3. WYODAK PRB COAL

This section is dedicated to the design and cost estimate for a hydrogen plant fed with Wyodak Powder River Basin (PRB) sub-bituminous coal. This coal is characterized having low volatility, high ash and moisture content, and a lower as-received heating value. The low sulfur content results in a lesser value-added from the sulfuric acid byproduct.

3.1 HEAT AND MATERIAL BALANCE

The heat and material balance for the IGCC plant is based on the maximum hydrogen production from 2,500 tons per day of dry coal. Ambient operating conditions are indicated in the plant design basis. The pressurized entrained flow E-Gas™ two-stage gasifier uses a coal/water slurry and oxygen to produce a medium heating value fuel gas. The syngas produced in the gasifier first stage at about 2450°F (1343°C) is quenched to 1900°F (1038°C) by reacting with slurry injected into the second stage. The syngas passes through a fire tube boiler syngas cooler and leaves at 1300°F (704°C). A second gas cooler in series cools the gas further to 645°F (341°C). High-pressure saturated steam is generated in the syngas coolers and is joined with the main steam supply. The process flow diagram resulting from the heat and material balance is shown as Figure 3-1.

The gas goes through a series of additional gas coolers and cleanup processes including a scrubber. Slag captured by the syngas scrubber is recovered in a slag recovery unit.

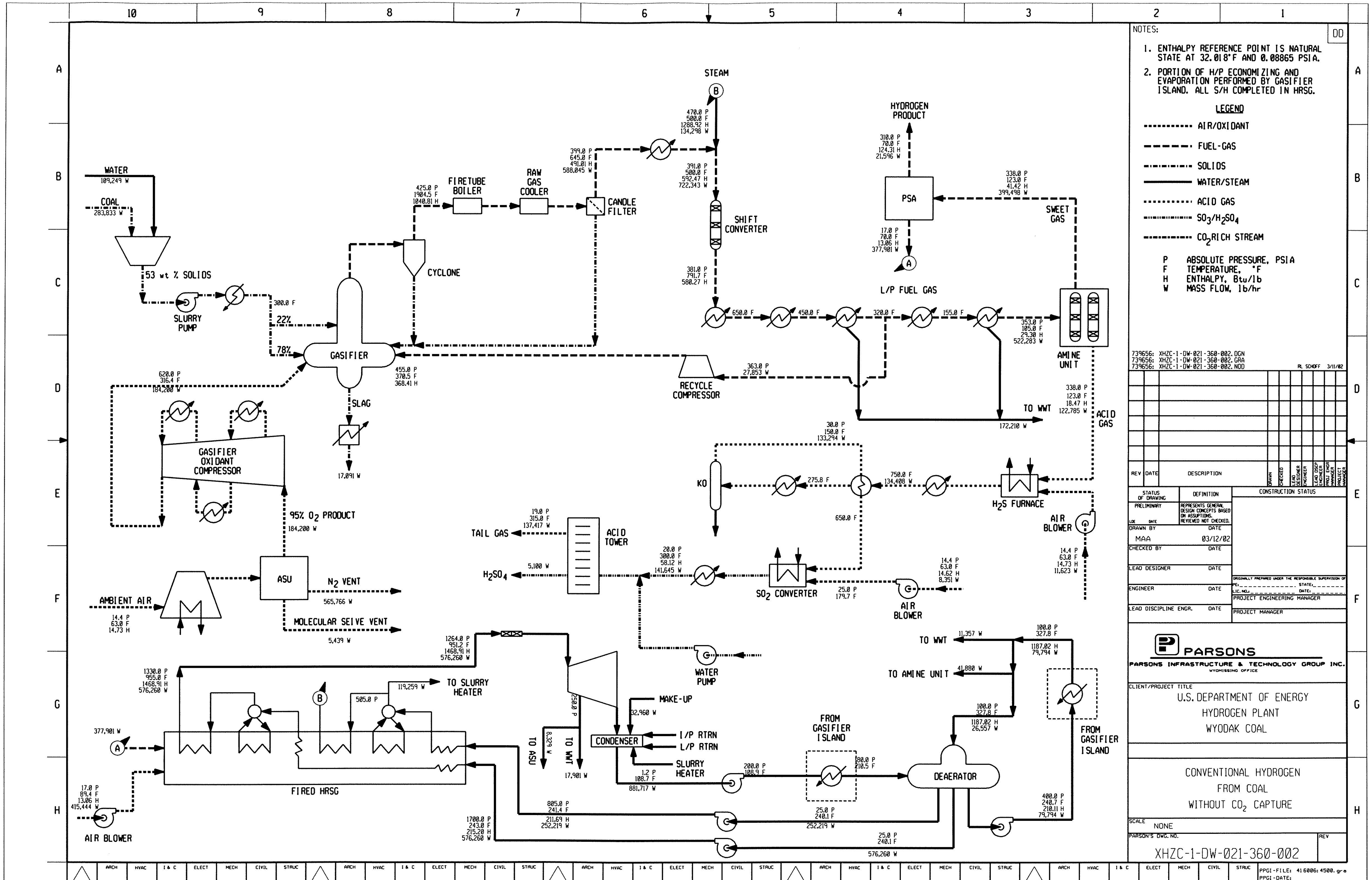
The syngas stream from the syngas scrubber enters the high-temperature shift converter, which contains a bed of sulfided shift catalyst. The shift reaction converts over 80 percent of the CO to hydrogen and CO_2 and hydrolyzes COS to H_2S. Following the shift converter, the cooled gas stream passes through a proprietary amine acid gas removal (AGR) process, which removes H_2S and some of the CO_2. The clean gas stream then passes through the pressure swing adsorption (PSA) for final purification of the hydrogen. Regeneration gas from the PSA contains fuel value, and is fed to the heat recovery steam generator (HRSG). Regeneration gas from the AGR plant is fed to a sulfuric acid plant.

