

SECTION 8
MATERIAL BALANCE

The overall material balance for the process sections of the complex is depicted in Figure 8-1. The results project that approximately 12,500 TPD of premium hydrocarbon and oxygenate products will be produced from 30,000 TPD of bituminous coal. The balance is based on miscellaneous internal consumption equal to approximately 1.2 wt % of the total product quantity.

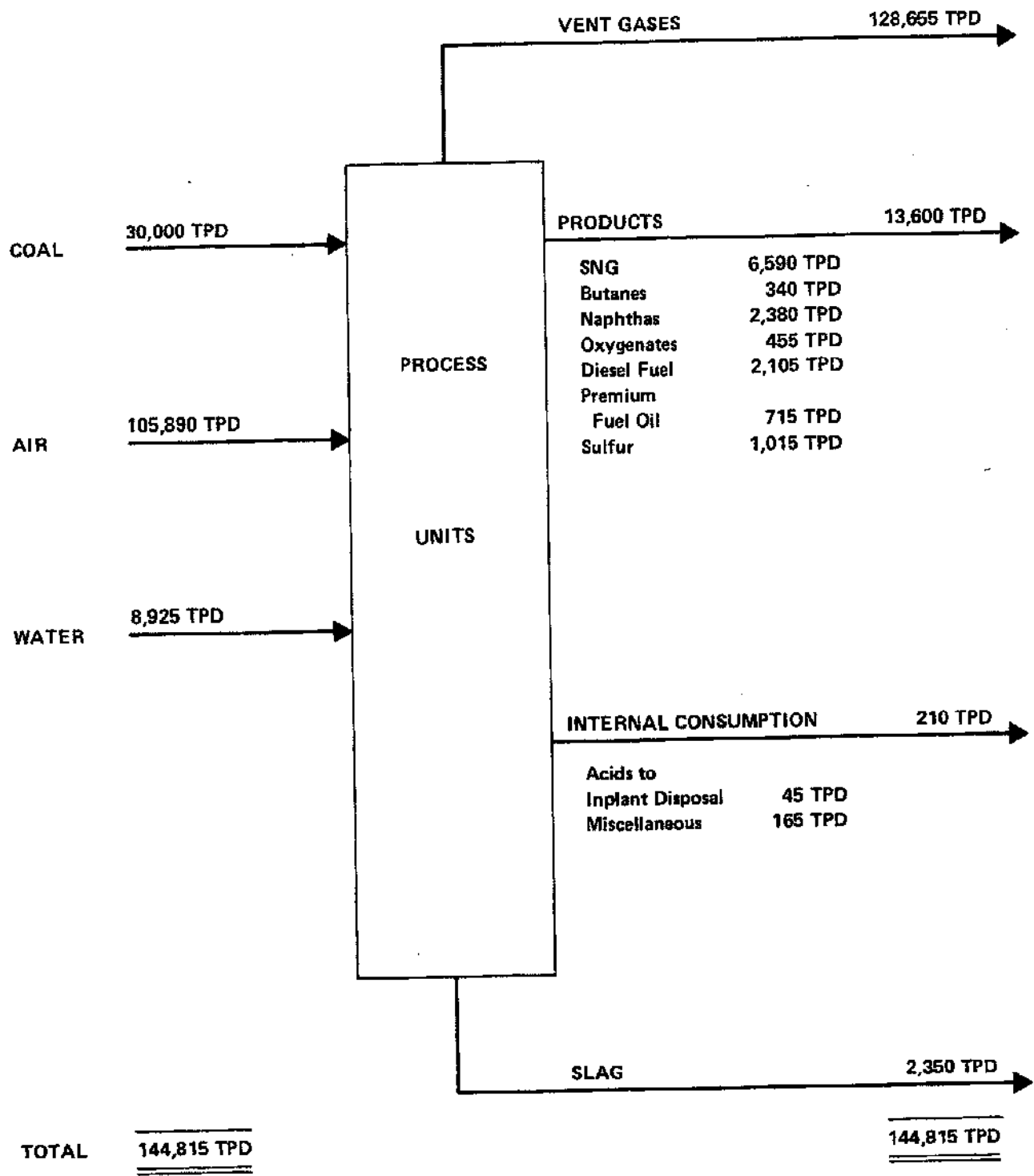


Figure 8-1 - Overall Material Balance
Process Units

SECTION 9
ENERGY BALANCE

The overall energy balance is illustrated in Figure 9-1. The results indicate that the energy value of products is approximately 525 billion Btu/day, which represents about 70% of the energy contained in the feed coal. The 30.3% energy efficiency loss can be distributed to the user units approximately as shown below:

	<u>Units</u>	<u>%</u>
Mine		0.9
Coal Preparation		1.4
Gasifier		2.8
Oxygen Plant		7.6
Shift Reactor		1.1
Acid Gas Removal		6.8
Product Recovery		1.1
Alcohol Recovery-Water Reclamation		0.7
Sulfur Plant-Beavon Unit		0.5
F-T Reactor & Methanation		0.8
Power Plant Auxiliaries		1.8
Power Plant Efficiency Loss		2.9
Miscellaneous & Unaccounted		<u>1.9</u>
	TOTAL ENERGY LOSS	30.3

Figure 9-2 presents a simplified summary of the projected thermal efficiency factors.

