problems.

- **DOE Should Consider:**

- A Strengthened Technology Base Program.
- Concentrated Environmental R&D.
- Providing Critical Generic R&D to Minimize Risk for First Phase.
- Pacing Support for Development of Second Wave Processes.
- Sustaining R&D for Supporting and Advanced Technologies.
- Reducing R&D in Areas Where Industrial and SFC Activities Lower DOE Priorities

NEXT STEPS

- **Obtain Industry Technical Review of R&D Technology Assessment.**
- **On Basis of Industry Comments Develop Specific National R&D Requirements.**
- **Assess Needed Redirections of FE R&D.**

RESPONSES TO INCENTIVES SOLICITATION

GENERIC TECHNOLOGY	SPECIFIC TECHNOLOGY	PROPOSER	SITE	POTENTIAL PRODUCTION
Oil Shale (Syncrude, Jet, Diesel)	Union Upward Flow Retort	Union Oil of California	Parachute Creek, Colorado	10,000--1983
Oil Shale (Jet, Diesel, Gasoline)	TOSCO II Surface Retort	TOSCO	Garfield Co., Colorado	48,300--Mid-1980's
Oil Shale (Syncrude)	VMIS/Surface Retort	Cathedral Bluffs Shale Oil Co.	Rio Blanco Co., Colorado	55,000--1988 94,000--1990
Oil Shale (Upgrading)	Hydrotreating	Paraho Development Corp.	Uintah Co., Utah	10,000--1984 30,000--1986
Oil Shale (Upgrading)	Hydroprocess	Plateau, Inc.	Roosevelt, Utah	20,000--1984
Oil Shale (Unknown)	Unknown	Shale Development Corp.	Utah	Unknown
Tar Sands (Syncrude)	Unknown	Great National Corporation	Sunnyside, Utah	10,000--1986
Tar Sands (Syncrude, Methanol)	Clark Hot Water K-T Gasifier	Great Basin Hydrocarbons, Inc.	Green River, Utah	60,000--Unknown

RESPONSES TO INCENTIVES SOLICITATION (CONCLUDED)

GENERIC TECHNOLOGY	SPECIFIC TECHNOLOGY	PROPOSER	SITE	POTENTIAL PRODUCTION
Tar Sands (Syncrude)	ADI Chemical Extraction	Aarian Development, Inc.	Eastern Utah	20,000--1986
Indirect Coal Liquefaction (Methanol, Gasoline)	KBW Gasification, Pulman-Kellogg Synthesis, Mobil MTG	Tennessee Synfuels Assoc.	Near Oak Ridge, Tennessee	20,000--1985
Indirect Coal Liquefaction (Gasoline, Fuel, Chemicals)	Lurgi, Koppers	Hampshire Energy	Campbell Co., Wyoming	20,000--Unknown
Peat (Methanol)	Unknown	Energy Transition Corp.	Creswell, North Carolina	17,000--1984
Coal Gasification (High-Btu)	Lurgi, Texaco	WyCoalGas, Inc.	Douglas, Wyoming	25,000--1986 50,000--1988
Coal-Oil Mixture	Production	Bonklick Corp.	Jacksonville, Florida	5,300--Unknown
Coal-Oil Mixture	Production	Coaliquid, Inc.	Shelbyville, Kentucky	3,600--Unknown

FIRST ROUND SOLICITATION AWARDS

FS*	CA	GENERIC TECHNOLOGY**	SPECIFIC TECHNOLOGY	PROPOSER	SITE	REQUESTED FUNDING (\$ MILLIONS)	POTENTIAL PRODUCTION (BOE/D)
	X	Ind. Liquefaction	Lurgi/Fischer-Tropsch	Texas Eastern Synfuels	Henderson, Kentucky	24.3	56,000
2		Ind. Liquefaction (Methanol)	Lurgi	Dakota Company	Dunn, North Dakota	4.0	40,000
8		Ind. Liquefaction (Methanol)	Winkler Gas/ICI Synth.	Cook Inlet Region	West Side of Cook Inlet, Alaska	3.9	22,900
1		Ind. Liquefaction (Gasoline)	HBC for Combined Cycle K-T, Lurgi	Hampshire Energy	Gillette, Wyoming	4.0	18,000
3		Ind. Liquefaction (Methanol)	Koppers-Totzek (K-T)	W. R. Grace	Moffat County, NW Colorado	.8	14,000
14		Ind. Liquefaction (Gasoline)	K-T Gasifier/ICI/Mobil MFC	Clark Oil & Refining	S. Illinois	4.0	11,600
6		Ind. Liquefaction (Methanol)	Texaco Gasifier	Houston Natural Gas/Texaco	Covent, Louisiana	3.3	11,400
12		Ind. Liquefaction (Liquids/MFC)		Celanese Corp.	Near Bishop, Texas	No Cost	10,000

