TECHNOLOGY ASSESSMENT GUIDE
NO. 4A
KOPPERS-TOTZEK

DRAFT

CHAPTER ONE: EXECUTIVE SUMMARY

1.1 OVERALL PROSPECTS FOR THE TECHNOLOGY

The Koppers-Totzek coal gasification system has been in widespread commercial use since 1949. During this time, 19 coal-fired plants have been constructed using the K-T gasifier to supply synthesis gas for ammonia production. As a result of this extensive operating experience, the K-T system is widely recognized for being a reliable, efficient method for gasifying coal. The entrained flow design, which is the basis for several advanced gasification technologies, offers high coal throughputs, slagging operation, produces no tars or oils, operates on fines and can accept any type of coal. These features combined with reasonable production costs indicate that the Koppers-Totzek gasifier could play an important role in a synthetic fuel industry based on coal.

1.2 ENGINEERING ASPECTS

Due to the fact that the gasifier operates in an entrained flow mode, pulverized coal is needed. As such, fines which are normally produced as a by-product of crushing operations to prepare coal for fixed-bed gasifiers (such as the Lurgi system) need not be sold but create an opportunity for using a K-T system in conjunction with a fixed-bed gasifier.

Pulverized coal is transferred and fed pneumatically to the K-T system. Because the gasifier itself is highly tolerant of moisture, the extent of drying is determined primarily by the potential for clogging pneumatic transfer lines. Drying is often accomplished simultaneously with crushing, and produces an added benefit of higher raw gas heating value due to the absence of the diluent moisture.

The entrained flow design allows gaseous and solid reactants to react in cocurrent flow. To maintain this cocurrent flow, gas velocities must be high enough to carry the solid coal particles completely through the reactor without deposition. These high velocities imply that, for any reasonably sized reactor, the residence time in the reaction zone will be quite limited. Thus, in order to insure complete reaction between gases and solids, the reaction rate must be rapid, which occurs only at high temperatures if no catalysts are present. (Catalysts are not used in the K-T system.) The high temperatures in the reactor destroy any higher molecular weight compounds such as tars and oils which would otherwise complicate downstream heat exchange and water treatment operations. The high velocities used in the reactor are responsible for the high coal throughput which is possible with a comparatively small device.

However, the need to maintain a minimum throughput because of the low reactor inventory results in a turndown ratio of only 2:1. In addition, the extremely high temperatures reached in the reactor, combined with its low (atmospheric) pressure operation, assure that no methane is produced in the raw gas. Low pressure operation imposes a requirement for expensive raw gas compression when high pressure applications are considered. The use of high temperatures in the reactor means an increase in oxygen consumption relative to other gasifiers operating under less severe conditions (although oxygen consumption in the K-T gasifier is typical of entrained flow systems). The high temperature operation also imposes a requirement to recover as much of the heat in the raw gasifier effluent as possible in the interest of process efficiency. This suggests that quenching of the raw gas is undesirable due to the unavoidable loss of heat which occurs with this method. Although more expensive, an indirect waste heat recovery system (most likely for steam generation) is indicated with this gasifier. High temperatures also require the use of a refractory lining in the gasifier, which is subject to fairly rapid deterioration.

Operation of other downstream equipment is primarily a function of coal type and application, and is relatively unaffected by gasifier characteristics.

1.3 CURRENT COSTS

The total capital requirement for this 50×10^{12} Btu per year plant is $790 million, which is dominated by a plant capital investment of $529 million. Interest during construction is the next largest at $173 million, with start-up and working capital making up the remainder.

Annual operating and maintenance (at a 90% plant capacity factor) costs, exclusive of coal costs, total $35.4 million. Major items contributing to these costs are maintenance, supplies, labor, and local taxes and insurance. By-product sulfur is given a credit of $40/ton which reduces operating costs to $30.6 million per year, net.

Taken together with a 20 percent capital charge, these operating costs result in a product cost of $4.19/million Btu, which is exclusive of coal costs.

1.4 RESEARCH AND DEVELOPMENT DIRECTIONS

The mature state of the K-T gasification technology suggests that many of the uncertainties normally associated with developing technologies have already been resolved in this case. However, further improvements in gasification efficiency may be possible. The recovery of high temperature heat in an efficient manner has traditionally been a difficult problem due to the severity of the environment. Even though materials are available which have acceptable lifetimes, the coating of solidified slag materials on cool boiler tubes drastically reduces the effective heat transfer coefficient. Methods to circumvent this difficulty have been explored by others, and have application in the K-T gasification system. An effective method for recovery of heat in the molten slag might also be incorporated in such a system.

Operation of the gasifier under elevated pressure would broaden its scope of application. Aside from a re-engineering of the structure, a new pneumatic feed system for pulverized coal would be necessary.

Operation of the gasifier at lower temperatures by means of a catalyst or other method would lower oxygen consumption, raise methane production (especially if done under pressure), decrease the rate of refractory deterioration and generally improve the longevity of the system. One method for achieving this might involve a slight adjustment in the flow patterns of gases and solids to achieve better mixing. A closer approach to ideal mixing would provide the most efficient use of reactor volume and help to reduce the amount of unreacted carbon which escapes the reactor (unreacted carbon is not a serious problem).

