4. HYDROGEN FUEL FROM WYODAK COAL/BIOMASS BLEND

The design and cost assessments of hydrogen fuel plants have been based on Pittsburgh No. 8 bituminous coal since work in this area began. The plants have been normalized by having a throughput of 2,500 tons per day of coal on a dry basis. In response to an inquiry regarding the performance of plants on fuels other than the base coal, a conceptual plant has been designed, based on a fuel consisting of a blend of 90 percent Wyodak subbituminous coal and 10 percent biomass. The results of this assessment are compared to the baseline plant performance and economics from Pittsburgh No. 8 coal.

4.1 INTRODUCTION

The baseline hydrogen fuel plant design (600°C hydrogen separation device [HSD] and hot gas desulfurization) was selected to evaluate the conversion of the coal and biomass mixture to synthesis gas, and achieve essentially total separation of hydrogen from the CO_2. Wyodak subbituminous coal and the biomass analyses for the study were provided by NETL, and are listed in Table 4-1. This concept utilizes hot gas desulfurization and particulate removal upstream of the HSD along with a modern non-ATS (conventional) gas turbine in the CO_2-rich stream. Table 4-2 provides the design basis established for the plant.

Table 4-1
Wyodak Coal and Biomass Properties (As Received)

Proximate	Wyodak Coal	Biomass* (Seward Sawdust)
Moisture	26.6	39.0
Volatile Matter	33.2	49.3
Fixed Carbon	34.4	11.5
Ash	5.8	0.31
Ultimate		
Sulfur	0.6	0.02
Hydrogen	6.5	5.9
Carbon	50.0	49.8
Nitrogen	0.9	0.2
Oxygen	36.2	43.6
Ash	5.8	0.51
Heating Value, HHV	8,630 Btu/lb	5,165 Btu/lb

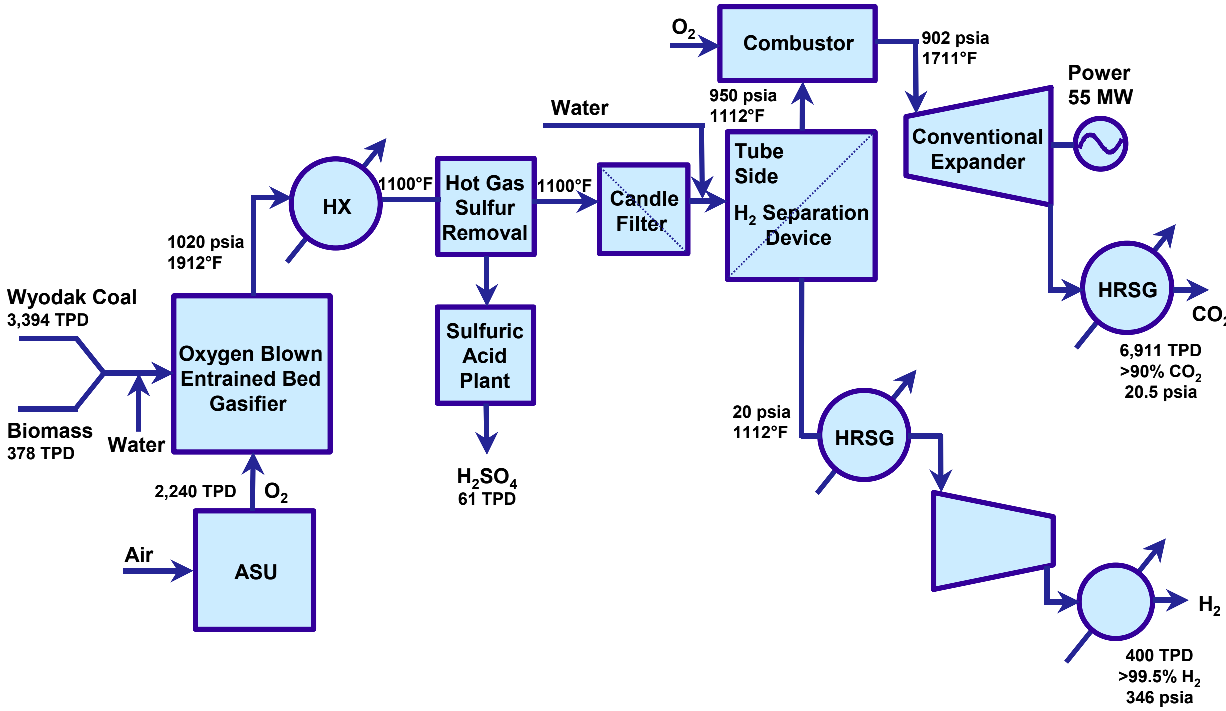
* Biomass is supplied in < ¼-inch size.