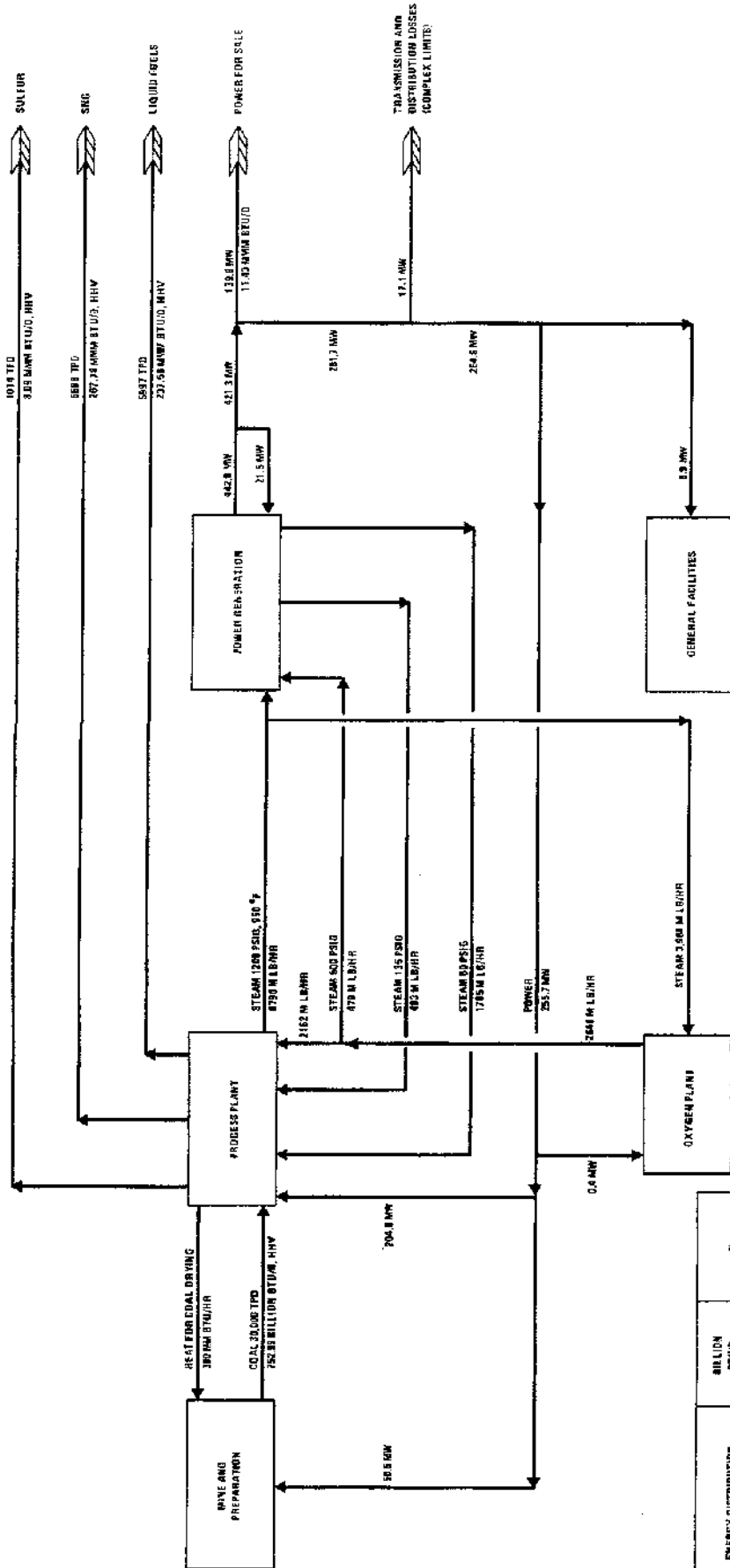
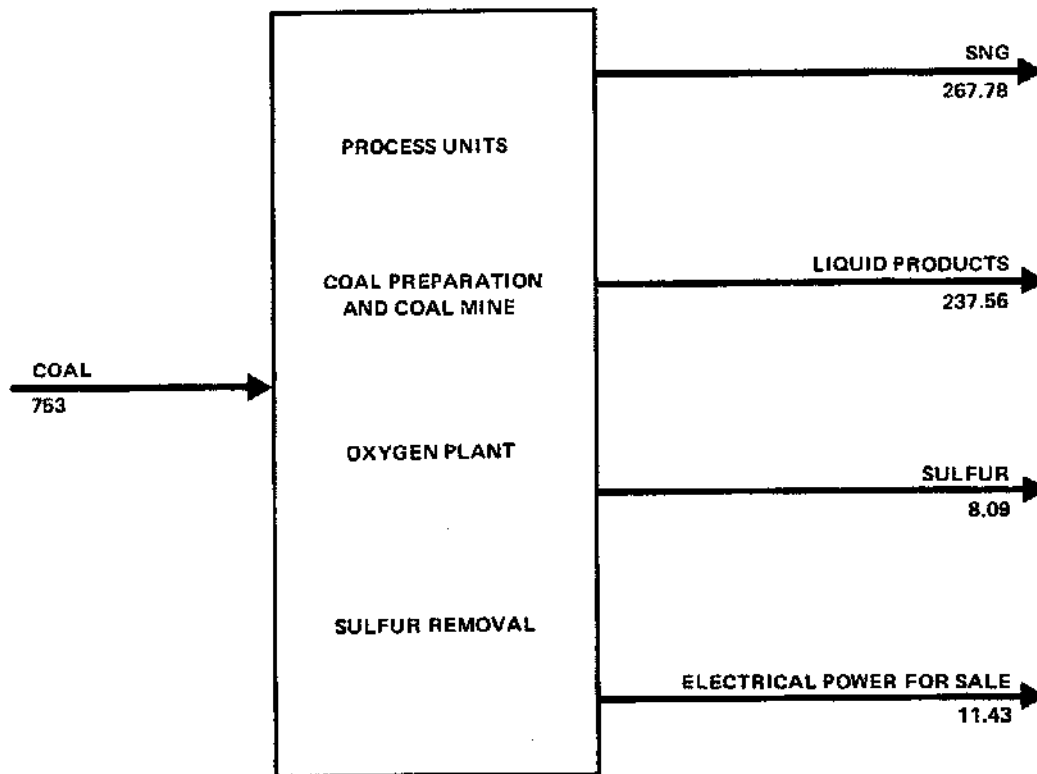


Figure 9-1 - Energy Balance

ENERGY DISTRIBUTION	BILLION BTU/D, HHV	%
ENERGY SOURCE	742.91	100.00
COAL		
ENERGY CONSUMED IN MFG AND PREPARATION	17.32	2.34
OXYGEN	65.46	7.00
PROCESS	154.05	20.49
TOTAL	222.83	30.16
ENERGY VALUE OF PRODUCT		
SNCG	287.74	35.56
LIQUID FUELS	237.58	31.55
POWER FOR SALE	11.43	1.52
SULFUR	8.05	1.07
TOTAL	544.80	68.70



ALL FIGURES ARE MMM BTU/D, HHV

$$\text{THERMAL EFFICIENCY} = \frac{267.78 + 237.56 + 8.09 + 11.43}{753} = 69.7\%$$

Figure 9-2 - Thermal Efficiency

SECTION 10

UTILITIES

The utility summary, which is presented in Table 10-1, tabulates the utility productions and consumptions by type and by unit. The summary is for the total complex.

All utilities required for operation are generated within the complex. In addition, excess electrical power is produced which is available for sale. Process heat recovery generates adequate steam for process and power generation usage with a net surplus of power for sale. Startup boilers and gas turbine electric generators are provided.

The high-pressure steam system is 1,200 psig. The steam turbines are rated at 1,250 psig at 950°F temperature. Bleeder turbines are used to produce 500-psig, 135-, and 50-psig steam. A small amount of 500-psig steam is produced in the gasifier, and 135- and 50-psig steam is produced in the sulfur recovery units.

Drawing No. R-25/27/28/31-FS-1, located in Section 6, depicts the combination of utility water systems. Two cooling towers provide cooling water for the steam condensers and oxygen plant process air cooling. Other services are air cooled. The major use for cooling water is for steam turbine-exhaust condensation at 2.25 inches Hg absolute. This results in a low cooling-tower operating temperature differential of fourteen degrees and a high cooling-water circulating rate of 600,000 gpm. Accordingly, two mechanical draft cross-flow cooling towers (28-1701 and 1702) are provided.

Cooling tower blow-down water is reused as quench water for the gasifier slag, as make-up water for the coal preparation plant operations, and as spray water for mine road dust control.

Raw water requirements for supplying cooling-tower water makeup is obtained from the nearby river source. It is given the conventional preliminary chemical treatment and sand filtration, with subsequent final treatment as specifically required for the end uses.

Figure 10-1 is an overall water balance for the complex.

Other factors related to serving the utility requirements of the complex include:

- A plant compressed-air system at 100 psig is supplied by one of two 20,000 cfm rotary compressors. One of the compressors is motor driven, and the other equipped with steam-turbine drive.
- A portion of the nitrogen produced at the oxygen plant, compressed to 100 psig, is used in lieu of air for operation of pneumatic instrumentation.

Since the nitrogen is dry and available, the drying of instrument air is avoided.

- Clean carbon dioxide gas from Unit 16 is used as the inert drying media in the coal dryers, and also as the inert cover gas in the coal grinding, conveying, and storage bins. A totally inert atmosphere is provided wherever coal fines are predominantly present under confined conditions.

