TECHNOLOGY ASSESMENT GUIDE
NO. 4b
TEXACO

CHAPTER ONE: EXECUTIVE SUMMARY

1.1 OVERALL PROSPECTS FOR THE TECHNOLOGY

The development of the Texaco coal gasifier was based upon over 40 years experience in the gasification of petroleum residual oils which are produced as part of the refining of crude oil. Although the Texaco device does not have the years of commercial operating experience that others do, its design is based upon similar experience. In addition, testing at a large pilot plant scale has been accomplished and construction activities are underway for a very large combined cycle power plant which will use Texaco gasification technology.

The flexibility offered by the entrained flow nature of the device, together with the option of gasifying with either air or oxygen, at high pressures or low gives the Texaco gasifier a broad range of application. This flexibility makes it potentially useful as a source of gas for:

- industrial boiler retrofitting
- synthesis gas generation
- combined cycle power generation
- industrial fuel gas generation

This adaptability and the sound engineering design of the Texaco system will guarantee it a significant role in a domestic synthetic fuels industry based on coal.

1.2 ENGINEERING ASPECTS

The Texaco gasifier is similar to other entrained flow systems in many respects. The use of pulverized coal is required because of the entrainment of the coal particles by the oxidizing gas reactant. This use of pulverized coal suggests that the Texaco system could be advantageously used in conjunction with a Lurgi or other system which required crushed coal. The fines resulting from crushing and sizing operations to generate the sized coal could then be used by the Texaco system rather than sold or burned in a power plant.

Caking coals can be gasified readily in entrained flow reactors because of the relatively large inter-particle distance typical of the reacting medium.

The Texaco gasifier, like other entrained flow gasifiers, operates at high temperatures and high gas velocities. Thus, no tars or oils are produced which complicate downstream heat exchange and water treating activities, but neither is any methane produced. Methane production is desirable in cases where a synthesis gas is being generated solely to produce SNG (substitute natural gas).

The Texaco gasifier is unlike many entrained flow systems in its ability to operate at high pressure. Coal feed to a pressurized reactor is accomplished by injection of a coal-water slurry. Although the slurry has a high coal concentration, additional oxygen is required and greater amounts of CO_2 are generated due to the presence of this water. The pumps used to feed the slurry are also subject to high wear rates because of the abrasive nature of the coal particles.

The low turndown ratio common to other entrained flow gasifiers also applies to the Texaco device. The high temperatures required to produce a fast reaction rate consume more oxygen than other gasifier types, (even slightly higher than some other entrained flow systems), increases wear rates of refractory and metal components and strongly suggests that waste heat recovery equipment be used to process the raw gasifier effluent (rather than direct quenching) in the interest of maximum efficiency.

Operating parameters and characteristics of other downstream equipment will primarily be a function of coal type and application and is thus relatively unaffected by gasifier characteristics.

1.3 CURRENT COSTS

The total capital requirement for this 50 x 10^{12} Btu per year plant is $534 million, slightly lower than that required for a Koppers-Totzek facility of the same size. The total plant investment of $388 million and interest during construction of $96 million comprises most of the capital requirement. Real differences exist in the cost of gasification and raw gas cooling (less than $100 million for Texaco, and approximately $150 million for K-T).

Annual operating and maintenance (at a 90% plant capacity factor) costs, exclusive of coal costs, total $41.1 million, slightly higher than the $35.4 million for K-T (the reader should bear in mind that these values are based upon different sources and therefore may not be strictly comparable). Major items contributing to these costs are maintenance, supplies and labor, local taxes and insurance (as was the case for K-T). By-product sulfur is credited at $40/ton and reduces operating and maintenance costs to a net of $38.1 million per year.

Taken together with a 20 percent capital charge, these operating costs result in a product cost (exclusive of coal cost) of $3.28/10^6 Btu.

1.4 RESEARCH AND DEVELOPMENT DIRECTIONS

Texaco is actively conducting research into the optimization of gasifier performance in a variety of operating modes, including pressure ranges from atmospheric to 600 psi, the use of air and oxygen for gasification, and the performance of a variety of coals.

Of critical importance to most applications of the Texaco gasifier is the performance of the waste heat recovery system. Texaco is using a design of the helical fire-tube type in which the hot gases pass on the tube side of a gas to water exchanger. The scouring action of the gas and suspended particulates helps prevent the deposition of frozen slag on the tube walls.

A further boost in efficiency would result from the elimination of the slurry feed system. Direct pneumatic injection would obviate the water used in the slurry system, which increases oxygen consumption, decreases raw gas heating value and increases the load on the acid gas removal system. Improvements in the efficiency of mixing of gaseous and solid reactants will also have similar results, and will control unreacted carbon levels to near their equilibrium levels.

2.1 GENERAL DESCRIPTION OF THE TECHNOLOGY

In the Texaco Coal Gasification Process (TCGP), ground coal is mixed with water to form a slurry and is reacted with oxygen in a pressurized entrained-flow slagging gasifier. Operating typically at temperatures between 2400°F and 2700°F, the reactor produces a fuel gas which is virtually free of tars, phenols, and oils - thus reducing the need for waste water and byproduct cleanup facilities.[2-1] The fuel gas passes through coolers to generate process steam and is scrubbed for the removal of particulates. An acid gas removal system cleanses the gas of H_2S and COS, yielding a low-sulfur medium-Btu (290 Btu/scf) fuel product.

The Texaco process has developed as a direct result of the Texaco Synthesis Gas Generation Process (TSGGP), which has been researched and commercially implemented since the 1940's. The TSGGP generates synthesis gas from gaseous and liquid hydrocarbon products ranging from naphthas to asphalt. The coal gasification process, on the other hand, is designed to produce gaseous products from solid feedstocks such as coke and coal. Developmental and pilot plant work on coal gasification began in the 1950's, and plans for construction of commercial plants to produce fuel gas and industrial chemicals were announced in 1980.

