TECHNOLOGY ASSESSMENT GUIDE
NO. 1
WELLMAN-GALUSHA LOW-BTU GASIFICATION

CHAPTER ONE: EXECUTIVE SUMMARY

1.1 OVERALL PROSPECTS FOR THE TECHNOLOGY

Wellman-Galusha gasification technology has been commercially available for approximately 40 years. During this time it has been operated in numerous industrial facilities, producing primarily low- and medium-Btu gases for firing process furnaces or for use as a synthesis gas. As a result of the experience with this gasifier, the system can be considered fully mature, making it an excellent choice in situations where a low-risk factor is of prime importance. In terms of overall thermal efficiency, the process is fully competitive with Lurgi and other first generation systems.

The relatively low throughput of the gasifier makes it a very suitable choice for small applications, which is often the case with industrial retrofits. Conversely, the excessive number of gasifiers which would be required to handle the throughput of a very large facility makes the Wellman-Galusha gasifier an unlikely choice in that situtation.

The high overall gasifier efficiency of 87 percent is partly responsible for an attractive economic projection. Lower capital costs play an equally important role. Non-fuel gas costs of $2.57/MM-Btu are considerably below that for Lurgi and other similar mature technologies.

The great number of potential industrial retrofit applications in the United States will be by far the largest market for Wellman-Galusha technology.

1.2 ENGINEERING ASPECTS

The Wellman-Galusha retrofit plant described in Chapter Two is representative of a design which would be used in a typical industrial retrofit situation. Sized coal (fines cannot be used) is gasified with steam and air in countercurrent flow, which produces a low-Btu gas rich in oils and tars. Following separation of the tar phase, acid gas components are removed from the main gas stream, which is then suitable for use as a fuel. Gas heating and expansion steps are included in the process to increase overall efficiency.

One feature of this design which affects process efficiency is the use of a gas quench system for cooling the raw gasifier effluent. Because the stream is quenched with water, the low level steam generated from this step is not useful, thus wasting all of the sensible heat present in the raw gas between the exit temperature and the quench temperature. Indirect heat exchange is one approach which has been used to recover some of this heat in a useful form. However, this alternative is considerably more capital intensive than quenching, and could encounter fouling problems in the Wellman-Galusha process because of the high tar fraction in the gas.

Downstream of the heat exchange (quenching or indirect heat recovery) section, standard technology can be used for production of the desired fuel gas. In the case of the Wellman-Galusha process, this includes acid gas removal, reheating of the gas with an internal process stream, and gas expansion to recover pressure energy provided to the gas during acid gas removal. A considerable experience base exists for these technologies from their use in the coal gas as well as petroleum refining and other industries.

1.3 CURRENT COSTS

The total capital requirement for this 10 x 10^{12} Btu/year plant is $120 million, which is dominated by a capital investment of $95 million. Interest during construction, working capital and start-up costs make up the additional $34 million.

Annual operating and maintenance costs (at a 90% plant capacity factor), exclusive of coal costs, total $8.3 million, and are largely comprised of labor, taxes and insurance. Sulfur is given a by-product credit of $40/ton, giving a net operating and maintenance cost of $7.6 million.

Taken together with a 20 percent capital charge, these operating costs result in a product cost of $3.70/$10^6$ Btu, which is exclusive of coal costs. At $1.50/$10^6$ Btu coal cost, the total product cost becomes $6.16/$10^6$ Btu.

1.4 RESEARCH AND DEVELOPMENT DIRECTIONS

The mature state of the Wellman-Galusha gasification technology suggests that the current gasifier design has been developed to its fullest. However, modifications in operating conditions which would call for a different reactor configuration are possible. One such modification might involve operation of the gasifier under slagging conditions. This change would increase gasifier efficiency, improve the ease of ash removal, and lower steam consumption in the gasifier. Development of this feature would also suggest development of a slag quench heat recovery system. Another beneficial change would be high pressure operation in the gasifier (the current design pressurizes the feed gas to the acid gas removal unit, but the gasifier operates at near atmospheric pressure). This would allow the gasifier to be used as a source of gas for combined cycle power generation or other applications requiring a source of high pressure gas.

All of these changes in gasifier operating condition or mode are significant in terms of the development program required to produce a commercial system. Extensive testing would be required at the bench scale, pilot plant, and demonstration plant levels. Changes in the process or particularly materials of construction may result from advances in chemical engineering or materials science. Changes of this nature may or may not require demonstration at various sizes before changes in the commercial unit are implemented.

CHAPTER TWO: ENGINEERING SPECIFICATIONS

2.1 GENERAL DESCRIPTION OF THE TECHNOLOGY

Wellman-Galusha gasifiers represent one of the commercially available fixed-bed gasifiers capable of gasifying a variety of feedstocks. It was first used (commercially) in 1941 in Germany and is currently licensed by the McDowell-Wellman Engineering Company of Cleveland, Ohio. It is an atmospheric pressure non-slagging reactor that can be generated with a steam/air or steam/oxygen gasifying medium, although the air blown mode is most common. Eight systems are currently operating in the United States. Some 150 gasifiers have been installed world-wide since its introduction in 1935. All of the earlier installations involved only single gasifiers, whereas later plants have multiple units.

The gasifier is a vertical cylindrical steel vessel with a diameter ranging from 1-1/2 to 10 feet. The vessel is either refractory lined or water jacketed for cooling. Crushed coal is fed to the gasifier through vertical feed pipes. The fuel bed can be unstirred or stirred. Agitation is a necessary requirement with caking coals but capacity increases of up to 35 percent can also be realized with the stirred bed. A steam and air/oxygen mixture is introduced from the bottom of the vessel and the product gas exits from the top of the unit. Gas leaving the vessel is at 900-1200°F and can be used directly as a fuel gas after passing through a ceramic lined cyclone to remove particulate. Depending upon the application, however, some additional gas clean-up may be required.

