"CLEAN ENERGY VIA COAL GASIFICATION"

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Part I - COAL GASIFICATION

Introduction

The commercial gasification of coal has been practiced for at least 50 years. Literature and patents on the Winkler coal gasification process date back to 1920 or earlier. Most of these early gasification processes were concerned with producing either an ammonia synthesis gas or a medium-heating-value fuel gas called "town gas."

In the past four to five years, it has become apparent that natural gas supplies are becoming short in the United States. Normally, large energy users would have switched to other forms of fossil fuel, such as coal, for which the proven reserves are very large. However, the current strong public concern with air pollution has worked against the increased use of coal. In fact, many industries now using coal are under extremely heavy pressure to develop and improve technology and apply it for the removal of sulfur from their coal or their stack gases.

This combination of events, a natural gas shortage plus the emphasis on removal of sulfur from fuels, has accelerated the search for new sources of Substitute Natural Gas (SNG) and new supplies of Liquefied Natural Gas (LNG). In the long term, it is apparent that the vast coal energy reserves in the United States must be utilized. Coal gasification can convert these large coal energy reserves into a high-Btu, clean-burning, sulfur-free fuel gas.

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Realizing this fact, a greal deal of technological development is currently underway in the United States on coal gasification processes. The following Table lists the current status of the major United States coal gasification development projects:

Table 1

Process	Pressure	Developer	End-Products	Current Status
Hygas	High	Institute of Gas Technology	Gas + Char	Pilot Plant*
Synthane	High	Bureau of Mines	Gas + Char	Pilot Plant**
CO_2 Acceptor	Medium	Consolidated Coal Company	Gas + Ash	Pilot Plant*
Bi-Gas	High	Bituminous Coal Research	Gas + Slag	Pilot Plant**

*Currently starting up.
**Pilot plants currently in design phase only.

The emphasis in these pilot plant programs is to develop processes suitable for the large-scale production (250-500 MM SCFD) of the type of gas (925-970 Btu/SCF) used in the United States, rather than adaptation and modification of the older European technology for producing medium-Btu town gas. Even if they are run successfully, they will only be stepping stones to larger demonstration plants before sufficient engineering data are available for full commercial plant design. These processes will probably not be ready for commercial application for at least five years and perhaps ten years.

On the other hand, the Lurgi pressure coal gasification process, which was first developed in 1930, has proven, large-scale commercial experience. Since 1936, the Lurgi process has been used commerically in many parts of the world, including Germany, Scotland, South Africa, and Korea.

The Lurgi gasification process will be used in both the recently announced New Mexico coal gasification projects . . . the WESCO and El Paso projects.

Chemistry

In the broad sense, coal gasification has been practiced since man first reacted coal with air. This simple act of combustion gasified the coal into its final products of combustion--carbon dioxide, water vapor and its sulfur to sulfur dioxide.

In a more narrow sense, coal gasification for SNG Production is the limited reaction of coal with essentially pure oxygen in the presence of a large excess of steam.

Although the competing chemical reactions which coal undergoes during this process are complex and not fully understood at the present time, they are usually represented by the following chemical equations, shown in Figure 1:

1. The overall reaction, as shown, represents the net result of coal gasification to produce methane (SNG) and is really a composite of numerous other chemical reactions and processing steps. Since coal contains only about 5 weight percent hydrogen, exclusive of its contained moisture, additional hydrogen must be supplied during the gasification process to meet pipeline quality SNG, which is 25 weight percent hydrogen--essentially methane (CH_4). This additional hydrogen is derived from the decomposition of steam (water) which is added to the gasifiers.

2. Devolatilization indicates that, at the temperature of coal gasification, some of the heavy hydrocarbons contained in the coal undergo a degree of thermal cracking to methane.

3. The hydrogasification reaction shows that methane can be formed directly from coal in the presence of large excess hydrogen concentrations.

4. The overall gasification heat balance is maintained by the heat supplied from the combustion reaction.

5. The last reaction shows that some of the steam added to the gasification process is decomposed to hydrogen in the presence of coal.

Although the coal has been represented as carbon in these reactions, we should remember that the additional components contained in the coal are also reacting--such as nitrogen to HCN and ammonia, and sulfur reacting to hydrogen sulfide, COS and CS_2.