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2.2 PROCESS FLOW, ENERGY, AND MATERIAL BALANCES

Chemical process units which are integral to the Texaco Coal Gasification Process are listed with corresponding plant area numbers in Table 2-1, while the interaction among these units is shown in the conceptualized process flow diagram of Figure 2-1. Detailed analyses of process flow streams in the Texaco process (based on data in Reference 2-2) are given in Table 2-2.

As shown in Figure 2-1, coal as received is conveyed to a grinding and slurry preparation area, where a mixture of approximately 65 percent coal in water by weight is prepared. The slurry is pumped to a cylindrical gasifier, where it is reacted with oxygen at approximately 2500°F and 600 psig average pressure. The gasifier is of the entrained flow slagging type, with coal and oxidant reacted in vertical downflow. Molten slag is removed from the bottom of the vessel, while a synthesis gas consisting primarily of CO and H_2 exits from the top. Fuel nitrogen is converted to ammonia or diatomic nitrogen gas, while sulfur exists as COS and H_2S. Carbon conversion, which typically exceeds 90 percent, is adjusted by oxidant feed levels, while the high gasification temperatures minimize the production of tars, oils, and phenols. Slag from the gasifier is delivered to an ash dewatering system, which separates water from coal ash. The water can be pumped to a treatment plant or reused in slurry preparation, while the ash is sent to a disposal area.

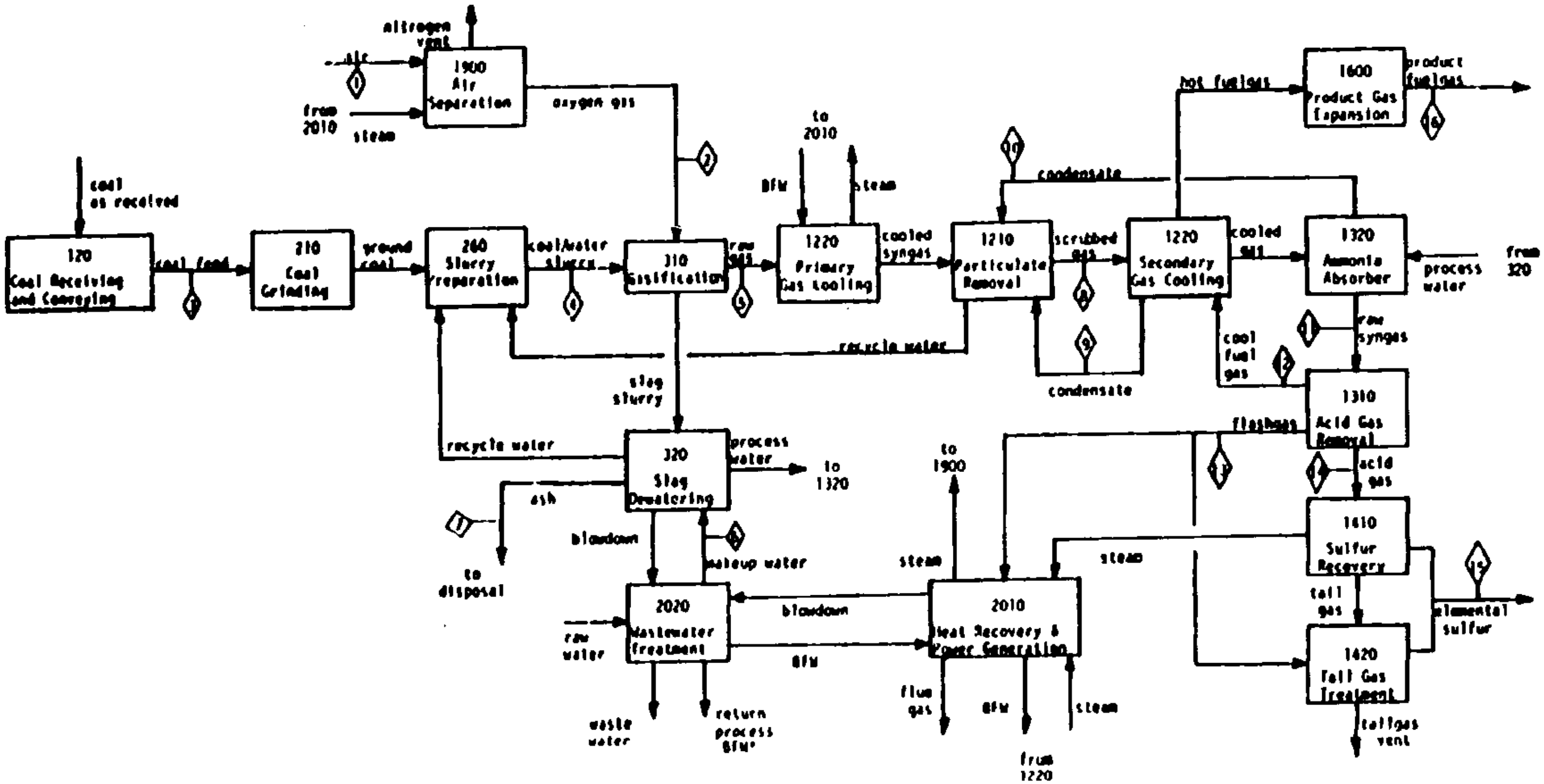
Table 2-1

Relevant Texaco Process Plant Area Numbers

100	COAL STORAGE AND HANDLING	
		120 Coal Receiving and Conveying
200	COAL PREPARATION	
		210 Coal Grinding
		260 Slurry Preparation
300	GASIFICATION	
		310 Gasification
		320 Slag Dewatering
1200	RAW GAS COOLING	
		1210 Particulate Removal
		1220 Gas Cooling
1300	ACID GAS REMOVAL AND GAS COOLING	
		1310 Acid Gas Removal
		1320 Ammonia Absorption
1400	SULFUR RECOVERY AND TAIL GAS TREATING	
		1410 Sulfur Recovery
		1420 Tail Gas Treatment
1600	PRODUCT GAS EXPANSION	
1900	AIR SEPARATION	
2000	UTILITIES AND SUPPORT SYSTEMS	
		2010 Heat Recovery and Power Generation
		2020 Wastewater Treatment
2100	OFFSITES AND MISCELLANEOUS	

Figure 2-1

Texaco Coal Gasification Process Conceptualized Process Flow Diagram



* BFW returned to units 1210, 1220, and 1410.
Flow streams omitted for clarity.