2.2 PROCESS FLOW, ENERGY AND MATERIAL BALANCES

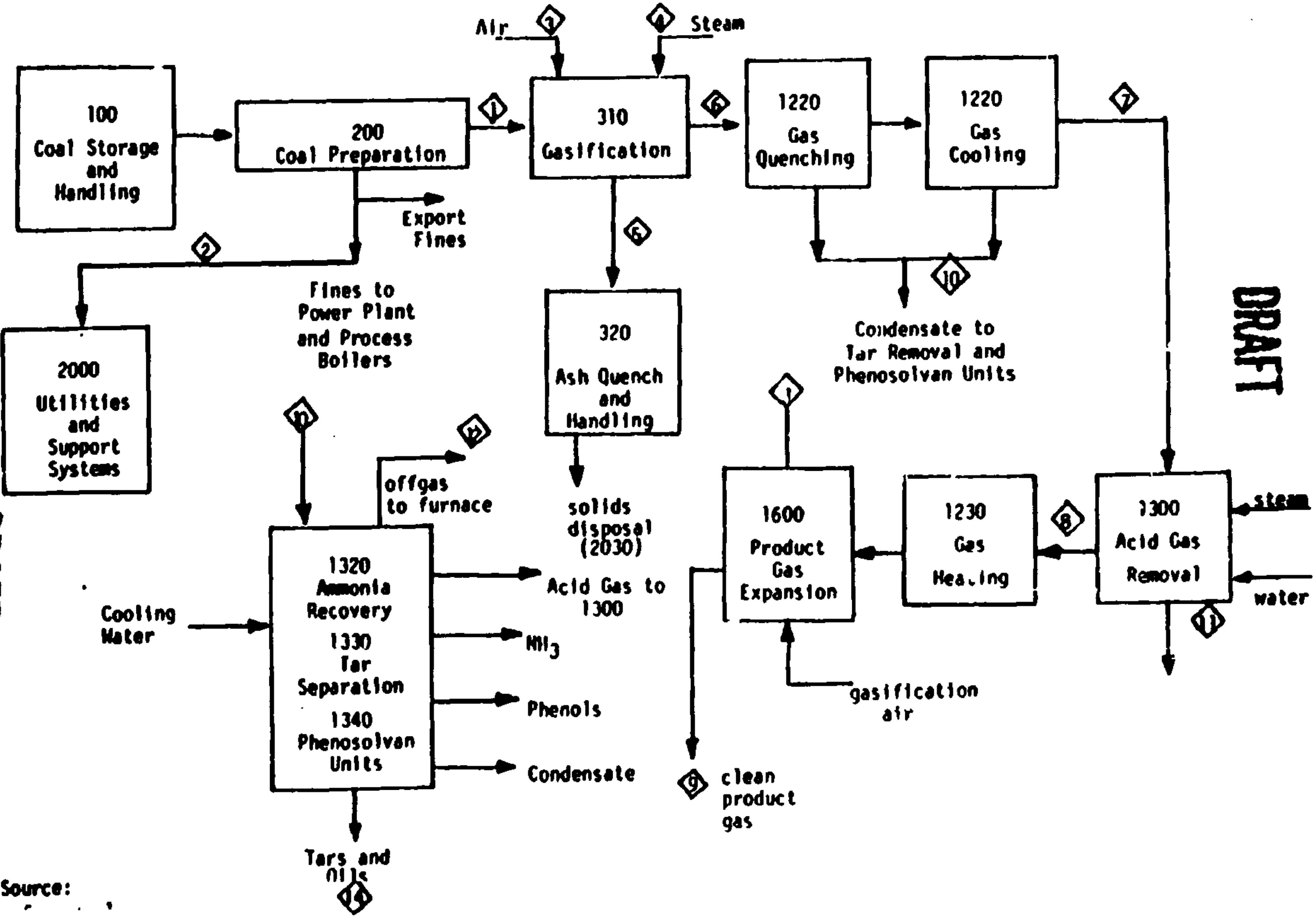
A conceptual process flow diagram for production of fuel gas is shown in Figure 2.2.1 and accompanying material flows are presented in Table 2.2.1. The diagram shows the major unit operations, their plant area numbers, and their connecting stream flows. A summary of plant area numbers is given in Table 2.2.2. Coal enters the plant at the receiving and storage yard. The type of coal preparation employed in plant section 200 depends strongly on the type of coal being used. The flow characteristics of the material in the gasifier, reaction rates and desulfurization requirements must all be tested before the proper front-end treatment system can be selected. Crushed coal is double screened to 2 by 1/8 inch and fed to the gasifier. Fines can not be accepted.

Gasification takes place at near atmospheric pressure. Steam required for gasification is supplied by saturating a slip stream of reaction air at 130°F. Saturated steam is generated within the reactor water jacket, and is consumed in the gasifier. Reactor operating data are summarized in Table 2.2.3.

Reactor offgas exits at 1200°F and is cooled and humidified in a water wash scrubber. Tars and oils condensing from this operation are combined with other condensate streams and sent to units 1330 and 1340 for separation and recovery of their various components. The raw gas is further cooled by heat exchange prior to acid gas removal in unit 1300. Sulfur laden gas recovered from unit 1300 is processed to produce elemental sulfur in the same unit. The main synthesis gas stream, free of sulfur, is reheated at low pressure and expanded further, providing power for the gasification air blowers. This stream is suitable for use as a boiler or turbine fuel. Table 2.2.1 gives the stream flows and compositions.

Fig. 2.2.1

Wellman-Galusha Coal Gasification System for Low-Btu Gas Production



Source:

DRAFT

DRAFT

Table 2.2.1

Material Flows for the Wellman Galusha Gasification System

Stream No.	1	2	3		4		5	6		7	
Description	Gasifier Feed	Power Plant Fines	Gasifier Air		Gasifier Steam		Ash	Raw Gas		Cooled Gas	
Temperature, °F			80		130			1200		100	
Composition	Klb/hr	Klb/hr	Klb/hr	mol %	Klb/hr	mol %	Klb/hr	Klb/hr	mol %	Klb/hr	mol %
H_2								5.4	13.76	5.4	14.06
CO								124.5	22.92	124.5	23.43
CO_2								43.0	5.04	43.0	5.15
H_2O			4.47	2.10	37.4	15.12		26.6	7.62	19.1	5.58
H_2S								4.5	0.68	4.5	0.07
N_2			257.7	77.34	257.7	67.05		259.2	47.69	259.2	48.73
O_2			78.3	20.56	78.3	17.83					
CH_4								7.1	2.29	7.1	2.35
Total	130.9	10.3	340.4	100.00	373.3	100.00	23.6	470.4	100.00	462.8	100.00

NOTE: All material flows are given at 100% plant capacity.
Source: Reference 1.