Table 4-2
Design Basis for Hydrogen Fuel Production Facility
with Conventional Expansion Turbine and Hot Gas Cleanup
Biomass/Coal Feed

Hydrogen Fuel Production Facility Parameter	Hydrogen Fuel Production Facility Plant Design Basis
Feed	90% Wyodak coal, AR 10% biomass, AR
Gasifier	Oxygen-blown E-Gas with second stage adjusted for 1905°F output
ASU	Cryogenic
Hot Gas Temperature	1905°F
Gasifier Outlet Pressure	1000 psia
Ambient Conditions	14.7 psia, 60°F
Hot Gas Desulfurization	Yes, 1100°F
Sulfur Recovery	Sulfuric acid
Ceramic Candle Filter	Before HSD
Hydrogen Separation	H_2 separation device Shell and tube configuration 95% separation 99.5% pure H_2 Zero sulfur 20 psia hydrogen compressed to 346 psia
Separated Gas	CO shifted to 1112°F equilibrium 5% of fuel value in gas 950 psia
Separated Gas Utilization	Combustion with oxygen Conventional turbine expander
CO_2 Product Pressure	19.4 psia
Hydrogen Utilization	346 psia offsite
Auxiliary Power Block	Conventional turbine expander Steam turbine bottoming cycle
Plant Size	Maximum H_2 production from 2,500 tpd dry feed basis gasifier Excess power sold offsite

The overall plant concept is shown on Figure 4-1. Key process components included in the plant are an E-Gas high-pressure slurry-feed gasifier, the Eastern Tennessee Technology Park (ETTP) HSD, and the transport reactor for desulfurization. The high-pressure syngas produced in the gasifier is quenched to 1905°F as a result of adjustments in the second stage of the gasifier. The hot raw gas is cleaned of larger particulates in a cyclone and then is cooled in a firetube boiler to 1100ºF. A hot gas cleanup system consisting of a transport reactor desulfurizer and a ceramic candle filter removes sulfur and particulates from the fuel gas stream. Sulfur is recovered as sulfuric acid.

Figure 4-1
Block Flow Diagram
Hydrogen Plant with Wyodak Coal/Biomass Fuel



For this case, water is added to both cool the hot clean syngas and ensure adequate water content for the high-temperature shift reaction to occur at the HSD inlet temperature. The gas enters the HSD at 717°F and leaves the HSD at 1112°F as a result of the exothermic shift reaction. The hydrogen produced from the HSD is 99.5 percent pure. It goes through a HRSG and is then compressed to 346 psia.

The CO_2-rich gas leaving the HSD at 950 psia contains about 5 percent of the fuel value of the inlet syngas stream. This gas goes to the gas turbine combustor with which oxygen is injected to combust CO and hydrogen to CO_2 and H_2O, respectively, resulting in a firing temperature of 1711°F. The hot gas is expanded to 20 psia and 814°F through the conventional gas turbine expander to produce 55 MW electric power. The gas is cooled in a HRSG, and steam is combined with other steam from cooling the hydrogen to produce an additional 28 MW and for process applications. The low-pressure CO_2 product is cooled to 100°F, dried, and sent offsite.

Table 4-3 presents the performance summary for the plant, and Table 4-4 identifies the plant auxiliary power requirements.

Table 4-3
Performance Summary

Wyodak Coal Feed	283,833 lb/h
Biomass Feed	31,537 lb/h
Oxygen Feed (95%) to Gasifier	186,650 lb/h
Oxygen Feed to Retentate Combustor	25,300 lb/h
Water to Prepare Feed Slurry	114,009 lb/h
Hydrogen Product Stream	33,337 lb/h
CO_2 Product Stream @ 90.2% CO_2	575,923 lb/h
Sulfuric Acid Product	5,057 lb/h
Gross Power Production	
Turbine Expander	55.4 MW
Steam Turbine	27.7 MW
Auxiliary Power Requirement	(69.2 MW)
Net Power Production	13.9 MW
Effective Thermal Efficiency (ETE), HHV	79.8%

Table 4-4
Auxiliary Power Load, kW

Gasifier Auxiliary Oxygen Compressor	11,560 kW
Combustor Oxygen Compressor	1,520
ASU Air Compressor	28,320
Gasifier Slurry Pumps	220
Sulfuric Acid Plant	90
Water Spray Pump	420
BF Water Pumps	470
Coal/Sawdust Handling	300
Slag Handling	700
Regenerator Air Blower	780
GT/ST Auxiliary	400
Hydrogen Compressor	23,690
Miscellaneous Balance of Plant	750
Total Auxiliary Load	**69,220 kW**