TYPICAL COAL GASIFICATION REACTIONS

$$2C + 2\,H_2O \rightleftharpoons CH_4 + CO_2 \qquad \text{(OVERALL)}$$

$$\text{VOLATILE MATTER} \longrightarrow CH_4 + C$$

$$C + 2H_2 \rightleftharpoons CH_4$$

$$C + O_2 \rightleftharpoons CO_2$$

$$C + H_2O \rightleftharpoons CO + H_2$$

FIGURE 1

The net result of these gasification reactions gives a crude gas composition which is a variable mixture of mainly carbon dioxide, carbon monoxide, hydrogen, and methane.

Lurgi Gasifier

The Lurgi gas producer, commonly referred to as a pressure gasifier, consists of a number of vessels or chambers stacked vertically. These are, from top to bottom: coal bunker or hopper, coal lock chamber, water jacketed gas producer chamber, ash lock chamber, and ash quench chamber. This chamber arrangement is shown diagrammatically in Figure 2.

Located near the top of the gas producer chamber is the rotating coal distributor which maintains a uniform flow of coal from the coal lock chamber and provides a level surface on the top of the coal bed. A rotating ash grate continuously moves ash from the gas producer into the ash lock chamber.

The coal flowing down through the gas producer represents a slowly moving bed of continuously changing composition: it enters the gas producer as coal and leaves as ash. Steam and oxygen are introduced near the bottom of the gas producer and are preheated by the high temperature ash leaving the reaction zone as they flow towards the high temperature reaction zone.

High temperature crude gas and unreacted steam leaving the reaction zone are cooled as they pass through the upper portion of the coal bed which contains fresh coal passing towards the reaction zone. This cooling of the reaction zone gases provides both preheating and devolatilization of the fresh coal before it enters the high temperature reaction zone.

Figure 3 shows a simplified flow sheet of the Lurgi gasification process which will be used for the proposed WESCO project.

Crude Gas Coolers

The crude gas is cooled and scrubbed with water, which removes heavy oils and phenolics. Solids carried out of the gasifiers are removed by a unit upstream from the crude gas coolers.

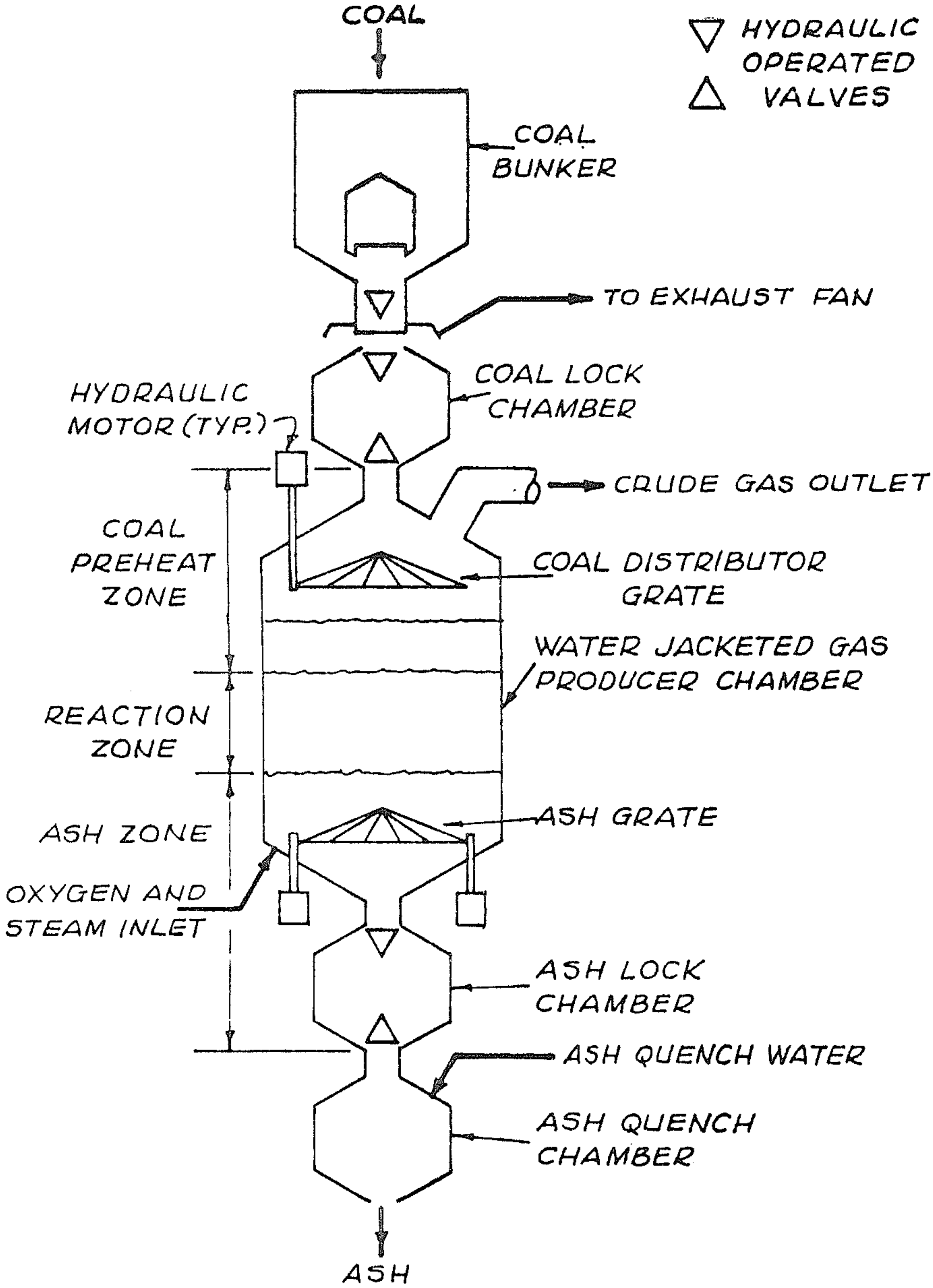
COAL
HYDRAULIC OPERATED VALVES
COAL BUNKER
TO EXHAUST FAN
COAL LOCK CHAMBER
HYDRAULIC MOTOR (TYP.)
CRUDE GAS OUTLET
COAL PREHEAT ZONE
COAL DISTRIBUTOR GRATE
WATER JACKETED GAS PRODUCER CHAMBER
REACTION ZONE
ASH GRATE
ASH ZONE
OXYGEN AND STEAM INLET
ASH LOCK CHAMBER
ASH QUENCH WATER
ASH QUENCH CHAMBER
ASH