Table 2.2.1, cont'd

Material Flows for the Wellman Galusha Gasification System

Stream No.	8		9		10	11	12		13	14
Description	Clean Gas		Product Gas		Condensate	Sulfur Product	Tar Unit Off-Gas		Phenols	Tars
Temperature, °F	115		627							
Composition	Klb/hr	mol %	Klb/hr	mol %	Klb/hr	Klb/hr	Klb/hr	mol %	Klb/hr	Klb/hr
H_2	5.4	13.70	5.4	13.70			0.51	7.03		
CO	124.5	22.82	124.5	22.82			5.70 (c only)	79.82		
CO_2	43.0	5.02	43.0	5.02						
H_2O	30.5	8.70	30.5	8.70			0.73	10.09		
H_2S	0.007	0.001	0.007	0.001			0.08 (S only)	1.09		
N_2	259.2	47.47	259.2	47.47			0.05	0.70		
O_2							0.09	1.27		
CH_4	7.1	2.29	7.1	2.29						
Total	469.8	100.00	469.8	100.00	40.45	4.83	7.3	100.00	0.73	7.28

NOTE: All material flows given at 100% plant capacity.
Source: Reference 1

Table 2.2.2

Relevant Plant Area Numbers for Wellman-Galusha Gasification

100	COAL STORAGE AND HANDLING
	110 Coal Storage 120 Coal Handling and Transportation
200	COAL PREPARATION
	210 Crushing and Grinding 250 Size Classification
300	GASIFICATION
	310 Gasification 320 Ash Quench and Handling
1200	RAW GAS COOLING
	1220 Gas Quenching and Cooling 1230 Gas Heating
1300	ACID GAS REMOVAL
	1310 H_2S Removal 1320 Ammonia Recovery 1330 Tar Separation 1340 Phenosolvan Units
1600	PRODUCT GAS EXPANSION
2000	UTILITIES AND SUPPORT SYSTEMS
	2010 Steam Generation and Power Recovery 2020 Wastewater Treating 2030 Solids Disposal
2100	OFFSITES AND MISCELLANEOUS

Table 2.2.3

Wellman-Galusha Gasifier Typical Operating Data

	Low BTU Gas
Gas Production, MM SCF/hr	0.3 - 0.4
Gas Composition, Volume %	
Hydrogen	19
Carbon Monoxide	25
Methane	1
Nitrogen	49
Carbon Dioxide	6
Other	-
Total	100
Gas Higher Heating Value, BTU/SCF (Dry Basis)	160 - 210
Feed Requirements, lb/lb coal:	
Air	3.5
Oxygen	
Steam	0.4 - 0.7
Operating Conditions	
Gas Outlet Temperaturs, °F	800 - 1200
Pressure	5-6 in. H_2O
Residence time, minutes	120 - 500
Turndown Capability	4:1
Coal Feed:	
Type	Bituminous
Size, Inches	1.25 - 2.0
Free Swelling Index	no limit
Ash Fusion Temperature, °F	2100
Feed Rates, tons/day	84

Source: Reference 2

Process Energy Flows

Energy flows into and out of the plant battery limits are shown in Figure 2.2.2. Overall plant thermal efficiency is 61 percent. Also shown in the diagram is the gasifier energy balance which indicates a conversion efficiency of 87 percent including sensible heat contained in outlet streams.

2.3 PLANT SITING AND SIZING ISSUES AND CONSTRAINTS

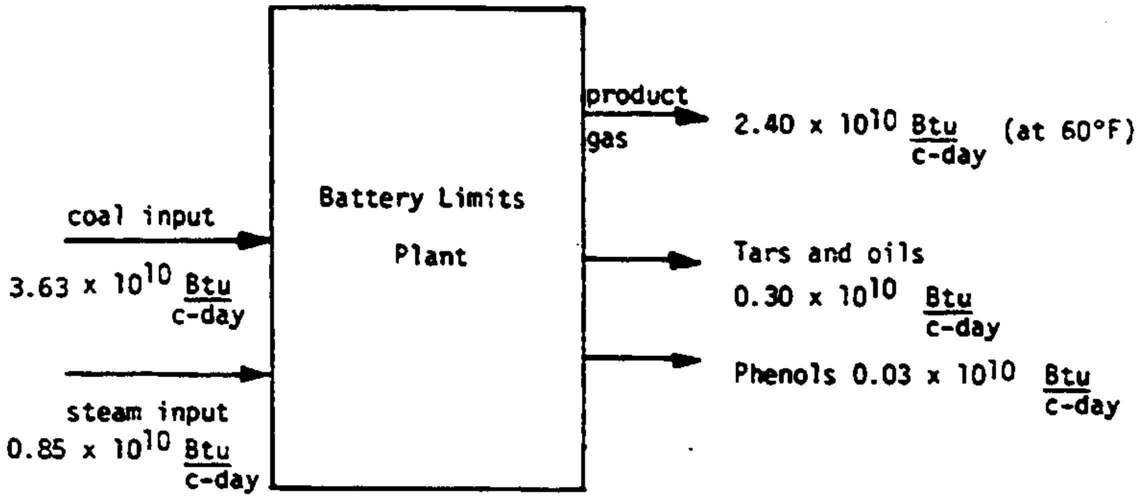
The Wellman-Galusha plant is sized to produce 10 x 10^{12} Btu/yr (including by-product tars, phenols and electricity), a comparatively small plant when judged by recent designs for many other gasification systems. This size was chosen to represent a scale which could be considered for the retrofit of a typical industrial consumer of gaseous fuel.

The availability of an industrial site as a retrofit candidate for the Wellman-Galusha technology will depend on several physical factors.