Table 2-2

Texaco Coal Gasification Process Flow Stream Descriptions

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Stream	1		2		3		4		5		6		7		8	
Description	Air Intake		Oxygen Gas		Coal as Received*		Coal/Water Slurry		Raw Gasifier Effluent		Makeup Water		Ash Disposal Stream		Scrubbed Syngas	
Temperature(°F)	88		300						2300-2600		70				352	
Pressure(psig)	0		720						720						557	
	klb/hr	mole %	klb/hr	mole %	klb/hr		klb/hr		klb/hr	mole %	klb/hr	mole %	klb/hr		klb/hr	mole %
CH_4									0.89	0.08					0.88	0.07
H_2									40.06	28.24					39.74	26.58
CO									819.32	42.45					819.02	39.13
CO_2									264.30	8.21					262.41	8.13
H_2S									23.65	1.01					20.82	0.95
COS									2.49	0.06					2.48	0.05
N_2	1840.43	76.07	7.07	1.50					12.79	0.66					12.79	0.61
Ar	38.83	0.98	3.31	0.50					3.31	0.12					3.31	0.11
NH_3									2.32	0.19					2.32	0.19
O_2	566.22	20.48	523.81	98.00												
H_2O	38.42	2.47					280.41		221.96	17.88	421.52	100	40.80		325.52	24.20
Coal					637.50		637.50									
Ash													61.20			
TOTALS	2478.90		534.19		637.50		917.91		1390.89		421.52		102.00		1494.29	

* See Table 2-4 for coal analysis.

Table 2-2

Texaco Coal Gasification Process Flow Stream Descriptions

Stream	9		10		11		12		13		14		15		16	
Description	Process Condensate		Process Condensate		Raw Synthesis Gas		Cool Fuel Gas		Flash Gas		Acid Gas		Elemental Sulfur		Product Gas	
Temperature(°F)	219		219		100		105		105		120					
Pressure(psig)					532		527		95		7					
	klb/hr		klb/hr		klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr		klb/hr	mole %
CH_4					0.88	0.10	0.86	0.10	0.01	0.16	0.003	0.01			0.86	0.10
H_2					39.74	35.79	39.62	36.38	0.11	12.61	0.01	0.25			39.62	36.38
CO					819.00	51.81	813.69	53.36	4.62	37.62	0.69	1.59			813.69	53.36
CO_2					267.41	10.77	221.75	9.26	8.20	42.49	34.05	49.98			221.75	9.26
H_2S					20.82	1.23	1.65	0.10	0.75	5.70	18.41	39.63			1.65	0.10
COS					2.40	0.07	1.60	0.05	0.08	0.31	0.80	0.86			1.60	0.05
N_2					7.65	0.48	7.59	0.50	0.05	0.42	0.01	0.01			7.59	0.50
Ar					3.32	0.14	3.31	0.15	0.01	0.05					3.31	0.15
NH_3																
O_2																
H_2O	331.05		133.34		2.13	0.21	0.93	0.10	0.05	0.63	2.13	7.66			0.93	0.10
Sulfur													31.94			
TOTALS	331.05		133.34		1163.43		1091.00		13.88		56.10		31.94		1091.00	

The hot synthesis gas which leaves the gasifier is directed to a primary gas cooling system in which process stream is produced. A wet scrubbing unit then removes entrained ash and carbon particles from the cooled gas stream. Waste water generated by the scrubber is nominally reused in preparation of the coal/water slurry. Upon removal of particulate matter, the gas is cooled further by a series of indirect heat exchangers and is directed to an absorber column for removal of ammonia.

At this point in the process, acid gas, which contains primarily H_2S and CO_2, must be removed from the fuel gas stream. The acid gas removal unit relies on solvent absorption to greatly reduce these constituents - lowering the sulfur content of the process gas stream to on the order of 150-200 ppm. The resulting fuel gas is normally heated (using the secondary gas cooling unit) and expanded, yielding a medium-Btu product which can be transported to a remote user or combusted on site. A commonly studied use of fuel gas produced by the Texaco process involves on site combustion in gas turbines in a combined cycle system.

The chief byproducts of the main fuel gas processing system are steam and acid gas. A heat recovery and power generation unit produces both process power and electricity for external use from steam. The acid gas is conveyed to a Claus sulfur recovery unit and a tail gas treating unit, which produce tail gas (predominantly CO_2) which is vented to the atmosphere and byproduct elemental sulfur, which can be sold to outside users.

An overall Texaco process plant material and energy analysis is shown in Table 2-3. A total coal input of 7,650 tons per day would be required to produce 50 x 10^{12}Btu/year of gaseous fuel products.

Table 2-3

Overall Material and Energy Balance

Input	Mass Flow Rate klb/Hr	Gross Heating Value MM Btu/Hr
Coal	637.5	7800[a]
Water	280.4	
Oxygen Gas	534.2	
Total Input	1452.1	7800[a]
Products		
Medium-Btu gas	1091	5690[b]
Electrical Power		1077
Sulfur	31.9	128
Total Products		6895
Overall Plant Efficiency		88%

[a]Heat content: 12,235 Btu/lb.

[b]Gas heating value: 290 Btu/scf

2.3 PLANT SITING AND SIZING ISSUES AND CONSTRAINTS

The plant assessed in this technical assessment guide is sized to produce energy in the form of medium-Btu (290 Btu/scf) fuel gas at the rate of 50 x 10^{12} Btu/yr. On-site facilities for receiving and processing of raw coal; separation of oxygen from air; and treatment of solid, gaseous, and liquid effluents are included in the plant design. The complex would have to be located in the vicinity of both a disposal area capable of handling 1200 tons of coal ash per day and adequate transportation routes for high-volume coal shipment.