FIGURE 2

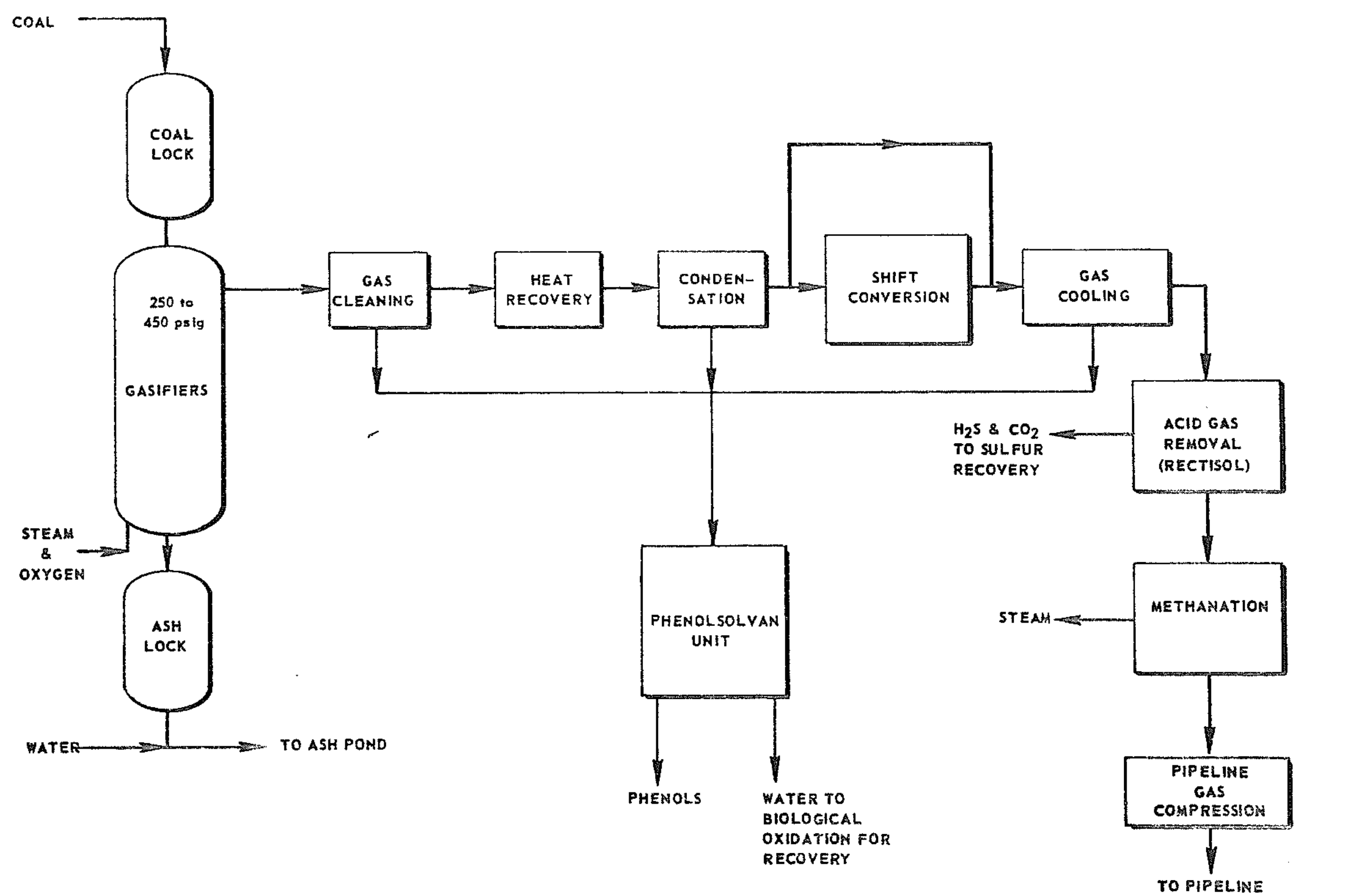

FIGURE 3

SIMPLIFIED FLOWSHEET
LURGI PRESSURE COAL GASIFICATION

Shift Conversion

The H_2 to CO ratio in the total crude gas is raised to at least 3 to 1 by "shifting" about half of the crude gas. The shift conversion is a catalytic process whereby carbon monoxide and steam are converted or "shifted" to carbon dioxide and hydrogen by the overall chemical reaction:

$$CO + H_2O \xrightarrow[\text{Catalyst}]{\text{High Temperature}} CO_2 + H_2$$

The selected operating conditions and catalyst used in this unit allow the carbon monoxide shift reaction to proceed in the presence of heavy hydrocarbons, tar-oils, and naphtha. Simultaneously, a mild desulfurization of these heavy hydrocarbons and hydrogenation of organic sulfur-bearing materials is provided.

Gas Cooling

The crude gas and the portion that has been shifted are combined and further cooled to remove light hydrocarbon oil byproducts and residual water containing phenols.

Rectisol

This is a physical absorption process utilizing low-temperature methanol for the selective removal of H_2S, CO_2, and other sulfur compounds such as carbonyl sulfide (COS). Two separate absorption steps are used:

1. In the first step, H_2S/COS are absorbed. This provides a sulfur-free (less than 0.2 ppm) methanation unit feed gas.

2. In the second step, methanated gas is upgraded to SNG quality by the simultaneous absorption of CO_2 and water.

Methanation