*DOE ranking within technology category (e.g., HBC).

**See Page 4 for definition of abbreviations used.

FIRST ROUND SOLICITATION AWARDS (CONTINUED)

FS*	CA	GENERIC TECHNOLOGY**	SPECIFIC TECHNOLOGY	PROPOSER	SITE	REQUESTED FUNDING (\$ MILLIONS)	POTENTIAL PRODUCTION (BOE/D)
5		Ind. Liquefaction (Methanol)	K-T or Lurgi Gasifiers	AMAX, Inc.	Duluth, Minnesota	2.2	6,800
	X	HBC	Lurgi & Texaco	Wycoal Gas, Inc.	Douglas, Wyoming	13.2	51,000
3		HBC (plus Methanol)	Lurgi	Texas Eastern Synfuels, Inc.	East of Navajo Indian Reservation	3.0	43,000
4		HBC	Lurgi	Crow Tribe of Indians	East of Billings, Montana	2.7	22,000
	X	HBC	Lurgi	Great Plains Gasification Assoc.	Mercer County, North Dakota	22.0	14,000
		HBC (from Peat)		Minnesota Gas Company	Minnesota	4.0	13,000
6		MBG		Transco Energy	Calvert, Texas	1.9	21,550
1		LBG/MBG		Union Carbide	Houston, Texas	3.9	21,550
11		MBG		Philadelphia Gas Works	Philadelphia, Pennsylvania	1.2	3,448
2		LBG		General Refractories	Florence, Kentucky	.9	1,034

*DOE ranking within technology category (e.g., HBC).

**See Page 4 for definition of abbreviations used.

FIRST ROUND SOLICITATION AWARDS (CONTINUED)

FS*	CA	GENERIC TECHNOLOGY**	SPECIFIC TECHNOLOGY	PROPOSER	SITE	REQUESTED FUNDING (\$ MILLIONS)	POTENTIAL PRODUCTION (BOE/D)
14		MBC/CCG	E-T or Slagging Lurgi	EC&C	Fall River, Massachusetts	4.0	28,500
4		MBC/CCG	Texaco Gasifier	Central Maine Power	Waldo County, Maine	3.6	14,138
5		MBC/CCG		Florida Power	Pinellas County, Florida	1.4	7,438
3		Oil Shale (Eastern)		Transco Energy Company	Lewis County, Kentucky	3.8	50,000
2		Oil Shale (Western)	Paraho Surface Retort	Paraho Development Corp.	Utah County, Utah	1.2	30,000
4		Oil Shale (Western)	Geokinetics In-Situ	Geokinetics	Utah County, Utah	1.9	2,000-7,800
1		Oil Shale Upgrading		Union Oil Energy Mining	Grand Valley, Colorado	4.0	10,000
2		Oil Shale Upgrading	UOP Hydro-processing & Hydro-Crack.	Gary Energy Corp.	Fruita, Colorado	3.0	10,000
8		Tar Sand		Natomas Energy Co.	Utah or California	.4	20,000
1		Tar Sand		Standard Oil of Indiana	Sunnyside, Utah	No Cost	2,000

*DOR: ranking within technology category (e.g., HBC).