CHAPTER TWO: ENGINEERING SPECIFICATIONS

2.1 GENERAL DESCRIPTION OF THE TECHNOLOGY

In the Koppers-Totzek process, finely pulverized coal is introduced through the vertices of an ellipsoidally-shaped gasifier and is reacted with steam and oxygen at atmospheric pressure. The resulting product is purified and cooled to yield a low-sulfur medium-Btu (280 Btu/scf) gas.

In some applications, the Koppers-Totzek product gas is processed by shift conversion, methanation, and CO_2 removal units to yield a high-Btu pipeline-quality gas. This and other modifications to the basic process are being researched by Koppers Co. Inc., the sole North American licensee for the process.

The first Koppers-Totzek demonstration unit was built in 1948 and was operated jointly by Koppers Co.; Heinrich Koppers, GmbH; and the U.S. Bureau of Mines. Although over thirty Koppers-Totzek coal gasification plants have been built in Europe, Asia, and Africa, a commercial plant has not yet been built in the U.S.

2.2 PROCESS FLOW, ENERGY, AND MATERIAL BALANCES

Relevant plant area numbers and corresponding unit descriptions for the Koppers-Totzek process are given in Table 2-1, while the interactions among these units in the overall complex is shown in Figure 2-1. Compositions and flow rates of streams shown in the conceptualized process flow diagram (Figure 2-1) are given in Table 2-2.

As shown in Figure 2-1, coal for the process is dried and pulverized to approximately 70 percent minus 200 mesh. Nitrogen produced by the air separation unit is used to convey the coal to beneficiation and storage units. The dried coal feed, along with steam and oxygen, is injected into the entrained-bed gasifier and reacted at approximately 3300°F to yield a synthesis gas composed primarily of CO and H_2. Molten coal ash is removed from the bottom of the gasifier as slag, quenched with water, and slurried to a wastewater treatment unit. The raw synthesis gas leaves the gasifier at 3000°F and sensible heat is extracted from this gas stream by a waste heat boiler which produces steam for compressor and pump power.

Gas leaving the waste heat boiler is piped to a series of washers for particulate removal and is further cooled to 105°F. Waste water from the washers and coolers is combined with the slag slurry in the wastewater treatment unit. Solid effluent is removed from this unit to a disposal site, while water is sent to a cooling tower and recycled to the plant.

The cooled synthesis gas is delivered to an acid gas removal unit which extracts CO_2 and sulfur-bearing compounds from the stream by absorption in a methyldiethanolamine (MDEA) solution. A sulfur recovery unit converts acid gas to liquid elemental sulfur and tail gas which can be burned to raise steam for power generation.

Portions of the clean fuel gas which leave the acid gas removal system are combusted in coal drying and power generation areas of the plant. The remainder of clean gas product (1.036 million lbs/hr) can be combusted in onsite boilers or shipped to remote users. Table 2-3 provides an overall material and energy analysis for the Koppers-Totzek plant. A coal input rate of approximately 1.6 million lbs/hr would produce 50 x 10^{12} Btu/year of medium-Btu product gas (heating value: 283 Btu/scf), while the overall plant efficiency, based on data in Table 2-3, is 68 percent.

Table 2-1

Relevant Koppers-Totzek Plant Area Numbers

100	COAL STORAGE AND HANDLING
	110 Coal Storage
200	COAL PREPARATION
	210 Coal Crushing
	220 Coal Pulverization
	230 Coal Beneficiation
	240 Coal Drying
300	GASIFICATION
	310 Gasification
	320 Slag Quench
1200	RAW GAS COOLING
	1210 Particulate Removal
	1220 Quenching and Cooling
1300	ACID GAS REMOVAL AND GAS CLEANING
	1310 Acid Gas Removal
1400	SULFUR RECOVERY AND TAIL GAS TREATING
	1410 Sulfur Recovery
1600	COMPRESSION
1900	AIR SEPARATION
2000	UTILITIES AND SUPPORT SYSTEMS
	2010 Steam Generation (Waste Heat Boiler) and Power Recovery (Steam Turbine)
	2020 Wastewater Treatment
2100	OFFSITES AND MISCELLANEOUS
	2140 Cooling Towers