The methanation unit includes all the equipment to catalytically combine carbon monoxide and hydrogen to form methane plus water:

$$CO + 3H_2 \xrightarrow{\text{Catalyst}} CH_4 + H_2O$$

The water, which is chemically formed in the methanation reaction, is condensed and recovered for use as boiler feedwater. The large heat release in this reaction is recovered by generation of steam.

Phenosolvan

All the phenolic water streams generated within the gasification facility are collected. After filtering, the phenolic water is extracted with isopropyl ether which transfers phenolic materials from the water phase to the isopropyl ether phase.

The extracted phenolic water is further processed to remove CO_2, H_2S, and NH_3. The water from this processing step is then routed to biological treatment and subsequently reused within the plant. The phenol-rich isopropyl ether leaving the extraction section is further processed to produce a "phenol lean" isopropyl ether which is recycled back to the extraction section, and saleable crude phenol as a byproduct.

Auxiliary Units

These include a cryogenic air fractionation plant which extracts oxygen from atmospheric air, a conventional catalytic Claus sulfur plant which will convert the rich H_2S off-gas from the Rectisol Unit to byproduct solid sulfur, a steam plant, extensive air-cooling systems, cooling water systems, byproduct storage and loading facilities, safety systems, effluent water treatment and reuse systems, ash return system, and numerous service facilities and buildings.