**See Page 4 for definition of abbreviations used.

FIRST ROUND SOLICITATION AWARDS (CONCLUDED)

FS*	CA	GENERIC TECHNOLOGY**	SPECIFIC TECHNOLOGY	PROPOSER	SITE	REQUESTED FUNDING (\$ MILLIONS)	POTENTIAL PRODUCTION (BOE/D)
2		Uncon. Gas (Tight Gas)	Massive Hydraulic Fracturing	Mountain Fuel Supply Co.	Sublette County, Wyoming	1.8	2,120
3		Uncon. Gas (In-Situ Gasif. & Conv. to Liquids)		Republic of Texas Coal Co. & Mitchell Energy Corp.	Texas Gulf Coast	.8	1,440
	X	Uncon. Gas (Coal-Bed)		U.S. Steel Corp.	Oak Grove, Alabama	.6	200
6		Uncon. Gas (Devonian)		Seneca Indian Nation	Salamanca, New York	.9	34
	X	COM		Banklick Corp.	Blount Island, Florida	1.0	6,000

*DOE ranking within technology category (e.g., HBG).

****Definitions of Abbreviations Used:**

CA - Cooperative Agreement
 CCG - Combined Cycle Gasification
 COM - Coal-Oil Mixtures
 FS - Feasibility Study
 HBG - High-Btu Gas

Ind. Lfq. - Indirect Liquefaction of Coal
 LBG - Low-Btu Gas
 MBG - Medium-Btu Gas
 SNG - Synthetic Natural Gas
 Tar Sand - Heavy Oil from Tar Sands
 Uncon. Gas - Unconventional Natural Gas

SUPPORTING AND ADVANCED FOSSIL ENERGY TECHNOLOGIES

- **Coal Mining and Preparation**
- **Drilling, Offshore and Arctic Technology**
- **Gas and Liquids Supply**
 - **Advanced Surface Coal Gasification Concepts**
 - **Peat Gasification**
 - **Underground Coal Gasification**
 - **Coal-Bed Methane**
- **Direct Utilization**
 - **Advanced Combustion Systems**
 - **Fuel Cells**
 - **High Temperature Turbine**
- **MHD**

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FOSSIL ENERGY TECHNOLOGY ASSESSMENT

Presented by Fossil Energy

December 1980

PURPOSE

- **Identify the Technical Readiness of Fossil Energy Technologies Which Are**
 - Ready for Immediate Deployment (First Wave)
 - Under Development and Could Be Deployed by the Late 1980's (Second Wave)
 - Necessary to Support Deployment of These Technologies or Represent Advances and Could Be Deployed in the 1990's
 - Currently Being Considered by Industry
 - Response to Alternative Fuels Solicitation
 - Announced Plans
- **Identify the Highest Priority R&D Tasks Required to Reduce Technical Risks and Remove Uncertainties**

TECHNOLOGY ASSESSMENT NOT LIMITED BY

- **Capital Costs**
- **Cost of Product**
- **Process Efficiency**
- **Infrastructure Constraints**
- **Institutional and/or Regulatory Barriers**
- **Availability of Other Needed Resources**
- **Socioeconomic Impacts**

SUMMARY

- The Domestic Fossil Resource Base Is Very Extensive.
- There Are a Number of Commercially Available Technologies That Can Be Deployed Now.
- Industry Has Responded with Widespread Interest to DOE Solicitations.
- Improved Technology in the R&D Pipeline Can Be Available by the Late 1980's.
- Supporting Technologies Require Further Development.
- Advanced Technologies Are Under Study and Could Be Available in the 1990's.
- Implications for R&D
 - Commercially Available (First Wave) Technologies Need Supporting and Environmental R&D.
 - Both Industry and Government R&D Programs Need Redirection to Assure Commercial Availability of Improved Technologies by the Late 1980's.

FOSSIL RESOURCE BASE

(Estimated)

Western Oil Shale	600 Billion Barrels (25 Gallons/Ton or More) 1200 Billion Barrels (15-25 Gallons/Ton)
Eastern Oil Shale	1000 Billion Barrels (10-25 Gallons/Ton)
Heavy Oil	74 Billion Barrels
Light Oil	230 Billion Barrels
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Tight Gas Formations	56-140 Billion Barrels Oil Equivalent
*Conventional Oil	150 Billion Barrels
*Conventional Gas	130 Billion Barrels Oil Equivalent