2.4 RAW MATERIAL AND SUPPORT SYSTEM REQUIREMENTS

2.4.1 Coal Quantities and Quality

For the purposes of this study, Illinois #6 coal is used as gasifier feedstock. An analysis of a typical Illinois coal is given in Table 2-4. Washed coal sized to 1-1/2" x 0 is to be shipped to the gasification plant site by unit train and received at the rate of 7600 tons per day. A dependable supply of this coal would be required for the duration of the plant lifetime - approximately 20 years.

2.4.2 Catalysts and Other Required Materials

The major chemicals required for the successful operation of the Texaco process are used in the acid gas removal and sulfur recovery systems and in boiler feedwater and wastewater treatment facilities. Selexol solvent used in acid gas removal is primarily recycled, although some makeup is required. Demineralizers and clarifiers used in water treatment are mostly lost in blowdowns and must be continually replenished. These chemicals are commercially available, so their supply would not pose a problem to system operation.

2.4.3 Water Requirements

The Texaco coal gasification plant will require an uninterrupted supply of process water for use in power generation, gas scrubbing, and slurry preparation. A potable water supply would be required also. Location of the plant within accessible range of a large water supply would be an important siting criterion.

Table 2-4

Coal Composition

(Illinois #6)

Proximate Analysis

Item	wt %
Moisture	4.2
Ash	9.6
Fixed Carbon	52.0
Volatile Matter	34.2
Total	100.0

Heating Value 12,235 Btu/lb

Ultimate Analysis (composition weight percent)

Element (DAF basis)	wt %
Carbon	77.26
Hydrogen	5.92
Oxygen	11.14
Nitrogen	1.39
Sulfur	4.29
Total	100.00

Source: Reference 2-2

2.5 EFFECT OF COAL TYPE

One of the most important advantages of the Texaco gasifier is its ability to accept a wide range of coal types. Compositions of gasifier effluent derived from western bituminous and eastern bituminous feedstocks are shown in Table 2-5. The relative similarity of these syngas samples is indicative of the gasifier operation's insensitivity to feedstock composition.

In particular, low-rank coal may be an attractive feedstock for the Texaco process. The alkaline nature of low-rank coal ash may result in reduced degradation of the ceramic lining of the gasifier. In addition, the high reactivity of such coals may permit operation of the gasifier at lower temperature than normal - resulting in decreased oxygen consumption and CO_2 production and, consequently, reduced capital costs for air separation and acid gas removal plants. The feasibility of operation at lower temperatures depends on the particular coal feed's ash fusion temperature, which must be low enough to enable the gasifier to operate in the slagging mode. Adjustment of slurry composition may be necessary also if low-rank coals are used because of their relatively high moisture content.

Table 2-5

Typical Syngas Compositions

Coal Composition, wt %	Western Bituminous	Eastern Bituminous
C	74.6	67.6
H	5.3	5.2
S	0.5	3.3
N	1.0	1.0
O	11.4	11.1
Ash	7.2	11.8
Syngas Composition, vol %		
H_2	35.8	35.7
CO	50.7	44.7
CO_2	13.1	18.0
N_2 + Ar	0.2	0.5
CH_4	0.1	0.1
H_2S + COS	0.1	1.1

Source: Reference 2-2

2.6 AIR POLLUTION CONTROL TECHNOLOGY

2.6.1 Ability of Existing Technology to Meet Regulations

The gasification plant described herein has been designed to meet both present and projected air pollution standards. Fuel gas produced by the Texaco process is expected to be an environmentally acceptable gas turbine fuel as well. However, the raw synthesis gas generated by the gasifier contains particulates and sulfur-bearing compounds which must be removed before a "clean" gaseous fuel can be produced.

A water scrubbing system is used to physically cleanse the synthesis gas stream of particulates (see Figure 2-1); the particulate level in the gas is thus reduced to on the order of 0.1 mg/m^3.[2-4] Sulfur-bearing compounds - primarily COS and H_2S - are removed in an acid gas removal unit. Although any of several commercially available absorption processes can be used to remove acid gas, the Selexol absorption process has been used by Texaco in developmental tests. While the acid gas removal unit reduces the fuel sulfur content to the order of 200 ppm, the acid gas itself, consisting mainly of CO_2 and H_2S, is directed to a Claus sulfur recovery unit for the production of elemental sulfur. Tail gases produced by the Claus unit are treated to yield a vent gas composed primarily of CO_2.

2.6.2 Impacts on Process Efficiency

The removal of particulates and sulfur-bearing compounds from the synthesis gas stream is required for the production of a fuel gas which can be burned under environmentally acceptable conditions. Effective removal of particulates is of particular importance to prevent damage to turbine blades if the fuel product is to be combusted in a gas turbine.

The Texaco process also can be designed to produce industrial chemicals instead of fuel gas (see Section 2.10.2 below). In this application, effective removal of sulfur is necessary for the production of chemical products of high purity.

As illustrated in Figure 2-1, the acid gas removal and sulfur recovery units can be important sources of fuel and steam for the heat recovery and power generation system and can produce a marketable byproduct sulfur stream from sulfur contained in synthesis gas.

2.7 WATER POLLUTION CONTROL TECHNOLOGY

2.7.1 Ability of Existing Technology to Meet Regulations

Because of high gasification temperatures, production of byproduct tars, oils, phenols, and heavy hydrocarbons by the Texaco process is kept to a minimum. The small amount of ammonia produced by the process is removed by absorption downstream of the secondary gas cooling unit. This ammonia becomes part of a wastewater stream which includes other organic and inorganic compounds produced by gas cleaning and ash dewatering processes. The wastewater is treated to produce recycled process water, boiler feedwater, and an effluent waste stream.