The overall gasification plant material balance for the WESCO project (shown in Table 2) provides a good indication of the magnitudes involved in this project. Based on producing 250 MM SCFD of product gas, the Lurgi process feedstocks of coal, oxygen, and steam total 52,700 tons per day. These feedstocks are converted to 5,440 tons per day of product gas and 105 tons per day of byproduct phenols, plus 47,155 tons per day of byproduct fuels, ash, sulfur, ammonia, and wastewater, all of which require special consideration and integration into an overall environmental design.

LURGI GASIFICATION MATERIAL BALANCE

BASIS: 250 MMSCF/D OF SNG PRODUCT GAS

	SHORT TONS PER DAY	WEIGHT %
INPUTS:		
SIZED COAL	21,860	41.48
STEAM & WATER	25,160	47.74
OXYGEN	5,680	10.78
TOTAL	52,700	100.00
OUTPUTS:		
PRODUCT GAS	5,440	10.32
PHENOLS	105	0.20
ASH	5,876	11.15
REUSE WATER	17,851	33.87
BY-PRODUCT WATER	3,730	7.08
TARS, OILS & NAPHTHA	1,475	2.80
OFF GAS	792	1.50
CO_2 GAS	16,631	31.56
NH_3 + WATER	800	1.52
TOTAL	52,700	100.00

TABLE 2

Part II - WATER REQUIREMENTS FOR COAL GASIFICATION

The gasification of coal to produce Substitute Natural Gas (SNG) requires water for process cooling, for the generation of steam energy, for supplying the hydrogen needed to produce SNG from coal, and for various other needs. Based on our present design for a coal gasification plant in the Four Corners area, a plant producing 250 MM SCFD of SNG from 21,800 tons per day of coal will require 5,100 gpm (8,200 acre-ft. per year) of raw water intake. This amounts to 1.4 pounds of raw water intake per pound of coal, and this includes water required by the coal mining operation as well as the gasification plant and its auxiliary utility services.

Since the supply of water to our project is contractually limited, every effort has been made in our design to conserve water usage and to maximize the recycle and reuse of water. Some of the major design features used to achieve those objectives are:

1. About 250,000 hp of large compressor-driving steam turbines will be provided with air-cooled exhaust steam condensers--this horsepower is equivalent to about 8-10 commercial jet aircraft engines. The condensed steam will be recovered and reused as boiler feedwater.

   The air-cooled condensers will provide about 2 billion Btu/hour of heat removal. If cooling water were used for this heat removal (instead of air), the evaporative water loss from our cooling tower would be increased by about 4,000 gpm (6,400 acre-ft. per year), which would almost double our raw water intake requirement. The larger cooling tower would also incur larger windage losses.

2. Raw water will be treated for removal of solids and minerals and then converted to high-pressure steam. A major portion of this steam is fed into the Lurgi gasifiers. This steam will be largely recovered as a phenolic "gas liquor" from which byproduct phenols will be extracted. The dephenolized gas liquor (wastewater) will be stripped of dissolved ammonia and hydrogen sulfide, treated for removal of oil and suspended solids, and biochemically oxidized in two stages of bio-treating. The treated and clarified effluent will then be reused as water makeup to the plant cooling water system. In fact, it will supply 100 percent of the cooling water makeup needs.

3. Byproduct water produced in the methanation reaction, and from NH_3 combustion, will be recovered and reused as boiler feedwater.

4. Mechanical refrigeration will provide the low temperatures needed in the Rectisol Unit. Mechanical refrigeration was chosen in preference to an absorption refrigeration system to avoid the very large cooling water evaporation losses associated with absorption refrigeration, since mechanical refrigeration lent itself to air-cooling for heat removal.

5. Water will be extracted from water treatment sludges and recycled for reuse.

6. Blowdown from the cooling water system will be reused for quenching of the Lurgi ash.

The total raw water available to WESCO from the San Juan River is contractually limited to 44,000 acre-ft. per year by the U.S. Department of the Interior. Since four gasification plants are eventually contemplated by WESCO, it was imperative that the water usage per plant be 11,000 acre-ft. per year or less. It is therefore apparent that the design features discussed herein were mandatory from the viewpoint of water usage conservation as well as minimizing the environmental problems that would result from higher water usages.

Based on our present design, each plant will require only 8,200 acre-ft. per year, or about 75 percent of the contract water availability. This provides us with a margin of safety for any unforeseen contingencies.