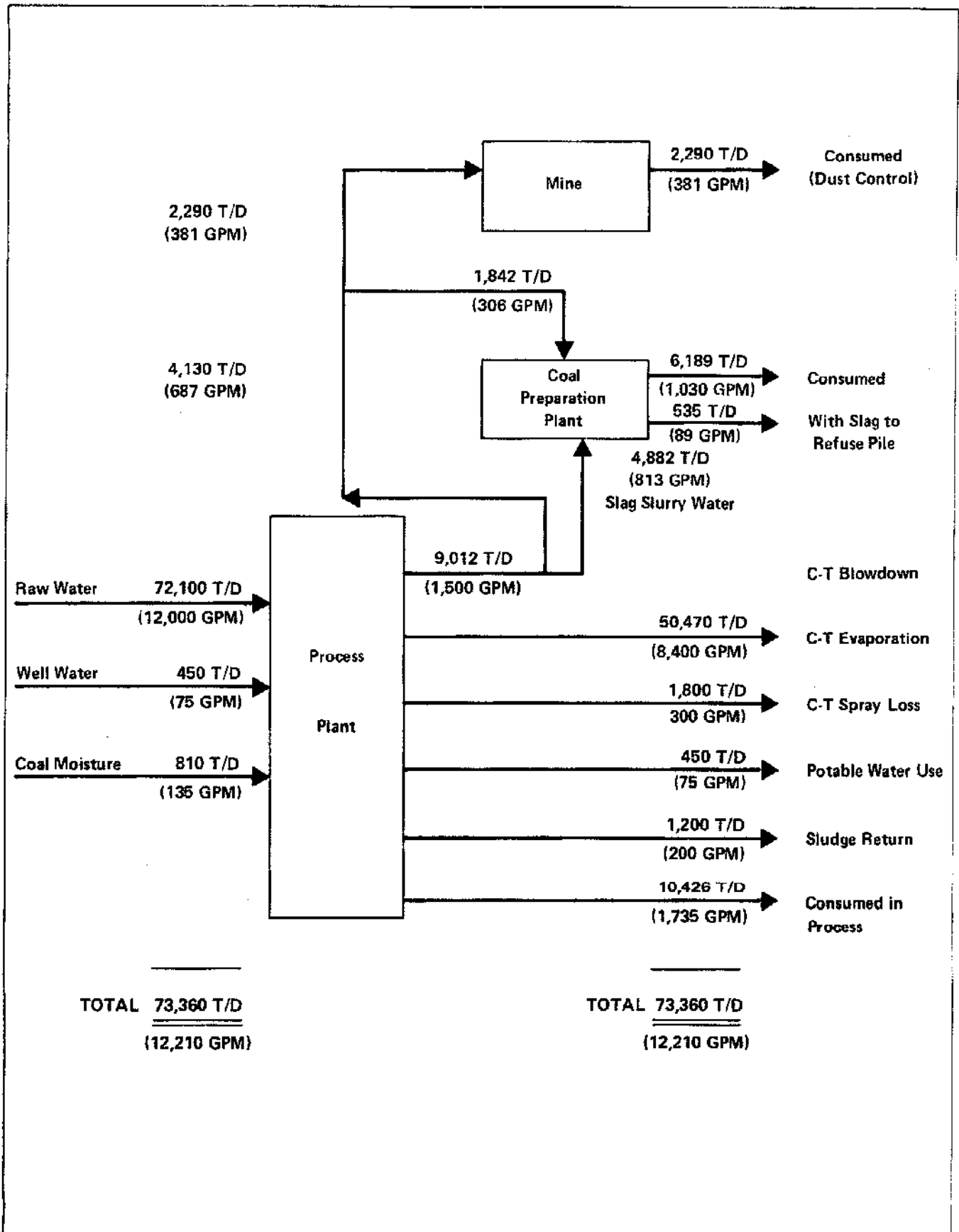


Figure 10-1 - Overall Water Balance

Number	Unit Description	Steam Produced (lb/hr) Pressure (psig, nominal)				Steam Used (lb/hr) Pressure (psig, nominal)				Condensate and Recovery (lb/hr)	Boiler Feedwater (lb/hr)	Cooling Water (gpm)	Electrical Power		Fuel Gas (MM Btu/hr)	Water Makeup (gpm)	Type of Water Makeup (RPM)		
		1200	500	285	135	50	1200	500	285				135	50				Used	Generated
9	Coal Mine																		
10	Coal Preparation																		
11	Coal Grinding and Drying																		
12	Classifier		230,000				1,432,000			340,000	236,900	50	20,800						
13	Heat Recovery	670,000									689,700		1,700						
14	Acid Gas Removal																		
15	Shift Conversion	526,000																	
16	Fischer-Tropsch Synthesis	6,333,000					585,000			405,000	539,800	100	91,550		87.0				
17	Methanation	1,263,000									6,523,500	100	26,650		5.4				
18	Liquid Recovery						10,000			78,000	1,301,000		19,750						
19	Chemical Recovery						3,968,000			99,300	16,060		1,260						
20	Oxygen Plant		2,641,170				37,000						600						
21	Sulfur Recovery				117,000					27,000	332,500		7,600						
22	Water Reclaiming					30,000							2,760						
26	Power Generation			804,000	800,000	4,782,000	479,000	604,000	634,000	75,000			21,500	442,800					
27-28-29	Water System												221,000				1,600	BFW Makeup	
39	General Facilities									10,000	8,880		16,680				10,200	C-T Makeup	
Loss	Transmission												50	17,100			(500)	Sludge Return to Silver	
	Total	8,790,000	2,871,100	804,000	917,000	1,839,000	8,790,000	2,871,000	604,000	1,858,000	8,789,000	586,800	302,200	442,500	319.12		12,000		
	Power for Site																		
	Total Circulated																		

Table 10-1 - Utility Summary Total for Two Trains

SECTION 11

ENVIRONMENTAL FACTORS

This conceptual design is responsive to requirements for control of gaseous, liquid, and solid emissions from the plant units and ancillary facilities. The means by which gas, vapor, liquid, and solid emissions control, as well as noise-level control have been accomplished are discussed below.

11.1 AIR POLLUTION ABATEMENT

The control of air contaminants released to the environment had a high priority in plant and process design. Applicable standards covering the process operations were used in design and engineering of the process and equipment.

The major air-pollution abatement effort is aimed at desulfurizing the gases generated during the coal conversion process to make the fuels produced environmentally acceptable. In a Fischer-Tropsch plant, environmental and process goals coincide because the presence of sulfur inhibits the effectiveness of Fischer-Tropsch catalysts.

11.1.1 GENERATION AND CONTROL OF GASEOUS CONTAMINANTS

The desulfurization procedure is outlined in Figure 11-1, which also shows the nature and amount of all streams vented to the air. For the most part, inert gases (nitrogen and carbon dioxide) are vented to the air.

Fugitive particulate emissions from coal sizing and handling and from residual ash disposal are prevented from becoming airborne by maintaining a wet condition when not in a closed system.

The coal grinding and drying unit is the only source of particulate emissions. A baghouse system removes most of the particulates from the vent streams, with emissions to the air (0.03 gr/cu ft maximum) meeting both the Federal standard for thermal dryer gases (0.03 gr/cu ft) and other standards related to coal gasification plants. The source of heat for the drying process is excess steam from the Fischer-Tropsch plant; no combustion gases are generated by the operation.