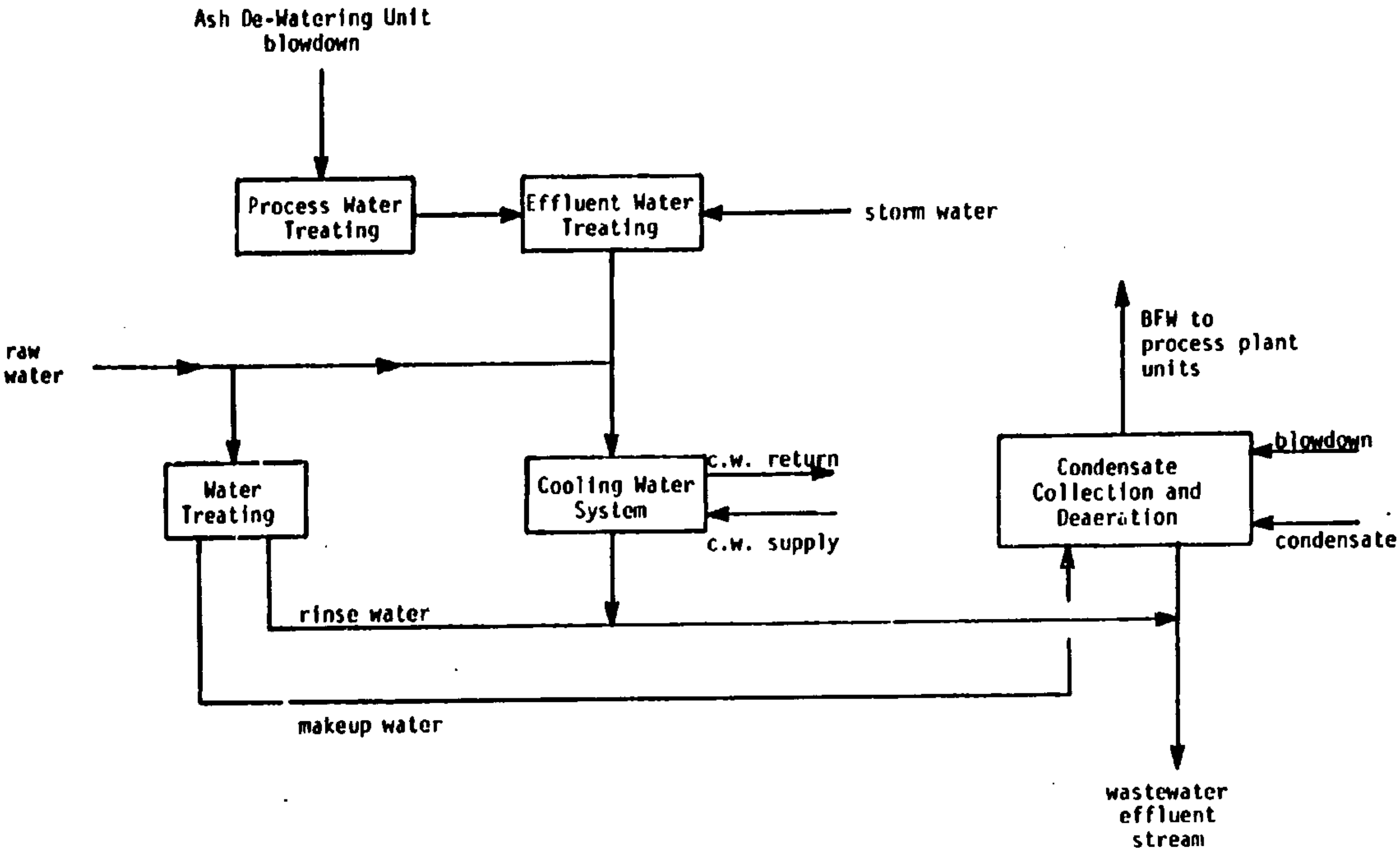
Tests conducted on wastewater generated by the Texaco process have shown that no polynuclear aromatics on the EPA priority pollutant list are generated, and that other organic pollutants are present at levels at or below 30 ppb. Partial results from such tests, which indicate the low pollutant generation level for the Texaco process, are shown in Table 2-6.

2.7.2 Water Recycling Systems

A simplified conceptualized process flow diagram of the Texaco water treatment is illustrated in Figure 2-2. The primary sources of aqueous and suspended pollutants which enter the treatment system are the ash dewatering plant and the gas scrubbing unit. Most of the overall plant wastewater enters the treatment system as ash dewatering unit blowdown. This stream contains not only leached trace elements and ash particles generated directly by ash collection but also synthesis gas effluents which are constantly recycled to the slurry preparation unit by the gas scrubber.

Figure 2-2

Wastewater Treatment System Detail



Source: Reference 2-2

Table 2-6

Characteristics of Wastewater Stream

pH	8.7
Total Organic Carbon	230 ppm
Total Inorganic Carbon	445 ppm

Constituent	Concentration (ppm)
Ammonia	1020
Formate	492
Chloride	432
Sulfide	264
Sulfate	166
Calcium	140
Magnesium	100
Sodium	80
Thiocyanate	70
Thiosulfate	69
Fluoride	39
Cyanide	31
Aluminum	20
Silicon	5.0
Iron	3.7

C_6 + Organics	
Naphthalene	30 ppb
Toluene	20 ppb
Benzene	10 ppb

Source: Reference 2-5

2.7.3 Impacts on Plant Efficiency

Treatment of wastewater streams is necessary in order to remove suspended solids, trace elements, and organic material for reuse of water in plant processes. Much of the treated water stream is fed back to the gasification, synthesis gas processing, and power generation units of the plant. This treatment requires power and steam from the plant for the operation of pumps and reaction vessels. However, such processing facilitates the efficient use of river water by recycling much of it back to the gasification complex.

2.8 SOLID WASTE HANDLING

2.8.1 Disposal Requirements

The primary solid waste byproducts of the Texaco Coal Gasification Process are dry particulates which are removed from the synthesis gas by the particulate removal unit and molten slag which is generated by the gasifier itself. The dry particulate material is removed from the gas in a water stream which is recycled to the coal slurry preparation unit. Hence, solid waste of this form is retained within the system.

The high volumes of slag generated by the gasifier must be processed and removed to a remote site for disposal. First, the molten slag is quenched and conveyed to an ash dewatering unit. Although some trace minerals in the slag may dissolve in the water, the solidifed form of the ash lessens the possibility of contamination. A portion of the water removed from the slag slurry is recycled to the coal feed slurry preparation unit, while the remainder is sent to the wastewater treatment area for processing. The 1200 tons per day of wet ash (734 TPD on a dry basis) produced by the ash dewatering system must be disposed of in a local landfill of suitable size.