4.2 PROCESS DESCRIPTION

The baseline hydrogen fuel plant design was modified to accommodate a blend of 90 percent Wyodak coal and 10 percent biomass. The basis for design was retained at a gasifier throughput of 2,500 tons per day *dry* fuel, but due to the higher moisture contents, the coal/biomass blend required increased material handling. However, the syngas and hydrogen production processes had only minor changes. Hydrogen production with the new feedstock is reduced by about

7 percent. The low sulfur content of the fuel also resulted in a reduction in the acid plant size by about 2/3. The flows and state points on Figure 4-2 result from the heat and material balance for the plant. Following are more detailed descriptions of the key process elements.

4.2.1 GASIFIER

The high-pressure system for producing hydrogen has resulted in utilizing two E-Gas gasifier trains, each having a throughput capacity of 1,250 tpd coal (dry basis). The E-Gas high-pressure entrained flow gasifier consists of two stages to gasify the coal-biomass-water slurry feed with oxygen. The slurry was prepared by fine grinding the 90/10 coal biomass (as received) feed fuel to about 200 mesh and mixing with water to achieve a ratio of 66 percent solids and 34 percent water, *including the moisture content of the coal and biomass*. The gasifier can operate at any pressure up to the capability of the oxygen compressor. By operating in two stages, it is possible to adjust the flow split between stages to achieve a desired outlet temperature of the product gas. A typical operating temperature for the E-Gas gasifier is 1900°F. This temperature is reached by using a 78/22 flow split between the first and second stages of the gasifier. Slag produced in the high-temperature gasifier reaction flows to the bottom of the first stage, where it falls into a water bath and is cooled and shattered to become an inert frit.

Gas leaving the gasifiers at 1905°F goes through an internal cyclone that separates entrained particles from the gas for recycle to the gasifiers, a firetube boiler to cool the gas to 1100ºF, and a hot gas cleanup system. Water is injected into the gas stream to cool and saturate the gas at 717°F, promoting the shift reaction, which will occur downstream in the HSD.