Figure 2-1

Koppers-Totzek Conceptualized Process Flow Diagram

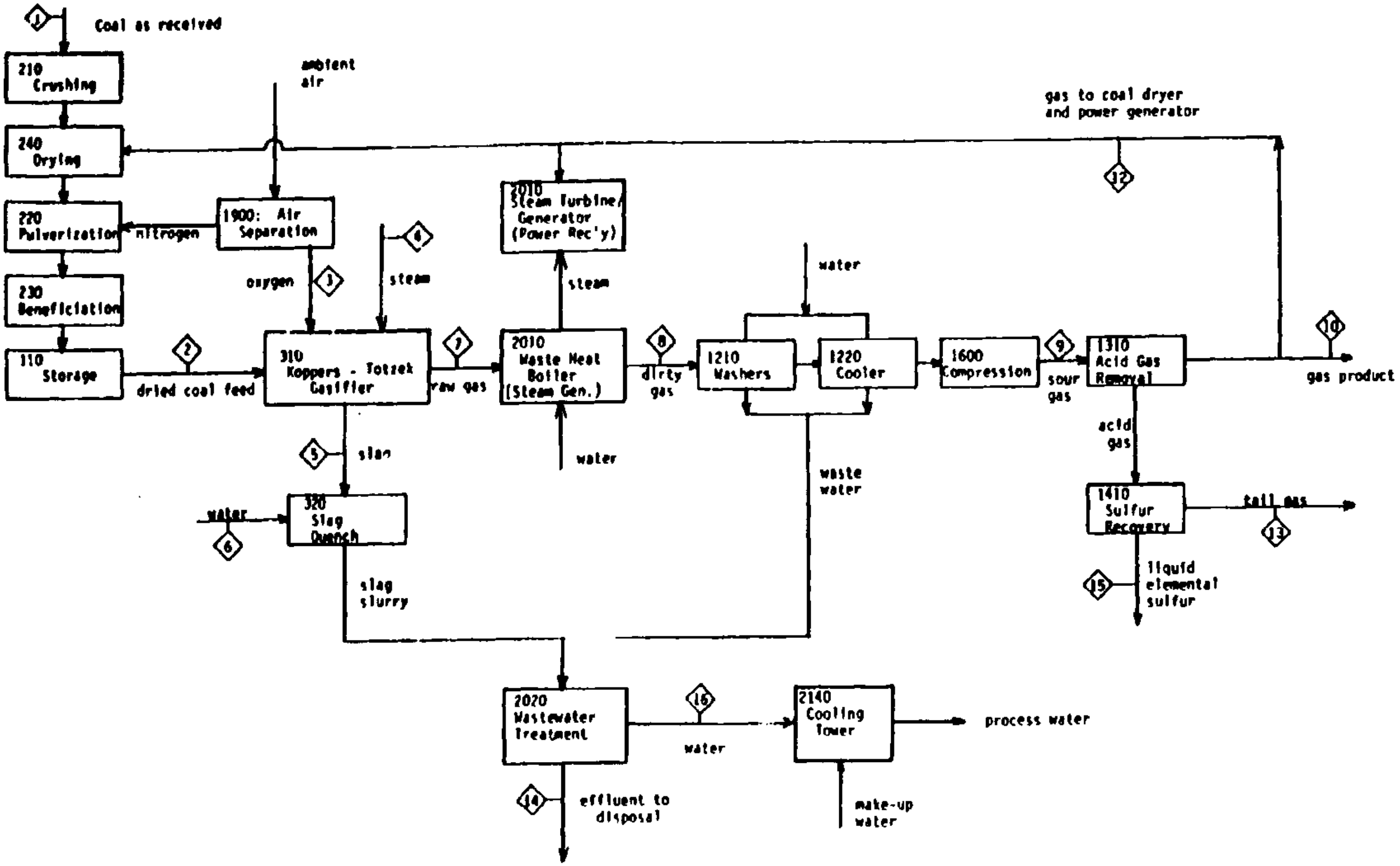

Table 2-2

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Koppers-Totzek Detailed Process Streams

Stream	1		2		3		4		5		6		7		8		9	
Description	Coal as Rec'd		Dried Coal Feed		Oxygen to Gasifier		Steam to Gasifier		Slag		Water to Quench Tank		Raw Gas		Cooled Raw Gas		Sour Gas	
Temperature, oF			160		270		250				85		2000		330		105	
Pressure, PSIG					25		25						7.1		7.0		4.5	
Flow	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %
S	27.619	3.50	27.619	3.75														
C	467.453	59.31	467.453	63.52														
H_2	31.973	4.05	31.973	4.34									39.995	24.56	39.995	24.56	39.995	32.31
O_2	53.289	6.76	53.289	7.24	555.237	98.0												
N_2	9.283	1.18	9.283	1.26	9.970	2.0							19.253	0.84	19.253	0.84	19.253	1.11
Ash	131.561	16.70	131.561	17.89					65.700	26.25								
H_2O	67.041	8.50	14.669	2.00			244.900	100	184.735	73.75	1670.295	100	411.987	28.14	411.987	28.14	60.738	5.47
CH_4																		
CO													870.960	38.24	870 960	38.24	870.960	50.29
CO_2													256.246	7.16	256.246	7.16	256.246	9.42
H_2S													27.275	0.99	27.275	0.99	27.275	1.30
COS													3.667	0.07	3.667	0.07	3.667	0.10
SO_2																		
Total	788.219		735.847		565.207		244.900		250.515		1670.295		1629.383		1629.383		1278.134	

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Table 2-2

Koppers-Totzek Detailed Process Streams(cont'd)