Attached hereto is Table 3, Water Requirements and Disposition. As can be seen, the ultimate disposition of the 5,100 gpm intake water can be briefly summarized as:

Process consumption	10.2%
Return to atmosphere	69.6%
Disposal to mine reclamation	8.4%
Others	11.8%
	100.0%

It is important to note that about 70 percent of the water will be returned to the regional atmospheric environment, and will eventually become rainwaters. Even the 10 percent converted to hydrogen contained in the product SNG will eventually return to the atmosphere as water, wherever the product SNG is burned as fuel.

TABLE 3

WATER REQUIREMENTS AND DISPOSITION

	GPM	%
Process Consumption		
To supply hydrogen	1,120	
Produced as methanation byproduct	- 600	
Net consumption	520	10.2
Return to Atmosphere		
Evaporation:		
From raw water ponds	420	
From cooling tower	1,760	
From quenching hot ash	150	
From pelletizing sulfur	250	
From wetting of mine roads	730	
	3,310	
Via stack gases[1]:		
From steam blowing of boiler tubes	200	
From stack gas SO_2 scrubbers	40	
	240	
Total return to atmosphere	3,550	69.6
Disposal to Mine Reclamation		
In water treating sludges	100	
In wetted boiler ash	30	
In wetted gasifier ash	300	
Total disposal to mine	430	8.4
Others		
Retained in slurry pond	20	
Miscellaneous mine uses	580	
Total others	600	11.8
GRAND TOTAL	5,100	100.0

1 Does not include water derived from burning of boiler fuel.

It is also important to note that the remaining 20 percent will be disposed of on-site, principally as sludges and wetted ash used in the reclamation of the coal mining area. THERE WILL BE NO RETURN OF WASTEWATER TO THE SAN JUAN RIVER.

A schematic diagram of the "Water Treatment and Reuse Systems" (Figure 4) is also attached hereto, and graphically illustrates the extent to which recycle and water reuse has been designed into the plant:

1. As already discussed, the water used to provide turbine steam is condensed and recycled for 100 percent reuse.

2. The water fed into the Lurgi gasifiers (as steam) provides hydrogen required to convert the coal carbon to methane (SNG), and steam required in the subsequent "shift conversion" of excess carbon monoxide to carbon dioxide and additional hydrogen. The hydrogen is also subsequently used in the methanation step to produce additional methane as well as byproduct water.

   After serving its beneficial use as a gasification reactant, the excess steam is condensed as phenolic gas liquor from which useful byproduct phenols are then extracted. After oil and solids removal, and bio-treating, the recovered water provides 100 percent of the makeup needs for the process cooling water system.

   This water has now served three useful functions:

   (a) Supplied necessary reactant in the conversion of coal to SNG.
   (b) Served as the medium for removal and recovery of byproduct phenols (as well as ammonia).
   (c) Supplied 100 percent of the cooling water makeup needs.

3. The cooling water system is a closed-loop with an evaporative cooling tower. Water is recycled and reused in the system about 3-6 times before the build-up of dissolved salts, because of the evaporative cooling, necessitates a blow-down to maintain a tolerable level of salts within the circulating water.

   Finally, the blowdown is reused again to quench the hot ashes from the Lurgi gasifiers.