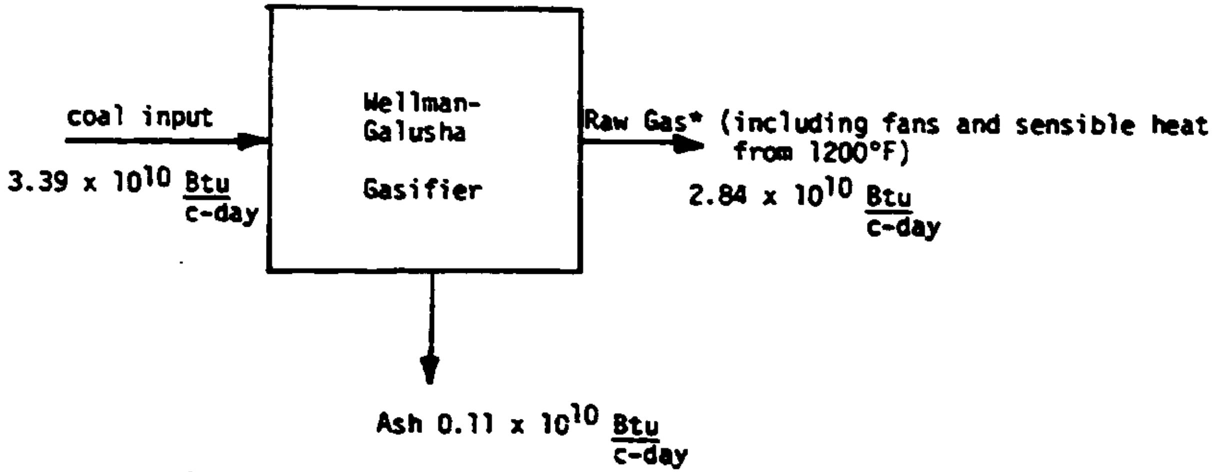
First, adequate plot space must be available to locate the facilities needed for coal storage, handling and preparation. The gasifiers and downstream equipment will also require space which may be difficult to integrate into the existing system. Some synergism may exist in the utilization of heat exchange equipment, steam and power systems and the acid gas removal step, although some adjustment to existing capacity may be required to take advantage of this fact.

Figure 2.2.2

Wellman-Galusha Energy Flows:
Overall Plant and Gasifier



Overall plant thermal efficiency = 61%



Overall gasifier efficiency = 87%

Note: gasifier steam supplied entirely by jacket cooling water.

* mean molal heat capacity of raw gas = 7.82 $\frac{\text{Btu}}{\text{lb mol °F}}$

2.4 RAW MATERIAL AND SUPPORT SYSTEM REQUIREMENTS

2.4.1 Coal Quantities and Quality

The type of coal used will have a significant effect on the design and cost of the entire gasification system. The design presented herein is based upon the following coal composition, which represents an average of those coals used by TVA in 1972:

Heat Content, Btu/lb	10,800
Ash content, %	16.7
Sulfur Content	3.5
Ash fusion temperature, °F	2,300 - 2,500

This coal had the following ultimate analysis:

	Wt. %
C	59.31
H	4.05
O	6.76
N	1.18
S	3.50
Ash	16.70
H_2O	8.50
	100.00

As the plant is designed, 2,109 tons per day of this coal will be used at 100% of the plant capacity.

2.4.2 Catalyst and Other Required Materials

The Stretford sulfur recovery system is the primary consumer of catalysts and chemicals. Since the Stretford process uses a regenerable scrubbing solution, the make-up chemicals are only required to replace those lost in the sulfur cake and solution blowdown. Rinsing of the sulfur cake minimizes loss. Blowdown is required to prevent accumulation of non-regenerable compounds such as thiocyanates which are formed from HCN in the feed gas and aqueous phase oxidation of HS^- radicals. The approximate make-up rates required with the chosen coal feedstock are listed in Table 2.4.1.

Table 2.4.1

Make-up Chemical Requirements

Chemical	Make-up Rate, lb/hr
Anthraquinone Disulfonic Acid	32
Sodium Metavanadate	21
Sodium Carbonate	17
Sodium Bicarbonate	79
Ethylenediamine Tetraacetic Acid (EDTA)	9
Iron	0.2

2.4.3 Water Requirements

The plant will require approximately 790,500 gallons (3,295 tons) of raw water per day for process use. A small amount (less than 4,000 gallons per day) of potable water will be required in addition to this but could probably be supplied by the existing potable water system at the industrial site implementing the Wellman-Galusha retrofit.

2.5 EFFECT OF COAL TYPE

One of the disadvantages associated with virtually all fixed bed gasifiers is their inability to process caking coals without some form of pretreatment or use of stirring devices in the gasifier during oepration. To this degree, coal properties may influence the type of coal pretreatment system required.

Another characteristic of fixed bed gasificaiton systems is the presence of heavy compounds (tars and oils) in the raw gasifier effluent. These compounds foul wastewater streams and process equipment and are often carcinogenic or toxic. The composition of the contaminants in this raw gas stream are strongly dependent on coal type and the time-temperature history of the coal particles passing through the reactor. Coals low in volatile matter, such as anthracite, produce only small amounts of these heavier compounds, while the reverse is true with high volatile coals such as lignite. Similarly, the moisture content of the raw gasifier effluent is directly influenced by the water content of the feed coal, as well as the amount of steam injected and the extent to which water vapor is either consumed or produced during the gasification process (usually small at lower temperatures). In addition to greater wastewater quantities, high moisture coals also result in the production of greater volumes of tars due to the retention of water by these substances.

Problems associated with moisture may be exacerbated when gasifying coals with low ash softening points. These coals require that enough steam be added during gasificaiton to limit bed temperatures below the ash softening point to prevent slagging, which is not compatible with the ash removal mechanism in the gasifier. The addition of steam adversely affects gasifier and overall plant thermal efficiency, since the enthalpy of the steam is not recovered in the process. Coals with ash softening points of approximately 2,200°F or higher are preferred but may be as low as 1,500°F with steam addition.

The quantity and characteristics of the particulates found in the product gas also depend on the properties of the coal feedstock. Gasification of hard coals such as anthracite, produces substantially fewer entrained particulates than gasification of the softer and more reactive coals such as subbituminous and lignite coals. Particulate removal is almost always required to meet product gas specifications and protect downstream equipment.

2.6 AIR POLLUTION CONTROL TECHNOLOGY

2.6.1 Ability of Existing Technology to Meet Regulations

Although no source emission standards exist for coal conversion plants in particular, the Wellman-Galusha plant described herein meets regulations established for utility and petrochemical plants (including 1979 NSPS regulations).

The primary airborne pollutants of concern are particulate matter (coal dust and ash) and gases of varying composition from two main sources in the plant.

Coal storage and handling activities are primarily responsible for emissions of coal dust, the composition of which is similar to that of the coal feedstock. One analysis(1) of the dust reports slightly positive results for the Ames test (carcinogenicity) with bituminous coal, but negative results with anthracite.