Stream	10		11		12		13		14		15		16	
Description	Clean Gas Product		Acid Gas		Gas to Dryers and Generators		Tail Gas Vent		Effluent to Disposal		Sulfur Product		Water to Cooling Tower	
Temperature, ^{o}F	105		105		105		280				250		115	
Pressure, PSIG	2.5		13		2.5		5							
Flow	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %	klb/hr	mole %
S											22.462	100		
C														
H_2	36.328	34.12			3.644	34.12								
O_2														
N_2	17.419	1.17			1.799	1.17	37.016	27.54						
Ash									89.273	25.0				
H_2O	54.320	5.68	3.094	5.14	5.570	5.68	16.388	18.97	267.820	75.0			2698.945	100
CH_4														
CO	790.511	53.11			80.541	53.11	1.261	0.94						
CO_2	133.853	5.72	108.870	72.86	13.597	5.72	108.985	51.60						
H_2S	3.323	0.19	23.493	20.39	0.338	0.19	0.802	0.49						
COS	0.344	0.01	3.323	1.61	0.040	0.01	0.458	0.16						
SO_2							0.917	0.30						
Total	1036.098		138.780		105.524		165.827		357.093		22.462		2698.945	

Table 2-3

Overall Material and Energy Balances

Input	Mass Flow Rate klb/hr	Gross Heating Value MM Btu/hr
Coal	788.2	8513[a]
Steam	244.9[b]	
Oxygen	565.2	
Total Input	1598.3	8513
Products		
Medium-Btu Gas	1036.1	5708[c]
Tail Gas	165.8	6
Sulfur	22.5	90
	1224.4	5804

$$\text{Overall Plant Efficiency} = \frac{5804}{8513} = 68.2\%$$

[a] Heat content: 10,800 Btu/lb

[b] Gasification steam generated from heat exchange on gasifier effluent.

[c] Gas heating value: 283 Btu/scf.

2.3 PLANT SIZING AND SITING ISSUES AND CONSTRAINTS

The Koppers-Totzek plant described herein, sized to produce 50 x 10^{12} Btu/year of medium-Btu gas should be located on several acres (a comparably sized plant requires approximately ten acres of land[2-1]) of relatively flat land located near a rail spur or riverside coal supply facility. The onsite air separation facility would be sized to produce 565,000 lb/hr of 98 percent pure oxygen. The required water supply described in Section 2.4 below would need to be readily available to the plant.

2.4 RAW MATERIAL AND SUPPORT SYSTEM REQUIREMENTS

Approximately 9500 tons per day of coal (as received) are required by the plant. Properties of the coal are assumed to be as shown in Table 2-4.

Total water requirements - including makeup for gas cleaning and water treatment processes, cooling towers, and potable supplies - would be on the order of six million gallons per day.

Table 2-4

Koppers-Totzek Coal Feed Properties

Component	Wt %
S	3.50
C	59.31
H_2	4.05
O_2	6.76
N_2	1.18
Ash	16.70
H_2O	8.50

Heat content:	10,800 Btu/lb
Ash fusion temperature:	2300-2500°F
Free-swelling index:	3-7

Source: Reference 2-1

2.5 EFFECT OF COAL TYPE

Coals of a wide variation in rank and ash fusion properties can be handled easily by the Koppers-Totzek entrained-bed slagging gasifier. Adequate coal preparation procedures should be able to keep gasifier feed moisture content to below 8 percent in order to ensure successful conversion. Relatively high-moisture coals may even improve overall plant efficiency by lowering gasifier steam requirements. In addition, the high reactivity of low-rank coals such as lignites would result in more complete carbon conversion and higher overall process thermal efficiencies. Although ordinarily not required, the addition of fluxing agents may be necessary in order to facilitate slag removal when coals with high ash fusion temperatures are gasified.

2.6 AIR POLLUTION CONTROL TECHNOLOGY

Fugitive dust emissions from the coal preparation area are controlled by a bag/filter dust collection system. Coal ash is removed primarily as slag, although some flyash is entrained in the raw gas flow and is removed by washers, keeping particulate emissions to a minimum.

Most of the sulfur in the product gas is removed by the acid gas removal and sulfur recovery units. A small quantity of tail gas containing COS, SO_2, and H_2S is produced. As an alternative to being vented, this gas can be combusted in a boiler along with the clean product gas.

2.7 WATER POLLUTION CONTROL TECHNOLOGY

Waste water from raw gas washing units is combined with the slag slurry from the gasifier in a waste water settling and treatment unit. Relatively pure water from this unit is removed at approximately 115° and sent to cooling towers. Effluent from the unit, consisting of ash and water, is conveyed to a disposal area - usually an evaporation pond where dry ash is collected and sold as concrete aggregate or disposed of in a landfill.

2.8 SOLID WASTE HANDLING

The most significant solid waste product from the Koppers-Totzek process is the gasifer ash, which is disposed of in the manner described in Section 2.7 above.

2.9 OSHA ISSUES

Worker safey may be endangered in the coal preparation and storage areas. The coal storage pile will be subject to dust generation and risk of fire. Coal preparation, during which coal is ground to a very fine 70 percent through 200 mesh, will generate dust and noise.

Gas leaks from the gasifier could expose workers to hot toxic gases, especially carbon monoxide and hydrogen sulfide. An advantage to the Koppers-Totzek process is that it produces no tars or liquid by-products, and so the hazards associated with handling liquid coal by-products are not present.