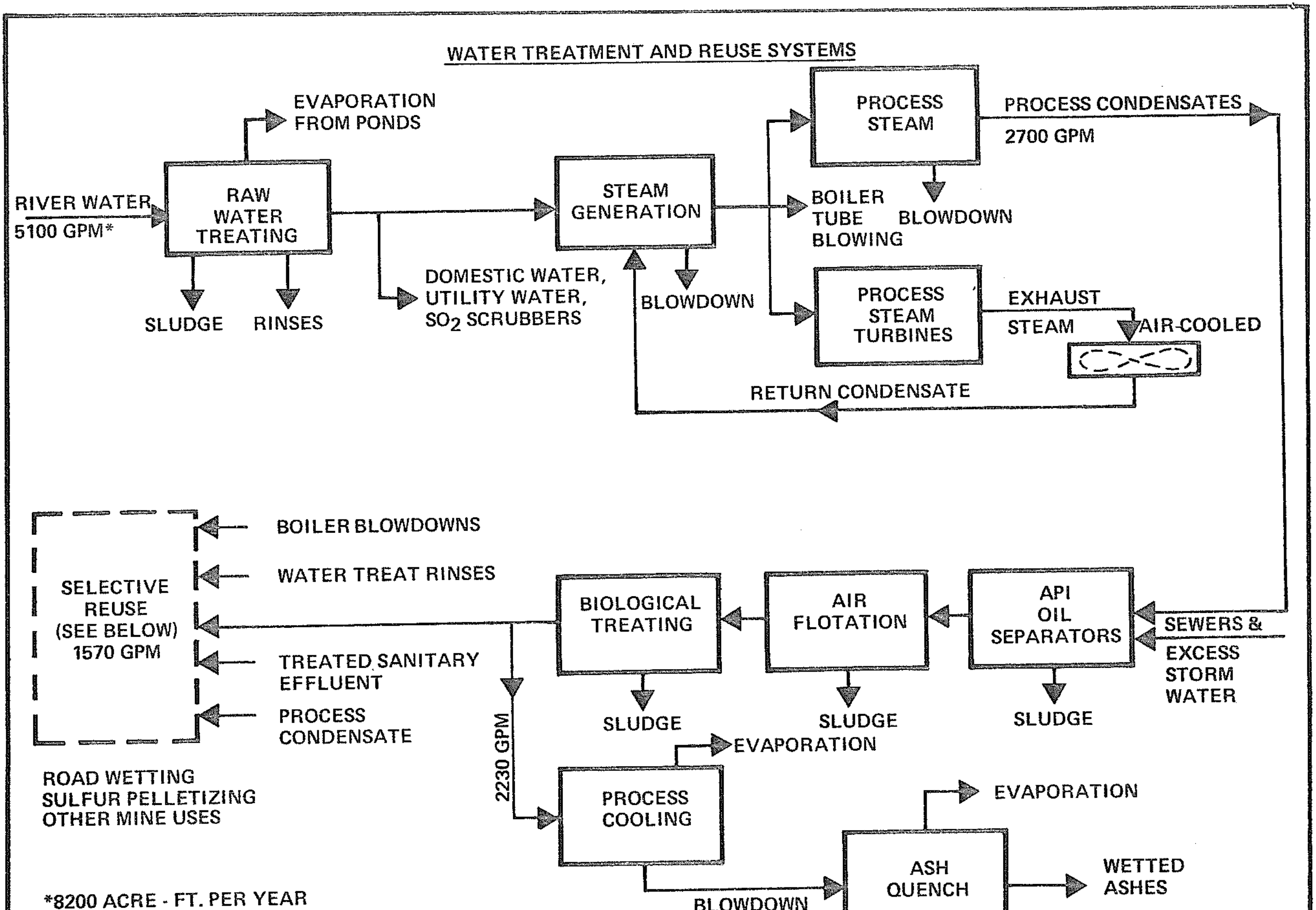
WATER TREATMENT AND REUSE SYSTEMS
EVAPORATION FROM PONDS
RIVER WATER 5100 GPM*
RAW WATER TREATING
SLUDGE
RINSES
DOMESTIC WATER, UTILITY WATER, SO2 SCRUBBERS
STEAM GENERATION
BLOWDOWN
PROCESS STEAM
PROCESS CONDENSATES
2700 GPM
BOILER TUBE BLOWING
BLOWDOWN
PROCESS STEAM TURBINES
EXHAUST STEAM
AIR-COOLED
RETURN CONDENSATE
SELECTIVE REUSE (SEE BELOW) 1570 GPM
BOILER BLOWDOWNS
WATER TREAT RINSES
TREATED SANITARY EFFLUENT
PROCESS CONDENSATE
BIOLOGICAL TREATING
AIR FLOTATION
API OIL SEPARATORS
SEWERS &
EXCESS STORM WATER
SLUDGE
SLUDGE
SLUDGE
2230 GPM
EVAPORATION
PROCESS COOLING
EVAPORATION
ASH QUENCH
WETTED ASHES
BLOWDOWN
ROAD WETTING
SULFUR PELLETIZING
OTHER MINE USES
*8200 ACRE - FT. PER YEAR

FIGURE 4

4. Boiler blowdown water, rinse waters from the intake water demineralizers, treated effluent from the sanitary system bio-treatment unit, and excess process condensate will be selectively reused to provide:

   a. water for wetting of roads in the mining area (dust abatement).
   b. water for pelletizing the byproduct sulfur; and
   c. other uses in the mining and coal processing operations.

It should be obvious now that the water intake to the plant will be beneficially used and reused many times over, and 80 percent will return to the atmosphere as water vapor.