The coal gasifier receives ground coal, steam, and oxygen, and generates hydrogen, carbon monoxide, carbon dioxide, methane, hydrogen sulfide, and minor amounts of ammonia, carbon oxysulfide, and sulfur dioxide; at the elevated reactor temperature, nil oils or tars are produced. The gaseous stream carries all the char produced by gasification of the coal; the largest part of these materials is removed by a series of cyclones, followed by a hot electrostatic precipitator. Recovered char is returned to the lower section

of the gasifier, where char gasification occurs by reaction with steam and oxygen while the accompanying ash melts and is removed as slag.

Part (30%) of the gaseous stream is diverted to a shift-conversion unit where the stream is enriched in hydrogen. At the same time, the shift catalyst reacts with part of the hydrogen sulfide present by conversion of the catalyst to metal sulfide; i.e., 0.8 TPD of sulfur is absorbed in this fashion. Each of the shift reactors (six used) is regenerated approximately every six months by passage of a steam and air stream; the reduced sulfur is oxidized to sulfur dioxide (47.4 tons per reactor), and emitted through the main stack over a 24-48 hour period.

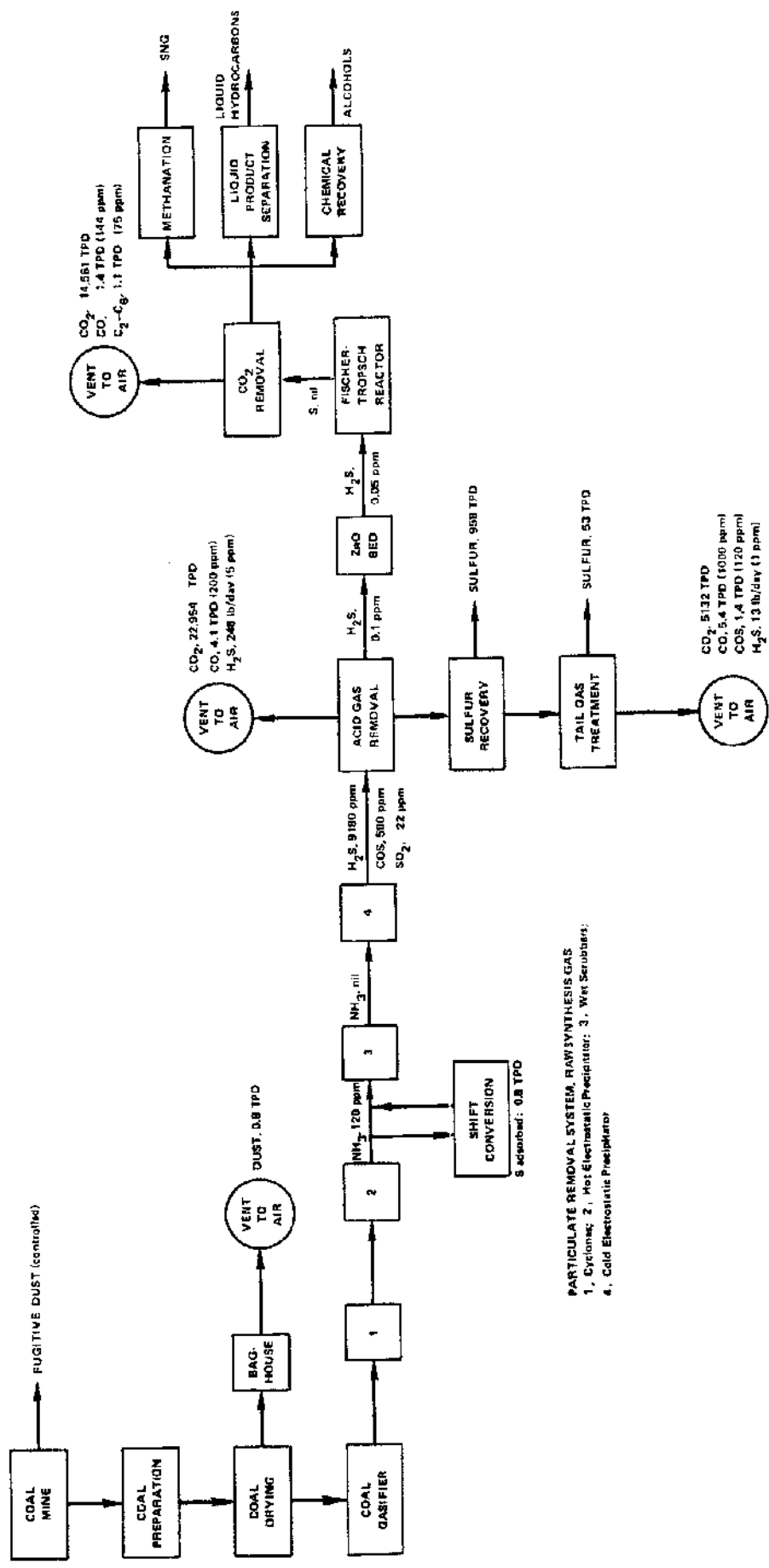
The gas-stream temperature is now reduced by a series of heat exchangers. This produces steam for process boilers and power generation. The small amount of char and ash particles still accompanying the gases is then removed by two wet scrubbers, followed by a cold electrostatic precipitator. All the ammonia and part of the hydrogen sulfide present are also removed by the scrubbers; any cyanides present, however, remain in the gas stream because of the acidic conditions of the sour water generated.

The next treatment step concerns the removal of acid gases (carbon dioxide and hydrogen sulfide). A physical solvent process removes these gases from the main stream, then on selective regeneration, releases a stream of hydrogen sulfide containing part of the carbon dioxide, and a stream of nearly pure carbon dioxide. The hydrogen sulfide stream is sent to the sulfur recovery plant. Hydrogen cyanide is also absorbed by the solvent; on regeneration, it joins the hydrogen sulfide stream, and is conveyed to the sulfur recovery plant where cyanides are destroyed by thermal oxidation. The carbon dioxide stream is vented to the air; small amounts of carbon monoxide and hydrogen sulfide (200 ppm and 5 ppm respectively) are vented to the air with it.

The sulfur recovery plant oxidizes 95% of the hydrogen sulfide to high-purity elemental sulfur. The remaining 5% is present in the tail gas, which is treated in a separate unit; namely, the tail gas unit, where all sulfur species are reduced to hydrogen sulfide, then absorbed by an alkaline solution and oxidized to give also high purity sulfur. The final vent gas contains carbon dioxide, plus traces of carbon oxysulfide (120 ppm), hydrogen sulfide (1 ppm), and carbon monoxide (1000 ppm). The concentration of the last contaminant (carbon monoxide) could be further reduced, but only by a severe treatment, such as incineration or catalytic oxidation; the concentration decreases on mixing with the other vent gases (see below).

At this point, the main stream consists mainly of hydrogen and carbon monoxide in a molar ratio (3:2) suitable for Fischer-Tropsch synthesis. The only remaining contaminant is 0.1 ppm of hydrogen sulfide; this concentration is halved by passage through a zinc oxide bed. The gas stream is now ready for conversion to hydrocarbon fuels. The Fischer-Tropsch reactor which carries out this conversion also generates carbon dioxide.