2.10 PROCESS PERFORMANCE FACTORS

2.10.1 Product Characteristics and Marketability

The primary product of the Koppers-Totzek process is a medium-Btu gas with a heating value of approximately 280 Btu/scf. A typical analysis of this gaseous product when derived from coal with a heating value of 10,800 Btu/lb is shown below.[2-1]

Compound	Volume %
H_2	34.12
N_2	1.17
H_2O	5.68
CO	53.11
CO_2	5.72
H_2S	0.19
COS	0.01

This Koppers-Totzek fuel gas can be substituted for natural gas by utilities for steam generation and by industries for process heat and steam production.

2.10.2 Capacity Factors, Flexibility, Reliability

The Koppers-Totzek gasification system described herein is designed to produce 50 x 10^{12} Btu/year of synthetic gas at full capacity. For the purposes of economic analysis, a capacity factor of 90 percent is assumed (see Chapter 3). Koppers-Totzek gasifiers are capable of firing a variety of fuels - including tars, oils, and essentially all ranks of coal. In addition, a wide range of products can be produced. The clean medium-Btu gas can be shipped directly to utilities and industries for process heat and steam generation or it can be upgraded by CO shift and methanation processes to produce high-Btu gas for residential as well as industrial use.

The Koppers-Totzek technology has been proven to be a feasible and reliable one. Since 1948, successful gasification plants have been operated in Europe, Asia, and Africa for synthesis of methanol and ammonia.

2.11 TECHNOLOGY STATUS AND DEVELOPMENT POTENTIAL

The first Koppers-Totzek demonstration unit was designed and built by the Koppers Company in 1948. The unit was operated jointly by Koppers Co.; Heinrich Koppers, GmbH; and the U.S. Bureau of Mines. Since that time, over thirty Koppers-Totzek coal gasification plants have been built in Europe, Asia and Africa. Although many years of successful experience have been achieved, a commercial plant has not yet been built inside the U.S.

As a result of the successful past experience, the limitations and technical uncertainties associated with this process are relatively few. However, some engineering difficulties remain, including:

- Corrosion, which may occur as a result of the direct contact of sour gases on heat exchanger surfaces;
- Recovery of waste heat from water quench of gasifier exit gas; and
- Maintaining an adequate supply of oxygen to to the gasifier.

2.12 REGIONAL FACTORS INFLUENCING ECONOMICS

A variety of constraints apply to the regional design and construction of a Koppers-Totzek plant. Sections 2.3 and 2.4 above describe the land, coal, and water requirements of such a complex. Environmental control constraints would be determined according to the particular meteorology and topography of a proposed site.

References

2-1. Tennessee Valley Authority (Waitzman, D.A., et. al.), "Evaluation of Intermediate-Btu Coal Gasification Systems for Retrofitting Power Plants." EPRI AF-531, August 1977.

CHAPTER THREE: ECONOMIC ANALYSIS

This section discusses the economics of a Koppers-Totzek medium-Btu gasification plant. In Section 3.1, the methodology used is explained. Section 3.2 presents itemized capital costs for a Koppers-Totzek facility. Section 3.3 contains operating and maintenance costs for the facility. Section 3.4 discusses the effect of technology development on gas costs. In Section 3.5, the cost of producing the gas, excluding fuel, is computed.

3.1 Methodology and Introduction

3.1.1 Economic Analysis Methodology

The economic analysis relied on published engineering cost estimated (3-1, 3-2, 3-3, 3-4). A report by Bechtel (3-1) was chosen as the best source of capital cost information on the Koppers-Totzek process. The cost estimate in the Bechtel report was scaled to a typical commercial plant size and corrected to third quarter 1980 dollars. The adjusted cost estimate was used to compute non-fuel gas costs.

3.1.2 Scaling Factors

The Bechtel report (3-1) presented costs for facilities with capacities of 3.5, 17.3, and 73 trillion Btu per year. Fifty trillion Btu per year was judged to be a typical size for a commercial-scale medium-Btu coal gasification plant. The cost for the 50-trillion-Btu plant was scaled up from the cost of the 17.3-trillion-Btu plant according to the formula:

$$\text{New Plant Cost} = \left(\frac{\text{New Plant Size}}{\text{Reference Plant Size}}\right)^{se} \times \begin{array}{l}\text{Reference}\\ \text{Plant Cost}\end{array}$$

where se is the cost scaling exponent.

Different scaling exponents were applied to different cost components. Operating personnel, with a scaling exponent of 0.57, displays more economies of scale than does the gasification section, which has a scaling exponent of 0.97. The cost scaling exponents were derived from costs presented in reference (3-1) and are presented in Table 3-1.

TABLE 3-1

CAPITAL COST SCALING EXPONENTS
KOPPERS-TOTZEK GASIFICATION SYSTEM[a]

ITEM	COST SCALING EXPONENT
Gasification Area	0.97
Air Separation	0.93
Other Facilities[b]	0.87
Operating Personnel	0.57

[a] Source: Derived by ERCO from Table 5-1 in Reference 3-1.

[b] Includes site improvements, buildings, coal-preparation, waste disposal, raw gas compression, gas sweetening, sulfur recovery, process utilities, and interconnecting piping.