*Mean Resources — USGS

MAJOR LEGISLATIVE ACTIONS WHICH AFFECT FOSSIL ENERGY TECHNOLOGIES

- **Energy Security Act of 1980**

- Goals**

- 500,000 BBL/Day Crude Oil Equivalent by 1987
 - 2,000,000 BBL/Day Crude Oil Equivalent by 1992

- Implementation**

- Defense Production Act (Amended 1980) to Procure Synthetic Fuel
 - Synthetic Fuels Corporation

- **Alternative Fuels Solicitations (PL 96-126 — First Round;
PL 96-304 — Second Round)**

- Feasibility Studies
 - Cooperative Agreements
 - Incentives

- **Incentives under National Energy Act of 1978**

INDUSTRIAL RESPONSE TO DOE SOLICITATIONS

Technology	1st Round Responses		2nd Round Responses		Incentives Responses
	FS	CA	FS	CA	
Liquids					
Coal					2
Shale					6
Tar Sands					3
COM					2
Peat					1
Gases					
Coal					
SNG					1
Low/Med BTU					
Underground Coal Gasification					
Unconventional					
Tight Sands					
Devonian					
Coal-Bed Methane					
Peat					

AWARDS TO FIRST ROUND ALTERNATIVE FUEL SOLICITATION

● Feasibility Studies

Coal Gasification	7
Combined Cycle (Gasification)	3
Indirect Liquefaction	8
Oil Shale	5
Tar Sands	2
Unconventional Gas	3

● Cooperative Agreements

Indirect Liquefaction	1
Coal Gasification	2
Coal-Bed Methane	1
Coal-Oil Mixtures	1

FIRST WAVE TECHNOLOGIES

Liquids

- Oil Shale — Surface Retorting
- Indirect Liquefaction — Fischer-Tropsch; Methanol; Methanol/Gasoline
- Enhanced Oil Recovery — Heavy Oils
- Enhanced Oil Recovery — Light Oils

Gases

- Surface Coal Gasification
- Tight Blanket Gas Formations
- Devonian Shale

Direct Utilization

- Pulverized Coal Firing/Improved Flue Gas Scrubbers
- Coal-Oil Mixtures
- Small Industrial AFB
- Synthetic Fuels — Low, Medium-BTU Gas, and Synthetic Liquids

SECOND WAVE TECHNOLOGIES

Liquids

- **Oil Shale**
 - Modified In-Situ, Advanced Mining and Retorting
- **Direct Coal Liquefaction**
 - SRC-I and II, EDS, H-Coal
- **Indirect Liquefaction**
 - Advanced Fischer-Tropsch and Alternative Synthesis Processes
- **Enhanced Oil Recovery**
 - Downhole Steam Generation for Heavy Oil
 - Chemical and Gas Flooding for Light Oil
- **Tar Sands**
 - Surface Mining and Recovery
 - In-Situ Recovery

Gases

- **Surface Coal Gasification**
 - Improved Entrained, Moving and Fluidized-Bed Gasifiers
- **Western Tight Gas**
 - Stimulation of Lenticular Formation

SECOND WAVE TECHNOLOGIES (CONCLUDED)

Direct Utilization

- **Direct Coal Firing**

- Dry and Regenerable Scrubbers
- Atmospheric Fluidized-Bed Combustion (Large Industrial, Utility)

- **Combined Cycles**

- Gasifier Combined Cycle Systems
- Pressurized Fluidized-Bed Combined Systems

- **Coal-Based Mixtures**

- Coal-Oil Mixtures Extension
- Coal-Water Mixtures
- Coal-Synfuels Mixtures

SUPPORTING AND ADVANCED FOSSIL ENERGY TECHNOLOGIES

- **Coal Mining and Preparation**
- **Drilling, Offshore and Arctic Technology**
- **Gas and Liquids Supply**
 - **Advanced Surface Coal Gasification Concepts**
 - **Peat Gasification**
 - **Underground Coal Gasification**
 - **Coal-Bed Methane**
- **Direct Utilization**
 - **Advanced Combustion Systems**
 - **Fuel Cells**
 - **High Temperature Turbine**
- **MHD**