2.8.2 Leachate Problems

Because the coal is in the form of solidified slag upon its disposal, the leaching of trace metals from the ash is minimized. ASTM leaching tests using deionized water have been conducted on coarse and fine slag particles generated by the Texaco process gasification of both Eastern and Western coals. Results of a series of such tests are shown in Table 2-7.

2.9 OSHA ISSUES

Operation of the gasification system at high pressures forms the major safety concern of the Texaco system. The product gas contains significant amounts of carbon monoxide, which is heavier than air, and a rupture of vessels or lines could fill the plant with poisonous gas. However, similar problems are routinely faced in many chemical process industries and can be handled by providing adequate precautions, such as vent valves and proper designs for ventilation.

Coal storage and preparation could expose workers to coal dust and noise from the milling operation. The coal storage areas will also present a fire hazard and should be wetted. Pulverized coal must be stored in an inert (nitrogen) atmosphere.

Table 2-7

Results of ASTM Tests for Slag Leachate

	Eastern Coal		Western Coal	
	Coarse Slag	Fine Slag	Coarse Slag	Fine Slag
pH	6.0	7.1	9.6	8.9
TDS, PPM	NR	NR	250	310
Conductivity	100	600	53	135
COD, PPM	NR	NR	45	28
TOC, PPM	2	3	15	9.1
Ammonia, PPM	1.2	4.6	NR	NR
Anions, PPM				
Bromide	<0.1	<0.1	-	-
Chloride	1.5	2.2	-	-
Fluoride	4.9	8.7	-	-
Cyanide	<.001	<.001	-	-
Formate	<1	<1	-	-
Nitrate	0.4	0.5	-	-
Nitrite	<0.1	<0.1	-	-
Sulfate	26.9	313	-	-
Elements, PPM				
Antimony	0.003	0.005	-	-
Arsenic	0.007	0.019	<0.01	<0.01
Barium	<0.38	<0.38	0.04	0.2
Beryllium	<0.001	<0.001	-	-
Boron	-	-	-	-
Cadmium	0.004	0.0006	-	-
Chromium	<0.002	0.002	0.015	0.003
Cobalt	0.029	0.028	<0.002	0.001
Copper	<0.003	0.016	0.03	<0.006
Fluorine	4.9	8.7	-	9.0
Lead	0.005	0.008	-	-
Manganese	0.105	0.212	0.002	0.03
Mercury	<0.005	<0.005	0.01	<0.002
Molybdenum	<0.9	<0.9	-	-
Nickel	0.875	0.131	<0.02	-
Selenium	<0.009	0.027	<0.002	0.05
Silver	<0.002	<0.002	-	-
Thallium	<0.006	<0.006	-	0.001
Vanadium	<1.8	<1.8	0.14	0.16
Zinc	0.098	0.052	<0.09	<0.09

NR-Denotes data not reported.

Source: Reference 2-4

2.10 PROCESS PERFORMANCE FACTORS

2.10.1 Product Characteristics and Marketability

The primary product of the Texaco Coal Gasification Process is a fuel gas with a heating value of approximately 290 Btu/scf and the following composition:[2-2]

Compound	Volume %
CH_4	0.10
H_2	36.38
CO	53.36
CO_2	9.26
H_2S	0.10
COS	0.05
N_2	0.50
Ar	0.15
H_2O	0.10

The most attractive end use of this fuel product would be in an on-site combustion system designed for electric power production - particularly in a combined cycle mode of operation. The focus of Texaco's present development program is this combined cycle system application of the fuel gas.

2.10.2 Capacity Factors, Flexibility, Reliability

The Texaco coal gasification plant assessed in this report is designed to operate with a 90 percent capacity factor (see Chapter 3) and to produce synthetic fuel gas at approximately 88 percent overall thermal efficiency.

The Texaco Coal Gasification Process has been the subject of development and pilot plant work since the 1950's. The success of pilot plant operation and the initiation of design of commercial plants (see Section 2.11.1 below) are indicative of the reliability of the system.

Among the advantages of the Texaco process are its flexibility with respect to the following criteria:[2-2]

- Feedstock - The TCGP is designed to operate on a wide range of coals, petroleum and coal cokes, residues and chars from coal liquefaction processes, and solid wastes.

- Operating Conditions - Pilot plant test runs have demonstrated that the Texaco gasifier can operate successfully at pressures up to 1200 psig. Operation under these conditions may reduce equipment size and cost requirements for synthesis gas refinement and processing, although the use of pressure vessels may cause other operational problems. In addition, the process may be operated in two basic modes: (1) direct gas quench with internal steam generation; and (2) gas cooling mode with external steam generation.* Choice of operational characteristics depends on the desired steam content of the synthesis gas.

- Products - As a result of process flexibility, a wide range of potential products of the TCGP has been identified. These products include hydrogen, ammonia, oxo-chemicals, reducing gases, and chemical or fuel grade methanol. Also, operating conditions can be adjusted to produce gaseous fuels with a wide range of heating values. Use of air as gasifier oxidant will result in low-Btu gas, while use of oxygen will produce medium-Btu gas. Methanation of synthesis gas can produce high-Btu pipeline quality fuel.

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*Operation of the TCGP in the second mode is emphasized in this report.

2.11 TECHNOLOGY STATUS AND DEVELOPMENT POTENTIAL

2.11.1 Current Status

The Texaco Coal Gasification Process has been developed as a result of many years of related experience with the Texaco Synthesis Gas Generation Process, which was designed for partial oxidation of residual oils. Development work on the TSGGP was started in the 1940's, and the process has been licensed for use in more than 70 plants in more than 20 countries. In the 1950's, extensive coal gasification research was begun at Texaco's Montebello Research Laboratory in California. Though development work was slowed by the wide availability of natural gas transported by newly-constructed pipelines, a resurgence of interest developed in the late 1960's and early 1970's.