This gas is removed by absorption in a caustic solution, then is vented to the air on regeneration of the absorbant. The vent stream contains



PARTICULATE REMOVAL SYSTEM, RAW SYNTHESIS GAS
 1. Cyclone; 2. Hot Electrostatic Precipitator; 3. Wet Scrubbers;
 4. Cold Electrostatic Precipitator

Figure 11-1 - Block Flow Diagram Air Pollution Abatement

traces of carbon monoxide (144 ppm), together with traces of light-boiling hydrocarbons (75 ppm) and methane (a non-pollutant). The Fischer-Tropsch catalyst absorbs the last traces of sulfur present; therefore all fuels produced, gaseous and liquid, and the chemical byproducts (alcohols) contain nil sulfur.

The streams shown vented separately to the air in Figure 11-1 from the plant proper (acid gas removal, tail gas treatment, and carbon dioxide removal units) are actually combined in a single stack before venting. The overall amounts and concentrations become therefore the ones shown in Table 11-1.

11.1.2 COMPLIANCE WITH SOURCE EMISSION STANDARDS

Source emission standards for coal conversion plants have not been issued by the Federal Government. Among the states, only New Mexico has issued specific regulations covering coal gasification plants; these regulations can be considered for illustrative purposes only, because the Fischer-Tropsch plant, as conceived, would be located in the U.S. Eastern Interior (coal) Region. Illinois has issued standards for petrochemicals; this technology is somewhat related to a Fischer-Tropsch operation. The standards are as strict or stricter than the Federal standards for petroleum refining.

For illustration purposes only, the Illinois and the New Mexico source emission standards are compared in Table 11-2 with the emissions from a conceptual Fischer-Tropsch coal-conversion plant. As shown in the table, all estimated emissions are projected to either meet or be below the standards.

11.1.3 CARBON DIOXIDE EMISSIONS

It is estimated that significant carbon dioxide emissions (on the order of 43,000 TPD, Table 11-1) would be generated by the Fischer-Tropsch commercial plant; therefore, it appears desirable to investigate the possible effects of these emissions. Carbon dioxide is not toxic, and the natural background concentration in the atmosphere has been estimated at 300 to 500 ppm.

Table 11-1 - Combined Gaseous Effluents

Gaseous Effluent	Amount	Concentration (ppm)
Carbon Dioxide	42,647 TPD	-
Carbon Monoxide	10.9 TPD	306
Carbon Oxysulfide	1.4 TPD	18
Organics (C ₂ - C ₆ Hydrocarbons)	1.1 TPD	21
Hydrogen Sulfide	261 lb/day	3

Table 11-2 - Comparison of Gaseous Emissions with Illinois and New Mexico Source Emission Standards

Pollutant	Illinois Standards, Petrochemical Plant	New Mexico Standards, Coal Gasification Plant	Gaseous Effluents, Fischer-Tropsch Plant
Particulate Matter	78 lb/hr	0.03 gr/ft ³	67 lb/hr, (a) 0.03 gr/ft ³
Sulfur Dioxide	1.2 lb/MM Btu	-	Nil (b)
Carbon Monoxide	200 ppm, 50% xs air	-	164 ppm (c)
Nitrogen Oxides	0.7 lb/MM Btu	-	Nil
Organics (methane excluded)	100 ppm (CH ₄ equivalent)	-	55 ppm
Total Reduced Sulfur (H ₂ S + COS + CS ₂)	-	100 ppm	21 ppm
Hydrogen Sulfide	-	10 ppm	3 ppm
Hydrogen Cyanide	-	10 ppm	Nil
Hydrogen Chloride/ Hydrochloric Acid	-	5 ppm	Nil
Ammonia	-	25 ppm	Nil
Gas Burning Process Boilers, Particulate Matter	-	0.03 lb/MM Btu, LHV	-(d)
Gas Burning Process Boilers, Sulfur Dioxide	-	0.16 lb/MM Btu, LHV	-(d)
Total Sulfur	-	0.008 lb/MM Btu of feed (coal) heat input, HHV	0.003 lb/MM Btu (e)

(a) From coal-drying plant
 (b) 47.4 tons of sulfur dioxide emitted twice a year, over 24-48 hours, on regeneration of the catalyst of each shift reactor (six reactors total). If this value were averaged out over the year, it would correspond to 0.004 lb/MM Btu/day.
 (c) Value obtained on application of the 50% excess air correction to the streams originating from the acid gas removal unit and from the sulfur plant.
 (d) Not applicable (none included in the design).
 (e) Includes the sulfur dioxide emitted occasionally on regeneration of the shift reactor catalyst (see Note (b) above).

Global weather modification effects have been attributed to increased carbon-dioxide generation by fossil-fuel combustion. A gradual warming trend on the order of 0.5°C in 25 years has been predicted; however, actual temperature trends have shown a cooling of 0.3°C from 1945 to the present.

On a localized scale, no micrometeorological effects due to increased carbon dioxide have been reported. Emissions from the Fischer-Tropsch facility could approximately double the average atmospheric carbon dioxide concentrations to 600 to 1000 ppm in the vicinity of the plant. The lowest concentration at which some physiological effects (dyspnea and headache) have been observed is 30,000 ppm; therefore, no effects are expected at the levels mentioned. However, vegetable life has been reported to benefit from increased atmospheric concentrations of carbon dioxide.

11.1.4 SULFUR BALANCE

The sulfur balance for the conceptual design of a commercial Fischer-Tropsch plant is detailed in Table 11-3. A total of 98% of the coal sulfur content is recovered as elemental sulfur. It is estimated that an additional 0.7% remains in the ash from the coal gasifier unit; most of this sulfur is part of unreacted coal, because at the high temperatures prevailing in the bottom of the gasifier, reaction of sulfur species with alkaline components of the ash is unlikely. The gaseous and liquid products obtained contain nil sulfur.

11.2 AQUEOUS EFFLUENTS

The geographic area where the Fischer-Tropsch plant, as conceived, would be located, is the U.S. Eastern Interior (coal) region, where an abundant supply of water is available.

Table 11-3 - Sulfur Balance (TPD)

Total Input from the Typical Feed Coal	1020.0
Outputs:	
As Elemental Sulfur from Coal Gasifier Gas	1011.4
As Reduced Sulfur Emissions (19% H ₂ S, 81% COS)	0.8
As Sulfur Dioxide Emissions (actually emitted every six months on regeneration of the shift catalyst)	0.8
In the Ash	<u>7.0</u>
	1020.0

As a consequence, the wastewater treatment is a combination of recycling and discharge of aqueous effluents. The most heavily contaminated streams are concentrated by evaporation, with residuals undergoing thermal destruction in the coal gasifier. The medium-contaminated streams are purified by oxidation, then reused as makeup for boiler feedwater. The lightly polluted streams are treated to make them acceptable to the environment, then are discharged to the river.

11.2.1 GENERATION AND CONTROL OF AQUEOUS CONTAMINANTS

The generation and control of aqueous contaminants is outlined in Figure 11-2, which shows the sources of wastewater (listed on the left-hand side) and their progressive treatment and disposition.

The river water supply provides 12,000 gpm of raw water, which, after purification by settling and sand filtration, is used for cooling water makeup and, after further deionization, for boiler feedwater makeup. Potable and sanitary water (75 gpm) is supplied by wells. The water supply from the river is not used for coal sizing and handling (a captive system feeding on a mine-based pond is used for this unit) or for coal grinding and drying, where no wet systems are employed.