OIL SHALE

First Wave — Surface Retorting

Second Wave — Modified In-Situ

Advanced Mining and Surface Retorting

ABOVEGROUND OIL SHALE PROCESSING OPERATIONS

OIL SHALE - FIRST WAVE

R&D SUPPORT

- Advanced Technology for Underground Mining
 - Shaft Sinking
 - Mechanized Extraction
 - Haulage
- Retort, Design, Operation and Control
 - Chemical Kinetics and Mechanisms
 - Scaleup
 - Demonstration of Equipment Reliability
 - Gas/Solids Contact and Temperature Control
 - Management of Solids Flow
- Upgrading Methods
 - Laboratory - Pilot-Scale Testing
 - Product Slate Flexibility
- Environmental R&D
 - Air Pollution
 - Wastewater Treatment
 - Acceptable Solid Waste Disposal Methods

MODIFIED IN-SITU

Vertical Modified In-Situ Process

Horizontal Modified In-Situ Process

OIL SHALE - SECOND WAVE

Processes: Modified In-Situ, Advanced Mining and Retorting

Advantages: Expected to Use Less Water; Create Less Problems With Disposal of Solid Residues; May Be More Applicable to Lower Grade Resources Than Wave I Processes.

R&D Needed:

Modified In-Situ

- Retort Clusters Preparation
- Retort Rubblizing Scaleup
- Improved Drilling
- Mine Ventilation
- Process Control/Instrumentation
- Improved Product Recovery
- Environmental Control, Air and Water
- Retort Abandonment

Commercial Demonstration by Mid-to-Late 1980's

INDIRECT COAL LIQUEFACTION

- First Wave**
 - Fischer-Tropsch
 - Methanol
 - Methanol to Gasoline — Fixed Bed
- Second Wave**
 - Integration with Second Wave Gasifiers
 - Alternative Synthesis and Upgrading Processes

INDIRECT LIQUEFACTION TECHNOLOGY

INDIRECT LIQUEFACTION - FIRST WAVE
R&D SUPPORT

- Liquefaction
 - Scaling of Methanol-to-Gasoline Fixed Bed
 - Upgrading of Fischer-Tropsch Liquids
- Product Characterization
 - Transportation and Storage
 - End-Use Testing
- Environmental R&D
 - Characterization of Effluents (Air, Wastewater, Solid Waste)
 - Wastewater Treatment
 - In-Plant and Public Health and Safety

Indirect Liquefaction

Process: Advanced Fischer-Tropsch, Alternative Synthesis Processes

R&D Needed:

- Fluid-Bed Process for Methanol-to-Gasoline
- Advanced Fischer-Tropsch (Kobel Process)
- Three-Phase Methanol Synthesis
- Fuel Grade Alcohol Synthesis
- Selective Catalysts for F-T Product Upgrading

DIRECT COAL LIQUEFACTION

First Wave — None

Second Wave — SRC I and II

— EDS

— H-Coal

COAL LIQUEFACTION GENERALIZED FLOW DIAGRAM

B-103

DIRECT LIQUEFACTION - SECOND WAVE

Processes: SRC-I and II; H-Coal, EDS

Advantages: Potentially Less Costly Products and More Energy Efficient Than First Generation Processes.

R&D Needed:

- Bottoms Processing and Hydrogen Generation
 - Gasification for Hydrogen Production from Residue (Texaco - SRC-II; K-T - SRC-I)
 - Flexicoking (EDS)
- Solid-Liquid Separation
 - Scaleup Design Data (SRC-I, H-Coal Fuel Oil Mode)
- Slurry Preheating
 - Scaleup Design Data
 - Heat Transfer and Hydraulic Properties
- Components and Materials
 - Erosion and Corrosion Resistant Materials
 - Component Reliability

DIRECT LIQUEFACTION - SECOND WAVE (CONTINUED)

R&D Needed (Concluded):

- Products Handling, Upgrading and Utilization
 - Upgrading to Specification Fuels
 - Carcinogenicity Before and After Upgrading
 - Additional Combustion Tests

ENHANCED OIL RECOVERY

First Wave

- Heavy Oils
 - Steam Flooding and Cyclic Steam
 - In-Situ Combustion
- Light Oils
 - Gas and CO₂ Flooding
 - Polymer Flooding