Presently, testing of the TCGP is being conducted in the Montebello Laboratory using two pilot plant gasifiers - each capable of processing 15-20 tons of coal per day. Demonstration-level testing has been conducted at a 150 ton-per-day unit at the Ruhrchemie Chemical Plant Complex in Oberhausen-Holten, West Germany since 1978. Specific units currently under particular study include the slurry preparation, slag removal, and gas cooling systems.

2.11.2 Key Technical Uncertainties

As noted above, the Texaco gasifier has been commercially proven for the gasification of liquid hydrocarbons, while the coal gasification process is still at the pilot plant stage. Although individual units of the overall complex are commercially available, their integration into a full-scale gasification system has yet to be proven. In particular, the coal slurry system is a potential source of problems in large-scale applications. Positive displacement pumping of the slurry can cause erosion from coal particles, resulting in high maintenance costs. Also, the presence of water in the coal feed dictates the need for high oxygen input to the gasifier, and subsequent CO_2 production and removal problems.

2.11.3 Availability For Commercial Production

In early 1980, plans were announced to begin commercial-sized development of the Texaco Coal Gasification Process to produce fuel gas and industrial chemicals.

Southern California Edison (SCE), in conjunction with the Electric Power Research Institute (EPRI) and Texaco have begun development of an integrated 1,000 ton-per-day gasifier and combined cycle power plant. The demonstration facility, located at the site of SCE's Cool Water Power Plant near Daggett in San Bernardino County, California, will be constructed by Bechtel Corporation and is designed to produce 100 MW of electricity when completed in the mid-1980's.

Tennessee Eastman Company is planning to use the Texaco process to generate acetic anhydride, an important chemical used in the manufacture of photographic film base. Currently, this chemical is produced from petroleum feedstocks, but Tennessee Eastman hopes to reduce petroleum consumption and energy costs by utilizing the Texaco process. Construction of the plant is to take place in Kingsport, New York, with production expected to begin in 1983.

2.11.4 Unit Design and Construction Times

Design and construction of a Texaco gasification complex of the type assessed in this technical assessment guide is expected to take approximately three years.

2.12 REGIONAL FACTORS INFLUENCING ECONOMICS

A wide variety of regional constraints apply to the design and construction of a Texaco coal gasification plant. The siting and resource requirements for such a complex are described in Sections 2.3 and 2.4 above. Environmental control constraints would be determined according to the particular meteorology, topography, and existing pollution regulations at a proposed site.

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References

2-1. Odle, T.D., W.B. Crouch, and G.N. Richter. "Clean Refinery Fuels by the Texaco Coal Gasification Process.

2-2. Chandra, K., B. McElmurry, E.W. Neben, G.E. Pack. Fluor Engineers and Constructors, Inc., Economic Studies of Coal Gasification Combined Cycle Systems For Electric Power Generation, EPRI AF-642, January 1978.

2-3. Child, E.T. "Current Status of the Texaco Coal Gasification Process," presented at the Ammonia From Coal Symposium, May 1979.

2-4. Schlinger, W.G., and G.N. Richter. "An Environmental Evaluation of the Texaco Coal Gasification Process," presented at the First International Gas Research Conference, June 1980.

2-5. Schlinger, W.G., J. Falbe, R. Specks. "Coal Gasification For Manufacturer of Hydrogen," presented at ACS/CSJ Joint Chemical Conference, April 1979.

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CHAPTER THREE: ECONOMIC ANALYSIS

This section provides data on the economics of the Texaco medium Btu coal gasification process.

3.1 Introduction and Methodology

3.1.1 Economic Analysis Methodology

The economic analysis relies on a design for a combined cycle gasification/electric power plant made by Fluor (3-1). Costs of gasification were separated from power generation, the data was adjusted for inflation since 1976 when the report was prepared and the adjusted data was used to compute non-fuel gas costs for the process.

3.1.2 Scaling Factors

The reference design produced 65.29×10^{12} Btu/year, 30.6% above the standard plant size of 50×10^{12} Btu/year. Costs were scaled down using a scaling factor of 1.0 in the Gasification (300), Raw Gas Cooling (1200), Acid Gas Removal and Gas Cleaning (1300), Sulfur Recovery and Tail Gas Treating (1400) and Air Separation (1900) areas because these areas employed 3 or more trains, and scaling the plant size down would require elimination of a train, rather than changing the size of individual equipment. When entire trains are added or eliminated, economies of scale are lacking. A scaling factor of .7 was used for the Coal Storage (100), Coal Preparation (200), Utilities and Support Systems (2000) and Offsites and Miscellaneous (2100) areas because these areas used two or one train and so changes in equipment size would be necessary, and economics of scale would apply.

3.1.3 Price Indices

Prices in the reference report (3-1) were presented in 1976 dollars and were corrected to third quarter 1980 dollars using the methodology described in the Background section.

3.1.4 Economic Criteria

The standard economic criteria as explained in the Background section were used. The schedule of investments was 25%, 50%, 25% over the three year construction period.

3.1.5 Contingencies

Two contingencies were applied to the capital cost estimates: an overall project contingency of 15% as explained in the Background section, and a process contingency to account for technical development of individual areas. Ten percent process contingencies were added to the cost of the Raw Gas Cooling (1200) and Gasification (300) areas.

3.2 Capital Costs

3.2.1 Itemized Capital Costs

The Total Plant Investment for a 50 trillion Btu per year Texaco medium Btu gasification plant would be $387.8 million, or $7.76/$10^6$ Btu of capacity. Air Separation, at $124.6 million or 37.9% of costs before contingencies is the most expensive plant area. Gasification, at $25.8 million, accounts for 7.8% of the costs before contingencies. Substantial savings over lower temperature systems are achieved because wastewater treatment and steam generation needs are reduced. Total Plant Investment is shown in Table 3-1.

Besides the capital required to construct the facility, funds are needed to pay interest on the construction loan and to maintain initial plant operations. Interest during construction adds $96.2 million, the most important additional cost. Other expenses include Start-Up, at $23.3 million, Working Capital, at $23.7 million, Paid-Up Royalties, at $1.9 million, and Catalysts and Chemicals, at $0.6 million. These expenses are shown in Table 3-1. The total capital requirement is $533.5 million.