One of the major contaminated streams is the sour water generated by the wet scrubbers cleaning the gases produced by the coal gasifier. The major contaminants present are hydrogen sulfide, ammonium sulfide, oil, phenols, thiocyanates, cyanides, and solids (ash and char particles). After removal of any oily materials by extraction, most of the gaseous contaminants (hydrogen sulfide and ammonia) are removed by a reboiler-stripper, and then conveyed to the sulfur plant where the hydrogen sulfide is converted to elemental sulfur and the ammonia is oxidized to nitrogen. The stripped aqueous stream is now treated in an oxidizer with oxygen at high pressure to convert most of the organics present (including cyanides) to inorganic gases such as carbon dioxide, nitric oxide, and sulfur dioxide. These are led back to the coal gasifier; the reducing atmosphere prevailing there is expected to reduce nitric oxide and sulfur dioxide to nitrogen and hydrogen sulfide. After settling and filtration, the aqueous effluent stream from the oxidizer is deionized and reused as boiler feedwater makeup.

The Fischer-Tropsch reactor produces, besides the desired hydrocarbon fuels, a number of oxygenate and organic acids. When the product stream is purified by treating with caustic, a waste stream containing alkaline salts of low-molecular weight organic acids is produced. This stream is combined with the boiler water blowdown and the solids slurry obtained as a residue from the settling of the treated sour water, and then concentrated in a triple-effect evaporator. The evaporator condensate is used for boiler feedwater, while the residue is sprayed on the feed coal at the entrance to the coal dryer. A more thorough evaporation occurs in the latter unit; the organic materials are then destroyed when the coal is fed to the gasifier, while the inorganic materials are removed with the ash.

The cooling-tower blowdown stream is the largest in volume, and is only lightly contaminated by corrosion inhibitors (zinc salts and inorganic

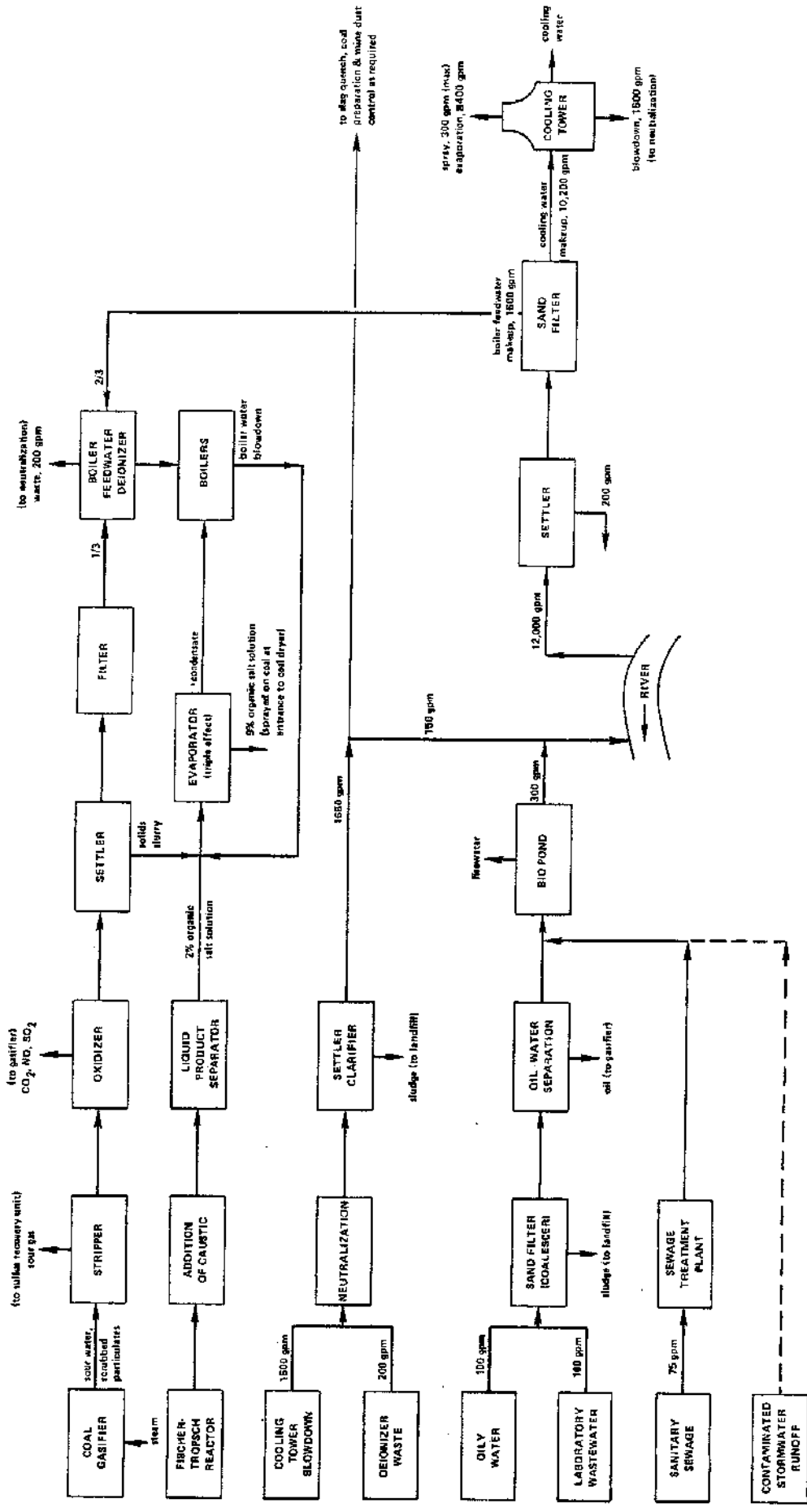


Figure 11-2 - Block Flow Diagram Water Treatment and Supply

phosphates) and scale control agents (organic phosphate esters); this stream is mixed with deionizer wastes containing mainly sodium sulfate and other inorganic salts. After neutralization, this stream is treated with lime in a settler-clarifier. The lime sludge, containing most of the zinc and phosphates, is disposed of in a landfill, while the treated stream is returned to the river.

Any oily water streams produced during plant operation are combined with laboratory wastewater, and then passed through a sand filter to coalesce the oily particles. After physical separation of the oil (returned to the gasifier), the aqueous effluent is led to a biopond, where the organic materials present are converted to inorganics by bacterial activity. The biopond also receives a minor stream from the sewage-treatment plant, and is used as firewater supply, with any overflow discharged to the river. Strict housekeeping is expected to contain contamination of stormwater to very small volumes; any contaminated water is collected in a stormwater pond (not shown in Figure 11-2) for subsequent metered feeding to the biopond for treatment.

11.2.2 COMPLIANCE WITH EFFLUENT STANDARDS

No aqueous effluent standards specifically addressed to coal-conversion plants have been issued by the Federal government, or by state legislatures. Standards that are somewhat related to a Fischer-Tropsch process are the Federal standards issued for petroleum refining. Average obtainable concentrations which were the base for such standards are reported in Table 11-4, together with the corresponding values for the aqueous effluents estimated for the Fischer-Tropsch plant. As shown in the table, these estimated values are either the same or lower than the Federal parameters.