3.1.3 Price Indices

The cost information in Reference (3-1) was presented in 1976 dollars and was corrected to third quarter 1980 dollars. Different cost indices were applied to different cost elements in order to ensure accuracy.

The *Chemical Engineering* Plant Cost Index (3-5) was used to correct elements of construction cost. The *Chemical Engineering* Plant Cost Index is a weighted average of the equipment, construction and engineering costs incurred during the construction of chemical process plants. Because equipment costs were not presented independently of engineering and construction costs in the reference document, each element of construction costs could not be inflated separately. The *Chemical Engineering* Index, as a weighted average of all elements of the construction cost, is a valid substitute for inflating each element of plant costs separately.

Labor costs were corrected with the Bureau of Labor Statistics index of wages in the refinery industry. Catalysts and chemicals were inflated with the Producer Price Index for Industrial Chemicals. The by-product sulfur credit was computed through reference to market prices. Sulfur prices, at $40/long ton, are lower than actual 1980 prices of $50-55/long ton. This discount was made because the market for elemental sulfur is relatively small, and byproduct sulfur from coal conversion plants will probably force market prices down. Table 3-2 details the inflators or prices used for each element of Koppers-Totzek costs.

TABLE 3-2

INFLATORS AND PRICES USED TO CORRECT COSTS TO 1980 DOLLARS

ITEM	SOURCE OF INFLATOR OR PRICE	INFLATOR OR PRICE
Plant Capital Costs, Supplies, Maintenance, Materials and Labor, Taxes and Insurance	*Chemical Engineering* Plant Cost Index	1.39
Operating Labor	Bureau of Labor Statistics Index of Petroleum Refining Wages	1.42
Engineering and Home Office Costs	*Chemical Engineering* Engineering and Supervision Manpower Index	1.47
Catalysts and Chemicals	Department of Commerce Producer Price Index for Industrial Chemicals	1.53
By-Product Sulfur	Market Prices	$40/ long ton

3.1.4 Economic Criteria

The economic analysis was based on the following economic criteria:

- Interest During Construction - Computed at a 15 percent annual compounded rate on funds borrowed during construction. It was assumed that the borrowing schedule was 25 percent in the third year before construction, 50 percent in the second year before construction, and 25 percent in the third year before construction, with all funds borrowed in a given year borrowed at the beginning of the year.
- Working Capital - Defined as the sum of:
  - 1.5 months total operating costs (with coal assumed to be $31.32/ton)
  - 3.5 percent of total plant investment
  - 1 month's supply of coal at full capacity ($10,095,000)
  - 1 month's catalysts and chemicals (method is from [3-7])
- Startup - Defined as the sum of:
  - One month variable operating costs excluding coal. Variable costs are catalysts and chemicals, utilities, and maintenance materials.
  - Two month's fixed costs. Fixed costs are operating and maintenance labor, administrative and support labor, general and administrative expense and property taxes and insurance.
  - 5 percent of total plant investment
  - 25 percent of one month's coal at full load

  Methodology source: 3-7.
- Plant Life - 20 years
- Capacity Factor - 90 percent
- Escalation During Construction - zero

3.1.5 Contingencies

Two contingencies were applied to the capital cost estimates: a process contingency and a project contingency. The process contingency covers technical uncertainties within a particular process which might cause costs to increase. The process contingency was applied on an area-by-area basis according to the level of technical development of each area as is shown in Table 3-3. The process contingency varies from 0 percent for a commercialized technology to 50 percent for a technology not yet at the pilot plant stage. These contingencies were derived judgmentally by ERCO with reference to industry contacts.

The process contingency percentages applied to each area are shown in Table 3-4. Gasification, because it has not been demonstrated in the United States, was assigned a 10 percent contingency. A 10 percent contingency was also assigned to the acid gas removal area to allow for technical development.

A project contingency of 15 percent was applied to the total of the costs of each area and unit (not including process contingencies) and contractor's fees. This project contingency is meant to allow for unanticipated cost increases, which usually arise as the plant design is made more complete.

3.2 Capital Costs

3.2.1 Itemized Capital Costs

The total plant investment for a 50-trillion-Btu/year Koppers-Totzek gasification facility would be $529.2

TABLE 3-3

PROCESS CONTINGENCIES BY LEVEL OF TECHNICAL DEVELOPMENT

LEVEL OF OF DEVELOPMENT	PROCESS CONTINGENCY (PERCENT)
Commercial scale	0
Demonstration Plant	10
Pilot Plant	25
No Pilot Plant	50

Source: ERCO.

TABLE 3-4

PROCESS CONTINGENCY BY PLANT AREA

NUMBER	ITEM	CONTINGENCY (PERCENT)
100	Coal storage and handling	0
200	Coal preparation	0
300	Gasification and power recovery	10
1200	Raw gas cooling	0
1300	Acid gas removal and gas cleaning	10
1400	Sulfur recovery and tail gas treating	0
1700	Shift conversion	0
1800	Methanation	0
1900	Air separation	0
2000	Utilities and support systems	0
2010	Offsites and miscellaneous	0

Source: ERCO.

million in third quarter 1980 dollars. The most expensive element of plant cost would be the gasification plant which would cost $150.6 million, or 28.5 percent of the total. Air separation to provide oxygen for the gasifier would be the second most expensive component of plant cost, at $109.1 million, or 20.6 percent of the total. A contingency of $83.6 million was added to plant costs to cover unanticipated technical problems or changes in design. Itemized plant capital costs are presented in Table 3-5.