Gaseous emissions result primarily from the coal gasificaiton and gas purification plant sectors. Coal feeder vent gases and fugitive emissions from gasification are limited to gaseous species found in the product gas, such as CO, H_2S, NH_3, light hydrocarbons, etc. Although start-up vent gases will not be produced during steady state operation (only during start-up), these gases will include the above mentioned compounds, plus a variety of particulate matter types (coal dust, tar, and oil aerosols). This stream will be a source of numerous carcinogenic organics, including fused aromatic hydrocarbons, heterocyclic nitrogen, sulfur and oxygenated compounds, carboxylic acids, amines, sulfonic acid, sulfoxides, phenols, thiols, benzene and substituted benzene hydrocarbons. Inorganics are also of concern, particularly heavy metals, H_2S, HCN, SO_2, CS_2 and the transition metal elements.

Gas purification consists of gas quenching and cooling (for tar liquor separation) and sulfur removal and recovery systems. Vent gases from separator vessels will contain the same compounds found in the start-up vent gases, although to a lesser degree. The Stretford sulfur removal process vents gases from evaporation and oxidizer vessels which contain water vapor, CO_2, N_2, O_2 and possibly NH_3.

Unlike other acid gas removal systems, the Stretford system incorporates acid gas removal and sulfur recovery in one process. Nearly 60 tons of elemental sulfur are produced per day by the process, which restricts the H_2S concentration in the product gas to less than 0.001 mol %, well below expected future limits or sulfur emissions for coal conversion facilities.

2.6.2 Impacts on Process Efficiency

Because there are no sensitive catalysts in the Wellman-Galusha process, the removal of sulfur compounds is performed for purely environmental reasons. Therefore, the energy consumption of this step and its impact on process efficiency is an accurate measure of the cost of sulfur control.

A similar argument can be made for particulate control, although it is not as clear cut due to the process advantages of handling a particulate-free gas. Particulate control, however, has a relatively insignificant impact on process efficiency due to the low (if not zero) energy consumption of these systems. For example, fugitive dust and many other sources of particulate can be controlled by simple covered containers or fan collection systems designed to recycle particles back to the process. Some vent gas streams can also be handled in this manner.

The most significant energy consumption (for environmental control) occurs with the Stretford system. For high sulfur bituminous coal, approximately 1.9 Btu is consumed in the sulfur recovery system for every 100 Btu of product gas produced.(1) This nearly 2% efficiency cost is significant in terms of plant productivity and profitability.

2.7 WATER POLLUTION CONTROL TECHNOLOGY

2.7.1 Ability of Existing Technology to Meet Regulations

One problem arising from fixed bed coal gasification is the production of tars and oils which appear in the offgas stream. This occurs because of the countercurrent flow of oxidizers and coal; hot gases rising up through the incoming coal feed cause pyrolytic devolatilazation, producing unreacted organics. Aside from fouling downstream equipment and being an undesirable product, these compounds can be toxic, carcinogenic, and mutagenic and thus require some form of control. They appear in the wastewater primarily as a result of gas quenching operations (with water) or as a result of condensation when the gas stream is cooled by indirect heat exchange.

Other liquid phase pollutants streams may include water runoff from coal storage piles (containing leachable organics and inorganics), water from ash quenching activities (containing soluble inorganics with a few organics), and solvent blowdown from the sulfur removal system (containing thiosulfate and thiocyanate salts in the case of the Stretford process).

The composition of coal gasificaiton wastewater will vary over a considerable range depending on feed coal composition and gasifier operating conditions. A wide variety of treatment options exist for reducing the organic content of this wastewater stream. Streams with high concentrations can usually be treated economically by solvent extraction, distillation or wet air oxidation, while low concentrations are often amenable to treatment by biomethanation or various adsorption or absorption systems (e.g., activated carbon). Wastewater streams initially high in organics may be most economically treated to meet applicable discharge standards by a combination of two of the above techniques. Thus, the technology for effective control of most wastewater organics is available, with cost being the primary determinant of process type.

Coal pile runoff may be controlled by the use of covered bins for coal storage or by collecting runoff water to help meet process needs. Wastewater from ash quenching oeprations should be collected, filtered and recycled to the ash quench system. Process blowdown from sulfur recovery systems may require containment and treatment at a hazardous waste facility, depending on its composition and concentration. Alternatively, the contaminants may be reduced by incineration at high temperature.

2.7.2 Water Recycling Systems

The recycling of process water can be an effective method for the control of aqueous phase contaminants as well as being an efficient use of natural resources. The range over which water recycling can be used is great, varying from no reuse (unlikely in today's economic and regulatory climate) to maximum reuse where the plant consumption of raw water is virtually zero. This later case would depend on moisture present in the feed materials (coal and air) to meet process water needs. Especially in the case of low-rank coals such as lignite, moisture levels can be extremely high in the feed material, as much as 40 percent by weight. The fact that these coals exist primarily in arid regions give the process designer a built-in method for obtaining a source of water which might otherwise be limited by resource conservation laws or actual physical unavailabiltiy. However, in extreme cases of water recycle, the capital costs for this alternative will usually outweigh any reduction in operation costs resulting from the savings in raw water purchases. Therefore, the extent to which water recycling is used will be determined by local water accessibility (as determined by physical and regulatory availability), water cost, discharge regulations and capital costs.

A Wellman-Galusha gasification system could employ water recycling for coal pile runoff, ash sluice water, process condensate and solvent blowdown from acid gas removal systems.

2.7.3 Impacts on Plant Efficiency

Water recycling and treatment systems are necessary for the conservation of natural resources and protection of the environment from emissions of hazardous materials. Primary energy users in these process operations are pumps and reaction vessels (requiring low levels of process heat). Energy use will vary according to the type of system used and the extent to which recycling and treatment is performed. However, in a worst case where maximum recycle is employed and the most energy intensive treatment systems are used (solvent extraction/distillation), overall impact on process efficiency would not exceed 2 percent.(2-3)

2.8 SOLID WASTE HANDLING

2.8.1 Disposal Requirements

Sources of solid waste from the Wellman-Galusha process include gasifier ash and ash leachate (solids leached from ash piles), particulate matter collected from hot cyclones, leachate from this material, and sulfur produced from acid gas cleaning processes.

Ash from the gasification process is recovered in a non-slagged form from the ash quench system. Flyash from the raw gas stream, together with any unreacted carbon, is also removed from the raw synthesis gas stream as a result of water scrubbing operations. These solid materials may be landfilled, returned to the mine, or sold for use in concrete manufacture or roadway construction.

2.8.2 Leachate Problems

The leaching of metal ions from unslagged gasifier ash has been demonstrated in laboratory simlulations. The extent of leaching in an actual burial situation will depend on many factors, among the most important are water pH, and the physical structure and the chemical nature of the ash.