Table 11-4 - Comparison of Aqueous Effluents with Federal Petroleum Refinery Standards^(a)

Parameter	Federal Standards, Petroleum Refinery	Aqueous Effluents, Fischer-Tropsch Plant (mg/l)
BOD 5	15	10
COD	100	100
Total Organic Carbon	33	33
Suspended Solids	10	10
Oil and Grease	5	5
Phenol	0.1	nil
Ammonia-N	80% removal	nil
Sulfide	0.1	nil
Cr, tertiary	0.25	nil
Cr, hexavalent	0.005	nil

^(a) Average attainable concentrations from the application of best practicable control technology currently available (EPA-440/1-74-014a).

For illustration purposes, Illinois has issued aqueous effluent standards applicable to all sources discharging to the natural waters of the state. These standards are reported in Table 11-5. All Fischer-Tropsch effluents are estimated to either meet, or be lower than such standards.

11.3 SOLID WASTES

The Fischer-Tropsch plant generates two main types of solid waste materials: ash from the coal gasifier, and sludges from various wastewater treatment units. Both materials are disposed of using environmentally acceptable procedures.

Table 11-5 - Aqueous Effluent Standards, State of Illinois

Constituent	Maximum Concentration (mg/l)
Arsenic (total)	0.25
Barium (total)	2.0
BOD 5	10.0
Cadmium (total)	0.15
Chromium (total hexavalent)	0.3
Chromium (total trivalent)	1.0
Copper (total)	1.0
Cyanide	0.025
Fluoride (total)	15.0
Iron (total)	2.0
Iron (dissolved)	0.5
Lead (total)	0.1
Manganese (total)	1.0
Mercury (total)	0.0005
Nickel (total)	1.0
Oil (hexane solubles or equivalent)	15.0
pH	range 5-10
Phenols	0.3
Selenium (total)	1.0
Silver	0.1
Zinc (total)	1.0
Total Suspended Solids	12.0

The mining and coal cleaning and sizing operations generate sizable amounts of solid wastes which are disposed of at the mine site.

11.3.1 ASH

The entrained gasifier adopted for the Fischer-Tropsch plant receives ground coal in the middle section (reducing zone), where by reaction with steam at the high-operating temperatures, carbon and volatile materials are converted to carbon monoxide and hydrogen (methane is also formed here). The unreacted carbon (char) and the inorganics present are carried out of the gasifier and separated from the gas stream by a series of cyclones and a hot electrostatic precipitator (with the last traces removed downstream by wet systems). The hot char and inorganics are then returned to the bottom of the gasifier, where they react with steam and oxygen, generating hot gases (mainly hydrogen, carbon monoxide and carbon dioxide) and inorganic oxides which melt and are withdrawn at the bottom as slag.

This slag, on quenching with water, is fragmented into vitrified granules which are returned to the mine for burial with the mine spoils. If outlets exist nearby, this material could also be utilized as filler in aggregates for construction blocks or road building.

The possibility of leaching of trace metals from the ash into ground or surface waters has been questioned. Some studies have been carried out (the latest, Project EPRI 202, by the Electric Power Research Institute) on the leaching of fly ash or unslagged bottom ash. It was found that selenium, chromium and boron, and, occasionally, mercury and barium were released on simulated leaching. The concentrations which were reached exceeded the values recommended by EPA for public water supplies. Possibly, slagged ash features a glass matrix which would inhibit leaching. An experimental study to verify this hypothesis, using slagged ash generated by a cyclone furnace power plant, is planned.

11.3.2 SLUDGES

The treatment of cooling-tower blowdown with lime produces an inorganic sludge containing mainly calcium and zinc phosphates. If this sludge were buried with mine spoils, possible contamination of groundwater by zinc could result. This sludge is therefore disposed of in a landfill.

The oily material present in oily water and laboratory wastewater is coalesced in a sand filter to facilitate the subsequent oil/water separation. When the filter becomes saturated, the oil is downwashed with steam, and then the filter is backwashed with water to dislodge the solids collected. The small amount of sludge produced is combined with the lime sludge mentioned above and disposed of in a landfill.

11.3.3 MINE WASTES

The surface mining operation proceeds in an orderly fashion, following an environmentally sound mining plan. The topsoil is removed and stored, then the overburden is stripped and used for refilling of the previous pit, in

combination with the inorganic wastes from the coal cleaning and sizing plant (rocks, clay and mud) and the vitrified ash from the coal gasifier. The mined-out area is restored to approximately the original surface contour, then the topsoil is replaced, fertilized, and reseeded, completing the land reclamation cycle.

The coal cleaning and sizing plant is located in proximity of the mine. This arrangement minimizes the exposure to the air of mine spoils, with consequent negligible oxidation of coal pyrites to oxygenated sulfur acids.

11.4 NOISE

Noise control will be an integral part of the layout and design of the Fischer-Tropsch commercial plant. The Occupational Safety and Health Act of 1970 (OSHA) regulates the amount of weighted noise a worker may be exposed to, in order to protect him from ear damage. Local codes usually regulate the level of noise that an industrial plant is permitted to generate, at the property line, above the normal ambient background level. The applicable regulations and codes will be used as the design basis for noise control in plant design and layout.

Special attention will be given to the coal gasifier and oxygen plant fans, compressors, and pressure-letdown valves. The sound-exposure standards will be met by a combination of noise-reduction engineering techniques, such as soundproofing of turbines, silencing of valves, and use of sound and vibration absorption materials. Process units not requiring close observation and capable of high-noise levels, such as oxygen compressors, will be barricaded.

11.5 TRACE ELEMENTS

Due to its organic origin and its intimate commixture with crustal formations, coal contains a large number of elements in minor or trace quantities. Actually, out of 92 known non-transuranic elements, only 15 (A, Ac, At, Fr, He, Ir, Kr, Nc, Os, Pa, Pm, Re, Ru, Tm, Xe) have not yet been found in coal.

Average amounts of trace and other elements for 82 coals from the Eastern Region of the Interior Coal Province are shown in Table 11-6. These values were developed during a recent study carried out with thorough analytical procedures; the coals analyzed were mainly composite face channel samples.

A number of studies have analyzed the behavior of trace elements in coal-fired power plant. (1)(2)(3)(4) In general, the elements have been divided into two groups, the ones appearing mainly in the bottom ash (elements or oxides having lower volatility) and the ones appearing mainly in the fly ash (elements or oxides having higher volatility). For power plants using dry particulate collection devices (e.g., electrostatic precipitators), it was believed that the most volatile elements, such as mercury and selenium, could actually escape at the elemental state with the flue gas. Wet scrubbers, however, were believed capable of removing most of the elements from the gas streams and transferring them to the liquid effluent.