Total plant investment is combined with other elements of plant cost in Table 3-6. Interest During Construction adds $173.3 million to the plant capital requirement. Working capital and startup costs add $46.4 million and $41.5 million respectively. The total capital requirement amounts to $790.4 million. The specific capital cost (cost per unit of capacity) was $15.81/$10^6$ Btu.

3.2.2 Variability of Capital Costs

The Bechtel report (3-1) produced an "order-of-magnitude" type estimate. This estimate is based on preliminary flow sheets, energy, and material balances. The plant plot was only outlined. Major plant elements were costed, while the cost of less important areas was estimated. Because the Koppers-Totzek is a commercialized technology, the "order-of-magnitude" method may be used without major risk of estimation error. This estimate can be considered accurate within ±30 percent.

TABLE 3-5

TOTAL PLANT INVESTMENT: KOPPERS-TOTZEK[a]

AREA		COST[b] (10^6 $)	PERCENT OF TOTAL
100	Coal Storage and Handling	N/A	N/A
200	Coal Preparation	N/A	N/A
	Total	10.1	1.9
300	Gasification	150.6	28.5
1300	Acid Gas Removal and Gas Cleaning	17,5	3.3
1400	Sulfur Recovery and Tail Gas Treating	15.7	3.0
1600	Product Gas Compression	24.7	4.7
1900	Air Separation	109.1	20.6
2000	Utilities and Support Systems	62.9	11.9
2100	Offsites and Miscellaneous	12.2	2.3
	Total	402.8	76.1
	Contractor's Fees	42.[illegible]	8.1
	Project Contingency	66.8	12.6
	Process Contingency	16.8	3.2
	Total Plant Investment	529.2	100.0

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[a] Total Plant Investment for a 50 x 10^2 Btu/year facility, Source 3-1, updated and scaled by ERCO.

[b] Third Quarter 1980 dollars.

N/A - not available.

TABLE 3-6

TOTAL CAPITAL REQUIREMENT: KOPPERS-TOTZEK[a]

ITEM	COST (10^6 $)[c]	SPECIFIC CAPITAL COST ($/$10^6$ Btu capacity)
Total Plant Investment	529.2	10.58
Escalation During Construction	0	0
Interest During Construction @ 15%	173.3	3.47
Startup[b]	41.5	0.83
Working Capital	46.4	0.93
Total	790.4	15.81

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[a] Capital requirement for a conceptual 50 x 10^{12} Btu/year Koppers-Totzek gasification facility, Source 3-1, updated and scaled by ERCO.

[b] Includes initial charge of catalysts and chemicals.

[c] Third quarter 1980 dollars.

3.3 Operating and Maintenance Costs

3.3.1 Itemized Operating and Maintenance Costs

Annual operating and maintenace (O&M) costs for a 50-trillion-Btu/year capacity Koppers-Totzek facility would total $35.37 million. This amount excludes the cost of coal. The largest component of these costs is labor at $13 million. Supplies will cost $10.3 million or 29.1 percent of the total. Local taxes and insurance would cost $7.9 million, or 22.3 percent of the total. Catalysts and chemicals add $4.2 million or 11.9 percent to costs. There is no allowance for administration and general overhead. Table 3-7 lists the elements of O&M costs.

The gasification plant will produce salable elemental sulfur as a by-product. This sulfur, valued at $40 per long ton, is worth $4.8 million. Net O&M expenses, which include both O&M expenses and by-product credits, total $30.6 million as is shown on Table 3-7.

3.3.2 Variability of Operating and Maintenance Expenses

Operating and maintenance (O&M) expenses are derived from the plant design. Therefore, O&M expenses are usually approximately as variable as the plant capital cost, especially in this case because 70.6 percent of the operating and maintenance expense estimate (maintenance supplies and labor, local taxes and insurance) was directly factored from the capital cost estimate. As a result, the basic operating and maintenance (O&M) costs estimate may be considered as variable as the capital cost estimate, or

TABLE 3-7

NET OPERATING AND MAINTENANCE EXPENSES: KOPPERS-TOTZEK[a]

ITEM	COST (10^6 $)[c]	PERCENT OF TOTAL GROSS EXPENSES
Local taxes and insurance	7.9	22.3
Labor:		
Process operation (includes supervision)	5.1	14.5
Maintenance	7.9	22.3
Total Labor	13.00	36.8
Supplies:		
Operating[b]	1.1	3.1
Maintenance	9.2	26.0
Total Supplies	10.3	29.1
Catalysts and Chemicals	4.2	11.9
Total Gross Operating and Maintenance Costs	35.4	100.0
By-Product Sulfur @ $40/long ton	(4.8)	
Net Operating and Maintenance Costs	30.6	

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[a] Expenses are for a Koppers-Totzek gasification plant with a capacity of 50 x 10^{12} Btu/year, producing at 90 percent capacity factor. Source 3-1, updated and scaled by ERCO.