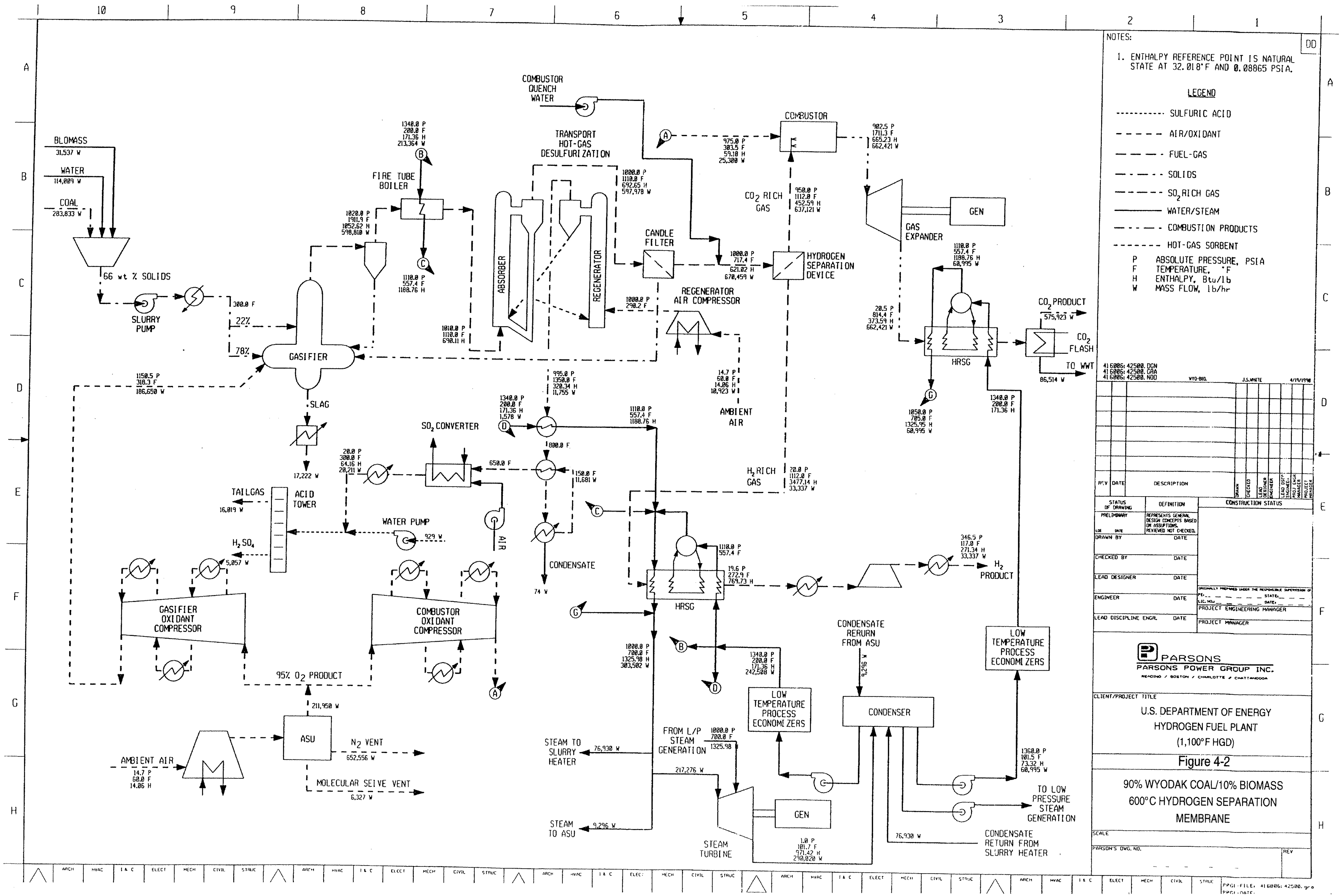
4.2.2 AIR SEPARATION UNIT

Oxygen supply for this plant is provided through a conventional cryogenic ASU. The air separation plant is designed to produce a nominal output of 2,600 tons/day of 95 percent pure O_2. The high-pressure plant is designed with one 100 percent capacity production train, with liquefaction and liquid oxygen storage providing an 8-hour backup supply of oxygen.

4.2.3 HOT GAS CLEANUP SYSTEM

The transport reactor desulfurizer consists of a riser tube, a disengager, and a standpipe for both the absorber section and regeneration section. Sorbent from the absorber passes through the regenerator riser, disengages, and transfers back to the absorber through the standpipe. Regeneration is conducted with neat air to minimize heat release and limit temperature. The regeneration heat has negligible effect on the sorbent temperature in the absorber. The regeneration off-gas containing predominantly SO_2 is sent to the sulfuric acid plant. Elutriated particles are disengaged from the gas by high-efficiency cyclones at the top of the absorber. A final ceramic candle filter is located downstream.

Figure 4-2


NOTES:
1. ENTHALPY REFERENCE POINT IS NATURAL STATE AT 32.018°F AND 0.08865 PSIA.
LEGEND
SULFURIC ACID
AIR/OXIDANT
FUEL-GAS
SOLIDS
SO2 RICH GAS
WATER/STEAM
COMBUSTION PRODUCTS
HOT-GAS SORBENT
P ABSOLUTE PRESSURE, PSIA
F TEMPERATURE, °F
H ENTHALPY, Btu/lb
W MASS FLOW, lb/hr
BIOMASS
WATER
COAL
66 wt % SOLIDS
SLURRY PUMP
GASIFIER
SLAG
FIRE TUBE BOILER
COMBUSTOR QUENCH WATER
TRANSPORT HOT-GAS DESULFURIZATION
ABSORBER
REGENERATOR
CANDLE FILTER
REGENERATOR AIR COMPRESSOR
AMBIENT AIR
COMBUSTOR
CO2 RICH GAS
HYDROGEN SEPARATION DEVICE
GAS EXPANDER
GEN
HRSG
CO2 PRODUCT
CO2 FLASH
TO WWT
H2 RICH GAS
H2 PRODUCT
SO2 CONVERTER
TAILGAS
ACID TOWER
H2SO4
WATER PUMP
AIR
CONDENSATE
GASIFIER OXIDANT COMPRESSOR
COMBUSTOR OXIDANT COMPRESSOR
95% O2 PRODUCT
ASU
N2 VENT
MOLECULAR SEIVE VENT
AMBIENT AIR
STEAM TO SLURRY HEATER
STEAM TO ASU
FROM L/P STEAM GENERATION
STEAM TURBINE
LOW TEMPERATURE PROCESS ECONOMIZERS
CONDENSATE RERURN FROM ASU
CONDENSER
TO LOW PRESSURE STEAM GENERATION
CONDENSATE RETURN FROM SLURRY HEATER
PARSONS
PARSONS POWER GROUP INC.
U.S. DEPARTMENT OF ENERGY
HYDROGEN FUEL PLANT
(1,100°F HGD)
Figure 4-2
90% WYODAK COAL/10% BIOMASS
600°C HYDROGEN SEPARATION
MEMBRANE