The extent of leaching can be controlled by the method of disposal. Landfills can be made such that contact with rainfall, surface runoff and groundwater aquifers is minimized; disposal with mine wastes by returning to the mine presents a greater risk of contamination of water supplies.

Disposal of solid wastes from Wellman-Galusha gasification activities must be planned on an individual basis, balancing the requirements imposed by the chosen feedstock against local alternatives for disposal.

2.9 OSHA ISSUES

The Wellman-Galusha gasification system poses several potential occupational hazards. The coal storage area will be subject to dust generation and spontaneous combustion and so provisions must be made for wetting the coal. Grinding coal is a noisy operation and workers in this area should have ear protection. Dust must also be controlled in the grinding area.

Gas may leak from faulty valves from the coal feeder and from the pokeholes. The gas contains carbon monoxide, aromatic hydrocarbons, volatized trace metals, phenols, ammonia and organic sulfur. Cleaning the gasifier will expose the worker to aromatic hydrocarbons, trace metals, phenols, ammonia and organic sulfurs. Care must be taken not to inhale or expose the skin to gasifier residuals.

Coal tars contain carcinogenic aromatic hydrocarbons and heterocyclic compounds. Exposing the skin to this tar can cause skin irritations and tumors. The Wellman-Galusha gasifier produces approximately 120 pounds of tar per ton of coal.

2.10 PROCESS PERFORMANCE FACTORS

2.10.1 Product Characteristics and Marketability

The composition of the low-Btu product gas from the Wellman-Galusha process is given below:

Compound	Mol % (% by Volume)
H_2	13.70
CO	22.82
CO_2	5.02
H_2O	8.70
H_2S	0.001
N_2	47.47
CH_4	2.29
	100.00

The higher heating value of this gas is approximately 143 Btu/SCF. Gas of this quality is adequate for firing gas turbines or boilers, although some boiler derating may be required because of the low intrinsic heating value of the gas. The extent of the derating (as compared to coal) could probably be minimized to around 5 percent by increasing fan capacity, removal of superheat and possibly economizer surfaces and installation of new burner heads and gas ducts.

Due to the low heating value of the gas, marketability would be limited to on-site or nearby use. Use as a residential fuel is not possible due to the toxicity of the carbon monoxide in the gas. The Wellman-Galusha process also produces sulfur, tar, ammonia (20% aqueous) crude phenols and electricity as by-products.

Tars and oils are produced in quantities of approximately 5 percent of the coal feed by weight. Its composition is 2 percent sulfur, 87 percent carbon, 8 percent hydrogen, 2 percent oxygen and 1 percent nitrogen by weight, giving a heating value of 17,000 Btu/lb. Production of crude phenols is approximately 10 percent of the tar production rate. By-products and their production rates are summarized below.

Table 2.10.1

Wellman-Galusha By-Products

Material	Production Rate
Tars and Oils	7,200 lb/hr
Phenols	730 lb/hr
Ammonia (20% aqueous)	6,858 lb/hr (including water)
Sulfur	4,235 lb/hr

The tars and oils have application to various construction activities (such as road building) or can be used as fuel. The phenols have a ready market in the chemical industry. The ammonia and sulfur will most likely be used for fertilizer and sulfuric acid production, respectively. In this case, it has been assumed that the electricity produced exactly balances plant needs thereby leaving no by-product electricity.

2.10.2 Capacity Factors, Flexibility and Reliability

The Wellman-Galusha gasification plant is designed to operate with a 90 percent capacity, producing synthetic fuel products at an overall efficiency of approximately 65 percent. Its design is based upon considerable operating experience with this gasifier in many installations where a coal derived synthesis gas was required. The turndown ratio of the gasifier is 4:1, which gives the system adequate flexibility to meet daily and seasonal changes in flowrates for most applications. Because of the gasifier's considerable operating history, virtually all of the operating problems associated with a developing technology have been resolved. Reliability is therefore expected to be excellent.

2.11 TECHNOLOGY STATUS AND DEVELOPMENT POTENTIAL

2.11.1 Current Status

Wellman-Galusha gasifiers have been commercially available since 1941. Approximately 150 gasifiers have been installed worldwide. In the United States, 11 systems are currently producing low-Btu gas from anthracite and low-sulfur bituminous coals. Table 2.11.1 summarizes the location, processes and coal feedstocks for each plant.

Typical previous applications of Wellman-Galusha technology are summarized in Table 2.11.2. Specific uses varied from heat treating (in glass and steel mills) to synthesis gas (for fertilizer manufacture). Feed materials included charcoal, coke, anthracite and bituminous coal.

Table 2.11.1

Applications of Wellman-Galusha Gasifiers in the United States

Coal Feedstock	Gas Purification Processes	Company/Location	Number of Gasifiers	Remarks
Anthracite, low sulfur (~0.7)	• Cyclone	Glen-Gery Brick Co. - York, PA - Reading, PA - Shoemakersville, PA - Watsontown, PA - New Oxford, PA	8	• Currently in commercial operation • Product gas used to fire brick kiln
Anthracite, low sulfur	• Cyclone	Hazelton Brick Co. - Hazelton, PA	4	• One gasifier in use • Three other gasifiers inactive • Product gas used to fire brick kiln
Anthracite, low sulfur	• Cyclone	Binghamton Brick Co. - Binghamton, NY	2	• Gasifiers not currently in use
Bituminous, low sulfur (~0.78)	• Cyclone	National Lime & Stone Co. - Cary, OH	1	• Currently in commercial operation • Product gas used to fire lime kiln • Lime will remove some of the sulfur species in the flue gas
Anthracite, low sulfur	• Cyclone • Gas Quench	Can Do, Inc. - Hazelton, PA	2	• Completed in 1980 • Product gas to be used in an industrial park • Possibility of adding two more gasifiers • Partial funding by DOC
KY Bituminous CO Subbituminous MT Bituminous ND Lignite	• Cyclone • Gas Quench • Tar/Liquor separation	Bureau of Mines - Ft. Snelling, MN	1	• Commercial-size demonstration unit • Partial funding by DOE • First series of test runs completed in 1978 • Additional tests conducted in 1979 • Product gas was used to fire an iron pelletizing kiln • Excess product gas was combusted
Bituminous, low sulfur	• Cyclone • Possibly gas quench, tar/liquor separation, wastewater treatment and sulfur removal (Stretford)	Pike County - Pikeville, KY	2	• To be completed in 1982 • Product gas used to fire boilers and process heaters • Partial funding by DOE
Anthracite, low sulfur (~0.78)	• Cyclone	Howmet Aluminum - Lancaster, PA	1	• To be completed in early 1980 • Product gas used to fire process furnaces • Possibility of adding up to 11 more gasifiers
Coke	• Cyclone	Gulf & Western (N.J. zinc) - Ashtabula, OH	1	• Start up in 1979 • Gas used in process furnace • Installed in 1961
Coke	• Cyclone	Olin Chemical Corp. - Ashtabula, OH	1	• Gas used in process furnace • Installed in 1963
Lignite	• Not Available	Chemical Exchange - Houston, TX	1	• Start up in 1979 • Gas end use not available