[b] Includes utilities.

[c] Third quarter 1980 dollars.

±30 percent. The estimate, however, omitted general and administrative expenses, which typically amount to 10 to 20 percent of gross O&M costs. Therefore, the range of variability should be considered approximately -20 to +40 percent.

3.4 Effect of Technology Development on Costs

As the Koppers-Totzek process is commercialized in the United States, the cost of constructing Koppers-Totzek gasification facilities will fall in real dollars. New techniques and better methods for using older techniques will be developed. The effect of increased experience on technology costs is often quantified through the use of "experience" (sometimes called "learning") curves. The experience curve describes an inverse relationship between the cumulative number of units of an item produced and the unit capital cost of the item. The effects of experience are shown with a log-linear curve which exhibits a constant percent decline in the unit cost of production capacity for each doubling of completed capacity. The slope of this curve is called the experience factor. For example, a 10 percent experience factor implies that the cost of the fourth plant would be 81 percent (90 percent times 90 percent) of the cost of the first plant. It has been estimated that 10 percent is the upper limit on the experience factor for new energy process technologies (3-6).

The 10 percent experience factor is valid for sections of plant using new technology. Most sections of the plant employ mature technologies whose costs would decline little as more Koppers-Totzek plants are built. The accumulated volume of production of these components is already so large that the construction of several gasification plants would result in negligible cost reductions through added experience. Areas employing immature technology, which include the Gasification and Acid Gas Removal sections account for 40 percent of total plant investment. Approximately 40 percent of the contractor's fees and contingency must be allocated to the immature technologies, and so approximately 40 percent of the total plant investment is spent on immature technologies.[1] The experience factor for Koppers-Totzek gasification plants is then 40 percent of the 10 percent maximum or 4 percent. Each doubling of Koppers-Totzek capacity might result in a 4 percent reduction in unit capital costs.

3.5 Non-Fuel Product Costs

The cost of the product gas is composed of 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 and O&M costs according to the following formula:

$$P = \frac{K \times CRF + OM}{CAP \times F}$$

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[1] The 40 percent of Total Plant Investment has two components: Direct expenditures on immature technologies, which cost 31.8 percent of total plant investment, and the portion of the fees and contingencies which are spent on the immature technologies, 8 percent of Total Plant Investment. These two components sum to approximately 40 percent of total plant investment.

where:

P = product cost excluding fuel

K = total capital requirement of the plant, \$790.4 million, from Table 3-4.

CRF = capital recovery factor, assumed to be 20 percent

CAP = total plant annual capacity, 125 trillion Btu

F = plant capacity factor, 90 percent

OM = net annual operating and maintenance expense, \$30.6 million, from Table 3-4.

This formula yields a product cost (excluding fuel) of:

$$P = \frac{(\$790.4 \times 10^6 \times 20\%) + 30.6 \times 10^6}{50 \times 10^{12} \text{ Btu/year} \times 90\%}$$

$$= \$3.51/10^6 \text{ Btu} + \$0.68/10^6 \text{ Btu}$$

$$= \$4.19/10^6 \text{ Btu}$$

The total non-fuel gas price is \$4.19/10^6 Btu with \$3.51/10^6 Btu capital costs and 0.68/10^6 Btu net operating and maintenance costs. The \$4.19/10^6 Btu figure is only as reliable as the cost estimates on which it is based. These were accurate within approximately ±30 percent.[1]

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[1] Capital cost estimates are accurate within ±30 percent; O&M costs within -20 to +40 percent. Because capital costs dominate the non-fuel gas costs, the weighted average variability is about ±30 percent.

REFERENCES

(3-1) Bechtel Corporation, "Effect of Plant Size on the Cost of Producing Industrial Fuel Gas." U.S. Department of Energy FE/WAPO/2526-1, March 1978.

(3-2) Tennessee Valley Authority (Waitzman, D.A., et al.), "Evaluation of Intermediate Btu-Coal Gasification Systems for Retrofitting Power Plants." Electric Power Research Institute, AF-531, August 1977.

(3-3) Purvin and Gertz, Inc., Dallas Texas (Manthos, G.J.; Ellington, E.E.), "Evaluation of a High-Pressure Sarberg/Otto Gasifier." U.S. Energy Research and Development Administration, FE-2024-3, January 1977.

(3-4) Michael, H.I., "Methanol from Coal Using the Koppers Gasification Process." Koppers Company, Pittsburgh, Pennsylvania, November 1979.

(3-5) "Cost Indices Maintain 13-Year Ascent" and "Economic Indicators," Chemical Engineering, May 8, 1978 and January 26, 1981.

(3-6) Hederman, W.F. (Rand Corporation), "Prospects for the Commercialization of High-Btu Coal Gasification." U.S. Department of Energy, R-2294-DOE, April 1978, pp.48-50.

(3-7) Fluor, Inc. "Economics of Texaco Gasification - Combined Cycle Systems." Electric Power Research Institute, AF-753, April 1978.