Second Wave

- Heavy Oil
 - Insulation and/or Downhole Steam Generation
- Tar Sands
 - Surface Mining and Recovery
 - In-Situ Recovery
- Light Oil
 - Chemical Flooding
 - Gas Flooding

ENHANCED OIL RECOVERY - FIRST WAVE
R&D SUPPORT

- Heavy Oils
 - Mobility Control: Improved Sweep Efficiency
 - Environmentally Acceptable Steam Generation With Alternate Fuels
 - Control of In-Situ Recovery Technique
- Light Oils
 - Mobility Control
 - Reservoir Plugging
 - Polymer Stability
 - Better Reservoir Characterization
- Environmental R&D
 - Preventing Contamination of Freshwater Aquifers
 - Assessing the Risk of Transport Storage and Use of EOR Chemicals

ENHANCED OIL RECOVERY - SECOND WAVE

Process: Heavy Oil Recovery

R&D Needed:

- Insulation and/or Downhole Steam Generation
- Improved Sweep Efficiency
- Improved Chemicals

Process: Tar Sands

R&D Needed:

- Separation of Bitumen from Ore
- Forward and Reverse In-Situ Combustion
- Interwell Communication

Process: Light Oil Recovery

R&D Needed:

- Mobility-Controlled Gas Flooding
- Chemical and Physical Mechanisms and Interactions
- Prevention of Deterioration

SURFACE COAL GASIFICATION

First Wave

- Lurgi**
- Winkler**
- Koppers-Totzek**
- Texaco (Initial Operations)**

Second Wave

- Entrained Gasifiers**
 - Shell-Koppers
 - Saarberg-Otto
 - C-E
- Moving Bed Gasifiers**
 - CONOCO BGC Slagging Lurgi
 - Lurgi Ruhr-100
- Fluidized-Bed Gasifiers**
 - ICGG COGAS
 - U-Gas
 - Westinghouse
 - High-Temperature Winkler

FLEXIBILITY OF COAL GASIFICATION

SURFACE GASIFICATION - FIRST WAVE
R&D SUPPORT

- Performance on U.S. Coals
 - More Information Required
- Near-Term Development
 - Refractory Life
 - Coal Feeding and Ash Discharge
 - Improved Waste Heat Boilers
 - Advanced Stirrer Technology
- Environmental
 - Tar Removal/Utilization
 - Particulate Removal
 - Fines Utilization
 - Wastewater Treatment and Reuse
 - Ash Disposal
 - Performance Testing of Control Technology

SURFACE COAL GASIFICATION - SECOND WAVE

Processes: Shell-Koppers, Saarberg-Otto, C-E, CONOCO BGC Slagging Lurgi, Lurgi Ruhr-100, ICGG COGAS, U-Gas, Westinghouse, High-Temperature Winkler

R&D Needed:

- Demonstrate Gasifiers With Appropriate End-Use Applications (Synthesis Gas, Fuel Gas, SNG)
- Coal Feeding, Preparation, and Fines Management
- Reactor Design and Performance
- Components, Instrumentation, and Materials
- Emission Characterization and Control (Air, Water, Solid)

ENHANCED GAS RECOVERY

- First Wave
 - Devonian Shale
 - Hydraulic Fracturing
 - Wellbore Shooting
 - Western Tight Blanket Gas Sands
 - Massive Hydraulic Fracturing
- Second Wave
 - Western Tight Sand Lenticular Formations

DEVONIAN SHALE

TIGHT GAS SANDS

ENHANCED GAS RECOVERY - FIRST WAVE
R&D SUPPORT

- **Instrumentation for Reservoir Characterization**
- **Resource Characterization**
- **Improved Stimulation Techniques - Multiple Stimulations**
- **Improved Propped Fractures**
- **Environmental R&D**
 - **Fracturing into Freshwater Aquifers**
 - **Water Availability**

ENHANCED GAS RECOVERY - SECOND WAVE

Process: Western Tight Sands, Lenticular Formation

R&D Needed:

- Reservoir Measurement and Characterization
- Improve Fracturing Techniques (Advanced Massive Hydraulic, Foam, Explosive Fracturing)
- Apply Technology to Stimulate Lenticular Formations

Demonstration by Mid-to-Late 1980's

DIRECT UTILIZATION

- First Wave**
 - Pulverized Coal Firing/Improved Flue Gas Scrubbers
 - Coal-Oil Mixtures
 - Small Industrial AFB
 - Synthetic Fuels Utilization
- Second Wave**
 - Direct Coal Firing/Advanced Scrubbers
 - Large Industrial and Utility AFB
 - Gasification and PFB Combined Cycle Systems
 - Coal-Based Mixtures

PRESSURIZED FLUIDIZED-BED COMBINED CYCLE SYSTEM

GASIFICATION COMBINED CYCLE SYSTEM

DIRECT UTILIZATION - FIRST WAVE

R&D SUPPORT

- Conventional Combustion
 - Lime/Limestone Improvement Including Reliability and Sludge Stabilization
 - Waste Disposal Strategies
- Coal-Oil Mixtures
 - Improved Components for Feeding
 - Investigation of Additional Coals/Precleaning
 - Full-Scale Coal and Oil Design Boiler Test
- Atmospheric Fluidized Bed (Small Industrial)
 - Carbon Burnup
 - Sorbent Utilization
 - Reliability and Control
- Synthetic Fuel-Gas
 - Waste Heat Boiler Improvements
 - Develop Hot Gas Cleanup Technologies
- Synthetic Fuel-Liquids
 - Performance, Reliability, and Emission Test on Gas Turbines, Diesels, Boilers
 - Occupational Health and Safety Concerns

DIRECT UTILIZATION - SECOND WAVE

Direct Coal Firing

Process: Improved Scrubbers

R&D Needed

- Development and Demonstration of Dry and Regenerable Scrubber Systems
- NO_x Control
- Fine Particulate

Process: Atmospheric Fluidized Bed (Large Industrial, Utility)

R&D Needed

- Large Industrial and Utility Demonstration
- Improve Carbon Burnup
- Improve Sorbent Utilization
- Tests on Wide Range of Coals

DIRECT UTILIZATION - SECOND WAVE (CONTINUED)

Combined Cycle

Process: Gasifier Combined Cycle System for Electricity Generation

R&D Needed:

- High Temperature Heat Exchanger
- High Temperature Turbines (2300⁰)
- Hot Gas Cleanup
- Control Systems

Process: Pressurized Fluidized-Bed Combined Cycle System for Electricity Generation

R&D Needed:

- Coal Feeding and Ash Letdown Under Pressure
- Hot Gas Cleanup
- Turbine

DIRECT UTILIZATION - SECOND WAVE (CONTINUED)

Coal-Based Mixtures

Processes: Coal-Oil Mixtures, Coal-Water Mixtures, Coal-Synfuels Mixtures

R&D Needed:

- Boiler Tests
- Mixture Preparation and Beneficiation
- Environmental Control

SUMMARY

- **The Domestic Fossil Resource Base Is Very Extensive.**
- **There Are a Number of Commercially Available Technologies That Can Be Deployed Now.**
- **Industry Has Responded with Widespread Interest to DOE Solicitations.**
- **Improved Technology in the R&D Pipeline Can Be Available by the Late 1980's.**
- **Supporting Technologies Require Further Development.**
- **Advanced Technologies Are Under Study and Could Be Available in the 1990's.**
- **Implications for R&D**
 - **Commercially Available (First Wave) Technologies Need Supporting and Environmental R&D.**
 - **Both Industry and Government R&D Programs Need Redirection to Assure Commercial Availability of Improved Technologies by the Late 1980's.**

SUPPORTING AND ADVANCED FOSSIL ENERGY TECHNOLOGIES

- **Coal Mining and Preparation**
- **Drilling, Offshore and Arctic Technology**
- **Gas and Liquids Supply**
 - Advanced Surface Coal Gasification Concepts
 - Peat Gasification
 - Underground Coal Gasification
 - Coal-Bed Methane
- **Direct Utilization**
 - Advanced Combustion Systems
 - Fuel Cells
 - High Temperature Turbine
- **MHD**