Table 2.11.2

Past Users of Gas Produced by Wellman-Galusha Gasifiers

- chemical plants
- glass plants
- steel mills
- magnesium manufacturers
- silk mills
- bakeries
- wire mills
- foundries
- potteries
- Aluminum and stainless steel manufacturers
- ordinance plants
- tin plate mills
- lime plants
- brick plants
- zinc smelters
- iron ore processors
- fertilizer plants

2.11.2 Key Technical Uncertainties

Because of the mature state of the Wellman-Galusha gasification system, gasifier operation is completely characterized. The same can be said for most of the process operations within the plant. Because of the importance of tar in the process, application of conventional water treatment technology when feeding a previously untested coal could require some potentially major modifications to the water treatment design. Attempts to improve process efficiency by placing (for example) heat exchange surfaces instead of a gas quenching step may result in poor availability or performance, especially in light of the presence of high tar concentrations in the raw gas.

2.11.3 Availability for Commercial Production

The Wellman-Galusha gasification system is fully available for commercial production.

2.11.4 Unit Design and Construction Times

Gasification systems featuring Wellman-Galusha gasifiers are most suitable for relatively small applications, with fuel demands ranging from about 8.8 to 88 MW of thermal energy (30 to 300 million Btu/hr). This would require from one to ten gasifiers. Energy demands greater than about 88 MW (300 million Btu/hr) may be better served by gasification systems using gasifiers with larger capacities (for example pressurized gasifiers).

McDowell-Wellman can deliver Wellman-Galusha gasifiers six to eight months from the date of order. However, systems using two to four gasifiers and including extensive gas purification will require 18 to 24 months from initial feasibility studies to full-scale operations.[2-1, 2-2]

Wellman-Galusha gasification systems will be most widely used in industrialized areas which also contain available coal reserves. Two areas of the country which meet these conditions are the Northeast and Midwest.

2.12 REGIONAL FACTORS INFLUENCING ECONOMICS

2.12.1 Resource Constraints

From the data presented in the material balance, the coal consumption fo the Wellman-Galusha plant is 707,460 tons per year, assuming a 90% stream factor. Raw water consumption can, to a large extent, be controlled as a design variable but considerable capital investment is required to achieve a significant reduction in use. Because of the small size of the plant, a dedicated mining operation would not, in most cases, be economically feasible. Purchase of the coal feed from outside sources, therefore, makes the operation vulnerable to changes in coal price with free market competition being the only safeguard against great increases in price.

2.12.2 Environmental Control Constraints

Included in the process design must be considerations which will assure that plant operation be economically feasible within the limits set by governing environmental regulations. Since these laws are somewhat variable as to severity and components depending on location, the specific emission characteristics of a Wellman-Galusha gasification plant should be reviewed with respect to possible plant site locations. Since most applications will be for industrial retrofit, only process configuration is open as a variable to planners. Environmental control systems in this case will be chosen to best meet existing regulations at minimum overall cost.

2.12.3 Siting Constraints

Because of the retrofit nature of most Wellman-Galusha applications, the general geographic site is already defined. Location of the system within the existing plant site should allow best access to sources of water, roads for coal delivery, short transmission distance for product gas to use, and close proximity to electric lines. The land should be relatively flat and of sufficient integrity to support heavy process vessels.

References

2-1. Waitzman, D.A. et al. "Evaluation of Fixed-Bed Low-Btu Coal Gasification Systems for Power Plants," Electric Power Research Institute, No. RP-203-1, February 1975.

2-2. Bartman, B.F. et al. "Low-Btu Coal Gasification Processes, Volume 2, Selected Process Descriptions," Oak Ridge National Laboratory, No. ORNL/ENG/TM-13V2, June 1978.

2-3. Personal Communication, Dr. Ronald Probstein, May 1980.

CHAPTER THREE: ECONOMIC ANALYSIS - WELLMAN-GALUSHA

3.1 INTRODUCTION AND METHODOLOGY

3.1.1 Introduction and Methodology

The economic analysis for the Wellman-Galusha system relies on a conceptual design for a low-Btu gasification system using this technology (3-1). The reference plant capacity was scaled to a size of 10 trillion Btu per year, costs were corrected from 1975 to 1980 dollars, and the adjusted capital and operating costs were used to compute product costs.

3.1.2 Scaling Exponents

The reference plant capacity was 39 x 10^{12} Btu/year, including gas, tar and phenol outputs, which was scaled down to 10 x 10^{12} Btu/year using the formula presented in the Background Section. A scaling exponent of 1.0 was used for gasification (Area 300) and .72 was used for the other items of plant costs (3-2). A scaling exponent of .6 was used for operating labor.

3.1.3 Price Indices

Costs were corrected from 1975 dollars to third quarter 1980 dollars using the indices presented in the Background Section.

3.1.4 Economic Criteria

The standard economic criteria presented in the Background Section were employed. In addition, maintenance was estimated at 3 percent of Total Plant Investment with a labor/materials allocation of 40 percent/60 percent. Administration and general overhead was estimated at 60 percent of the sum of operating and maintenance labor, with administrative and support labor at 30 percent of operating and maintenance labor. Local taxes and insurance were estimated at 2.5 percent of Total Plant Investment. Steam and electricity imports were not priced as they were included in the efficiency calculation.

The schedule of construction investment was 50 percent, 50 percent, over two years.

3.1.5 Contingencies

A project contingency of 15 percent was applied to the sum of area costs, design costs and contractor's fees to cover unanticipated cost increases. No process contingency was applied because the equipment is commercially available and proven.