3.2.2 Variability of Capital Cost Estimate

Fluor estimated the accuracy of its estimate at ±25 percent (3-1). The estimate was based on a preliminary equipment list with items sized and specified. Because of possible errors which could have been introduced into the cost estimate when it was updated and scaled, the confidence interval should be increased to ±30 percent.

TABLE 3-1

TOTAL CAPITAL REQUIREMENT: TEXACO GASIFIER

AREA	ITEM	COST (10^6 $)	PERCENT OF SUBTOTAL
100	Coal Storage and Handling	(in 200)	
200	Coal Preparation	25.4	7.7
300	Gasification	25.8	7.8
1200	Raw Gas Cooling	71.1	21.6
1300	Acid Gas Removal and Gas Cleaning	30.3	9.2
1400	Sulfur Recovery and Tar/Gas Treating	(in 1300)	
1900	Air Separation	124.6	37.9
2000	Utilities and Support systems	43.0	13.1
2100	Offsites and Miscellaneous	(in 2000)	
	Sales Tax	8.6	2.6
	Subtotal	328.8	100
	Process Contingency	9.7	
	Project Contingency	49.3	
	Total Plant Investment	387.8	
	Interest During Construction	96.2	
	Start-up	23.3	
	Working Capital	23.7	
	Paid-Up Royalties	1.9	
	Catalysts and Chemicals	.6	
	Total	533.5	

[a]Source: 3-1, updated to 1980 dollars and scaled by ERCO to 50 trillion Btu/year.

3.3 Operating and Maintenance Costs

3.3.1 Itemized Operating and Maintenance Costs

Itemized annual operating and maintenance costs are shown in Table 3-2. Total gross operating and maintenance costs are $41.1 million, with maintenance materials, at $11.4 million the largest cost. Operating, Maintenance, and Administrative and Support labor costs total $12.7 million. Local taxes and insurance, at $9.7 million, are also important expenses.

By-product credits for sulfur production total $3 million per year. These offset the gross operating and maintenance costs to yield a net operating and maintenance cost of $38.1 million.

3.3.2 Variability of Operating and Maintenance Costs

The reliability of the operating and maintenance costs lies well within the ±30% of the capital cost estimates. Manpower needs, catalysts and chemicals, utilities and solids disposal are derived from the general characteristics of the design, and so are not subject to much variability. Maintenance. Taxes and insurance costs are directly factored from the capital cost estimate, and so would be as variable as that estimate.

3.4 Effect of Technology Development On Costs

As of April, 1981, Texaco gasifier experience in the United States was at the pilot plant stage. Therefore, the technology must be considered immature. The Raw Gas

TABLE 3-2

NET OPERATING AND MAINTENANCE COSTS TEXACO[a]

ITEM	COST (10^6 \$)	PERCENT OF TOTAL[b]
Administration and General Overhead	5.9	14.4
Local Taxes and Insurance	9.7	23.6
Labor		
Operation	2.2	5.4
Maintenance	7.6	18.5
Administrative and Support	2.9	7.1
Total	12.7	30.9
Maintenance Materials	11.4	27.7
Catalysts and Chemicals	.2	.5
Solids Disposal	.3	.7
Utilities	.9	2.2
Total	41.1	100.0
By-Product Credit	(10^6 \$)	
Sulfur	(3.0)	
Net O & M Costs	(10^6 \$)	
Gross O & M Costs	41.1	
By-Product Credit	(3.9)	
Total	38.1	

[a]Source: (3-1), adjusted to Third quarter 1980 dollars and 50 trillion Btu/Year by ERCO.

[b]Column does not add to 100 percent because of rounding.

Cooling sections, and Coal Preparation sections are also immature. These three sections account for 40% of the Total Plant Investment. Assuming that the maximum experience factor for energy technologies is 10%, this results in an experience factor of 40% times 10%, or 4% for Texaco technology. Each doubling of Texaco capacity should result in a 4% cost reduction in real costs. The concepts behind the experience factor were described in the Background Section.

3.5 Gas Costs

The cost of the product gas has three components: capital charges associated with plant capital costs, plant operating and maintenance (O&M) costs, and coal costs. The cost of the gas excluding the cost of coal (non-fuel costs) yields an indication of the economic viability of the process. Non-fuel gas costs can be computed from capital charges (based on $533.5 million capital requirement) and O&M costs (based on $41.1 million net O&M costs) according to the formula given in the Background.

This formula yields a non-fuel gas price of:

$$P = \frac{(\$533.5 \times 10^6 \times 20\%) + \$41.1 \times 10^6}{50 \times 10^{12} \text{ Btu} \times 90\%}$$

$$= \underset{\text{(capital costs)}}{\$2.37/10^6 \text{ Btu}} + \underset{\text{(O\&M costs)}}{\$.91/10^6 \text{ Btu}}$$

$$= \underset{\text{(Total)}}{\$3.28/10^6 \text{ Btu}}$$

Capital costs are $2.37/10^6 Btu, and operating and maintenance costs are $.91/10^6 Btu, for a total non-fuel cost of $3.28/10^6 Btu.

The non-fuel gas cost can be converted to a total energy cost by adding the cost of coal as was explained in the Background. The coal to gas efficiency of the process is 69%. With coal at $1.50/10^6$ Btu, the coal cost would be $2.17/10^6$ Btu. Combining the coal cost of $2.17/10^6$ Btu with the non-fuel cost of $3.28/10^6$ Btu yields a total energy cost of $5.45/10^6$ Btu.

Reference

3-1. Fluor Engineers and Constructors, "Economics of Texaco Gasification/Combined Cycle Systems." Electric Power Research Institute AF-753. April 1978.

References

3-1. Chandra, K., B. McElmurry, and S. Smelser (Fluor Engineers and Constructors), "Economics of Fuel Gas From Coal - An Update Including the British Gas Corporation's Slagging Gasifier." Electric Power Research Institute AF-782, May 1978.