Table 11-6 - Mean Analytical Values for 82 Coals from the Illinois Basin

Constituent	Mean	Constituent	Mean (%)
As	14.91 ppm	Cl	0.15
B	113.79 ppm	Fe	2.06
Be	1.72 ppm	K	0.16
Br	15.27 ppm	Mg	0.05
Cd	2.89 ppm	Na	0.05
Co	9.15 ppm	Si	2.39
Cr	14.10 ppm	Ti	0.06
Cu	14.09 ppm	ORS	1.54
F	59.30 ppm	PYS	1.88
Ga	3.04 ppm	SUS	0.09
Ge	7.51 ppm	TOS	3.51
Hg	0.21 ppm	SXRF	3.19
Mn	53.16 ppm	ADL	7.70
Mo	7.96 ppm	MOIS	10.02
Ni	22.35 ppm	VOL	39.80
P	62.77 ppm	FIXC	48.98
Pb	39.83 ppm	ASH	11.28
Sb	1.35 ppm	RTU/LB	12748.91
Se	1.99 ppm	C	70.69
Sn	4.56 ppm	H	4.98
V	33.13 ppm	N	1.35
Zn	313.04 ppm	O	8.19
Zr	72.10 ppm	HTA	11.18
Al	1.22 %	LTA	15.22
Ca	0.74 %		

Note: Abbreviations other than standard chemical symbols: organic sulfur (ORS), pyritic sulfur (PYS), sulfate sulfur (SUS), total sulfur (TOS), sulfur by X-ray fluorescence (SXRF), air-dry loss (ADL), moisture (MOIS), volatile matter (VOL), fixed carbon (FIXC), high-temperature ash (HTA), low-temperature ash (LTA).

From: R.R. Ruch, H.J. Gluskoter, N.F. Shimp, Illinois State Geological Survey Note No. 72, August 1974 (NTIS PB-238 091).

In the Fischer-Tropsch process, no particulates from coal combustion escape into the atmosphere. Particulate streams, wet or dry, are returned to the bottom of the gasifier (see Figure 11-2), where ash and salts melt and are removed as slag. Any eventual dispersion of the elements present depends on the possibility of leaching, discussed in Section 11-3. The concern, therefore, is to identify elements which may be occurring in the gaseous state. The reducing atmosphere present in the middle and top part of the gasifier may also favor different chemical combinations, absent in the oxidizing atmosphere of a power-plant boiler.

Among the high-volatility elements, beryllium, mercury, and lead do not form gaseous hydrides, and will condense on cooling. They are very likely to be almost completely removed by the Fischer-Tropsch wet-scrubbing system (see Figure 11-1). Arsenic, antimony, and selenium can form gaseous (covalent) hydrides, namely arsine, stibine, and hydrogen selenide. Various metals, such as iron and nickel, can also combine with carbon monoxide to give metal carbonyls. Both metal carbonyls and As, Sb, and Se hydrides, however, have stability characteristics which preclude their formation at the temperature and pressure prevailing in the Fischer-Tropsch coal gasifier.

From application of known chemical principles, it can, therefore, be concluded that nil harmful heavy and/or trace metals would be released to the atmosphere. Experimental confirmation, however, would appear desirable. Useful data could be obtained by conducting a trace-element mass balance in power plants presently using wet scrubbers.

11.6 OCCUPATIONAL SAFETY

OSHA and MESA (Mining Enforcement and Safety Administration) standards concerning the health and safety of the workers who would be running the Fischer-Tropsch operation will be strictly adhered to in the engineering design.

Of particular interest in coal-conversion projects is the possible formation of carcinogenic compounds on hydrogenation and pyrolysis of coal. These compounds are usually found in coal tars, and are not expected to be formed under the operating conditions of the entrained coal gasifier used in the Fischer-Tropsch plant.

SECTION 12
STARTUP PROCEDURES

Plant startup facilities and procedures are important because, during normal operation, the energy for steam and electricity production are generated by heat recovery from process streams. The means of bringing the complex to the operating mode are briefly described below.

12.1 GENERAL PROCEDURE

The plant startup will follow the usual procedures for pretesting of individual equipment items to assure performance, and operation of the plant on air and water for hydraulic performance. This startup description is general, not detailed as would be the completed plant procedures which will be based on pilot and incomplete semi-commercial testing.

The plant is provided with two 250,000-pounds steam per hour startup boilers and two 15 MW startup gas-turbine electrical power generators. The plant will also be tied into an outside public utility power grid (which may be used for startup).

The following is a brief sequence of startup activities with clarification and further details presented later:

- 1.0 Start the gas turbine generators to provide 30 MW of electrical power.
- 2.0 Start cooling-water system, instrument gas system, boiler feedwater system.
- 3.0 Run startup boiler to heat system.
- 4.0 Start oxygen compressor to compress combustion air to gasifier.
- 5.0 Light off oil burner on oil and air.
- 6.0 Pressure system to 400 psig to run at 20% level and burn vent gas.
- 7.0 Start oxygen plant.
- 8.0 Run gas-treating and sulfur plant, burn vent gas.
- 9.0 Start coal feed, reduce oil feed.

- 10.0 Operate Fischer-Tropsch reactor, shift reactor, products recovery, and methanator.
- 11.0 Bring plant to 100% of design rate.
- 12.0 Remove oil feed.

The plant will be provided with a low sulfur, liquid-petroleum fuel oil for initial startup, while startup fuel is Fischer-Tropsch liquid for subsequent startups. Both the gas turbines and boiler are oil fired. These provide utilities for testing initial operation of the coal mine and coal preparation, operation of the cooling water and boiler feed water systems. The main alternator is also heated and made ready. The oxygen compressor is run on air to provide for initial startup combustion air.

The gasifier is initially started on fuel oil with gasifier temperature maintained to acceptable limits with water-spray injection. Auxiliary fuel oil burners are provided in the gasifier lower zone. Process plant steam generators are used to cool the combustion gas. When operation on oil is satisfactory and the gasifier heated and functional, the coal feed can be started. The system is pressurized to full operational pressure, and the gas-treating and sulfur plants placed into operation. Then the shift reactor, Fischer-Tropsch synthesis section is operated along with the liquid recovery system and methanation. Gas made is flared since it is nitrogen-rich from the combustion air.

The oxygen plant can be started and tested by use of the startup boiler, and may be made fully operative as process steam generation provides sufficient quantities of steam. The gasifier can be switched from air-oil firing to oxygen-coal firing as the plant reaches an operating level of 20 percent of normal.

Before coal is introduced, either with oxygen or air firing, the lower stage should be at 3,000°F, or the fluxing temperature of coal ash from 2,800 to 3,200°F. The feed coal is introduced at the upper stage, and steam and water spray used to keep gasifier top outlet temperature at 1,700°F. Coal char is recovered in the cyclone and used as fuel to the lower stage.

To generate maximum steam at the start of operation, the gasifier can generate syngas high in carbon dioxide. As steam is generated, the oxygen plant can be started. The flare will burn any carbon monoxide released as well as hydrogen sulfide. Steam generation at 20 percent gasifier capacity is sufficient to run the oxygen plant at over 10 percent capacity. Thus the gasifier may be operated on enriched air feed. Further increase in operating rate allows higher oxygen plant production until full oxygen feed is possible.

The plant may be operated on part oil fuel to the gasifier until smooth operation is obtained. A small oil pilot is retained as well as an instantaneously available supply to furnish full combustion rate in case of coal supply failure, failure of slag withdrawal system, or failure of the gas cleaning or acid gas removal units.

12.2 SAFETY AND PERFORMANCE

The conceptual plant will have each step and each component tested on a reasonable scale before operation.

As now conceived, safe operation will be assured by:

- 1.0 Control of gasifier on flame out or coal feed interruption
- 2.0 Complete vent capacity on synthesis gas blockage
- 3.0 Containment of tube rupture in reactors and exchangers
- 4.0 Emergency oil and gas feed to the gasifier on coal stoppage
- 5.0 Flame out and oxygen detectors in synthesis gas
- 6.0 Rapid venting of unsafe gas mixtures.