3.2 CAPITAL COSTS

3.2.1 Itemized Capital Costs

The total capital requirement for the Wellman-Galusha system is itemized in Table 3-1. Gasification, at $22.3 million, is the most expensive plant area. Design and field

TABLE 3-1

TOTAL CAPITAL REQUIREMENT: WELLMAN-GALUSHA

AREA	UNIT	ITEM	COST (1068)	PER COST OF SUBTOTAL
100		Coal preparation	(in 200)	
200		Coal storage and handling	.9	1.2
300		Gasification	22.3	29.9
1200		Raw gas cooling	5.3	7.1
1300		Acid gas removal and gas cleaning		
	1310	H_2S and CO_2 removal	10.3	13.8
	1330	Tar and oil separation	4.5	6.0
	1340	Phenol Recovery	3.1	4.2
2000		Utilities and support systems	5.0	6.7
2100		Offsites and miscellaneous	5.6	7.5
		Design and field expense	17.6	23.6
		Subtotal	74.6	100.0
		Contractor's fees	7.7	
		Process contingency	-	
		Project contingency	12.3	
		Total Plant Investment	94.6	
		Start-up	5.7	
		Working Capital	5.8	
		Interest During Construction	22.3	
		Paid up royalties	.5	
		Total capital requirement	128.9	

Source: 3-1, updated to third quarter 1980 dollars and scaled to 10 trillion Btu per year by ERCO.

expenses would absorb $17.6 million. The Total Plant Investment would be $94.6 million, including a contingency of $12.3 million.

Start-up adds $5.7 million and Working Capital adds $5.8 million to the Total Capital Requirement. Interest during construction amounts to $22.3 million and royalties $.5 million.

The total capital requirement is $128.9 million.

3.2.2 Variability of Capital Costs

Because the Wellman-Galusha system is commercially available, technical uncertainties are not a source of cost variability. In addition, in the basic capital cost estimate used (3-1) major equipment was specified and costed, which also reduces cost uncertainty.

However, the capital cost estimate used was for a size 3.9 times the standard size. Although the scaling factors were carefully chosen, scaling the plant size down may have introduced some variability into the estimate.

Therefore, the capital cost estimate should be considered accurate within only ±30 percent.

3.3 OPERATING AND MAINTENANCE COSTS

3.3.1 Itemized Operating and Maintenance Costs

Operating and maintenance costs are itemized in Table 3-2.

3.3.2 Variability of Operating and Maintenance Costs

Most of the operating and maintenance costs (i.e. maintenance labor and materials, local taxes and insurance and part of administration and general overhead and administrative and support labor) were estimated using the capital cost estimate as a base. Therefore, the O&M cost estimate should be considered as accurate as the capital cost estimate, that is, within ±30 percent.

3.4 EFFECT OF TECHNOLOGY DEVELOPMENT ON COSTS

Further development could improve the performance of the Wellman-Galusha gasifier and its associated gas cooling and gas clean-up equipment. As more of these units are installed, real capital and operating costs could decline as better methods are learned. These immature technologies account for approximately 60 percent of the total plant investment. With a maximum experience factor of 10 percent on new energy technologies (as described in the Background Section), the experience factor on Wellman-Galusha technology would be 60 percent of 10 percent or 6 percent. Each doubling of Wellman-Galusha gasifier capacity could result in a 6 percent real cost reduction because of experience.

3.5 PRODUCT COSTS

The cost of the Wellman-Galusha product gas has three discrete components: capital costs, operating and maintenance (O&M) costs and coal costs. A non-fuel product cost can be computed using the capital costs in Table 3-1 and the net O&M costs in Table 3-2. This non-fuel product cost yields an indication of the incremental cost of producing the synthetic fuel from raw coal.

TABLE 3-2

NET OPERATING AND MAINTENANCE COST - WELLMAN GALUSHA[a]

ITEM	COST (10⁶ $)[b]	PERCENT OF TOTAL
Administration and general overhead	1.3	15.7
Local taxes and insurance	2.4	28.9
Labor		
Operations	1.0	12.0
Maintenance	1.1	13.3
Administrative and support	.6	7.2
Total	2.7	32.5
Maintenance materials	1.7	20.5
Catalysts and chemicals	0.2	2.4
Total	8.3	100.0

By-Product Credit	(10^6 $)
Sulfur	(0.7)

Net O&M Costs	(10^6 $)
Gross O&M costs	8.3
By-product credit	(.7)
Total	7.6

[a] Source: (3-1), adjusted to 10 trillion BTU/yr by ERCO. 90 percent operating facctor.

[b] Third quarter 1980 dollars.

The total capital requirement of the plant is \$128.9 million from Table 3-1 and net O&M costs are \$7.6 million from Table 3-2. Therefore, the non-fuel product cost is:

$$P = \frac{(\$128.9 \times 10^6 \times 20\%) + \$7.6 \times 10^6}{(10 \times 10^{12} \text{ Btu}) + 90\% \text{ capacity}}$$

$$= \underset{\text{(Capital charges)}}{\$2.86/10^6 \text{ Btu}} \quad + \quad \underset{\text{(O\&M charges)}}{\$.84/10^6 \text{ Btu}}$$

$$= \underset{\text{(non-fuel product cost)}}{\$3.70/10^6 \text{ Btu}}$$

Using the formula presented in the Background Section the non-fuel product cost can be combined with a coal cost to yield a total product cost. The overall coal to product thermal efficiency of the process is 61 percent. Coal is assumed to cost \$1.50/10^6 Btu. Therefore, the total product cost is:

$$E = \underset{\text{(non-fuel cost)}}{\$3.70/10^6 \text{ Btu}} \quad + \quad \underset{\text{(coal cost)}}{\frac{\$1.50/10^6 \text{ Btu}}{61\% \text{ efficiency}}}$$

$$= \underset{\text{(non-fuel cost)}}{\$3.70/10^6 \text{ Btu}} \quad + \quad \underset{\text{(coal cost)}}{\$2.46/10^6 \text{ Btu}}$$

$$= \underset{\text{(total product cost)}}{\$6.16/10^6 \text{ Btu}}$$

The total product cost is \$6.16/10^6 Btu.

References

3-1. Waitzman, D.A., et. al, "Evaluation of Fixed-Bed Low-Btu Gasification Systems for Retrofitting Power Plants", Electric Power Research Institute, February 1975, NTIS No. PB241672.

3-2. Bechtel Corporation, "Effect of Plant Size on the Cost of Producing Industrial Fuel Gas," U.S. Department of Energy No. FE/WAPO/2526-1, March 1978.