The cryogenic oxygen plant supplies 99 percent pure oxygen to the gasifiers at the rated pressure. A dedicated air compressor provides air supply for the oxygen plants.

The steam cycle is based on maximizing heat recovery from the gasifier cooler and HRSG, as well as utilizing steam generation opportunities in the shift process.

The steam turbine selected to match this cycle is a two-casing, reheat, double-flow (exhaust) machine, exhausting downward to the condenser. The HP and IP turbine sections are contained in one casing, with the LP section in a second casing. The steam turbine drives a 3600 rpm hydrogen-cooled generator. The turbine exhausts to a single-pressure condenser operating at a nominal 1.2 psia at the 100 percent load design point. Two 50 percent capacity, motor-driven pumps are provided for feedwater and condensate.

Figure 3-1


NOTES:
1. ENTHALPY REFERENCE POINT IS NATURAL STATE AT 32.018°F AND 0.08865 PSIA.
2. PORTION OF H/P ECONOMIZING AND EVAPORATION PERFORMED BY GASIFIER ISLAND. ALL S/H COMPLETED IN HRSG.
LEGEND
AIR/OXIDANT
FUEL-GAS
SOLIDS
WATER/STEAM
ACID GAS
SO_3/H_2SO_4
CO_2 RICH STREAM
P ABSOLUTE PRESSURE, PSIA
F TEMPERATURE, °F
H ENTHALPY, Btu/lb
W MASS FLOW, lb/hr
WATER
COAL
53 wt % SOLIDS
SLURRY PUMP
22%
78%
GASIFIER
CYCLONE
FIRETUBE BOILER
RAW GAS COOLER
CANDLE FILTER
STEAM
SHIFT CONVERTER
HYDROGEN PRODUCT
PSA
SWEET GAS
L/P FUEL GAS
AMINE UNIT
RECYCLE COMPRESSOR
SLAG
GASIFIER OXIDANT COMPRESSOR
95% O_2 PRODUCT
ASU
AMBIENT AIR
N_2 VENT
MOLECULAR SEIVE VENT
TAIL GAS
ACID TOWER
H_2SO_4
KO
SO_2 CONVERTER
AIR BLOWER
H_2S FURNACE
ACID GAS
TO WWT
WATER PUMP
TO SLURRY HEATER
MAKE-UP
CONDENSER
I/P RTRN
L/P RTRN
SLURRY HEATER
TO ASU
TO WWT
FIRED HRSG
FROM GASIFIER ISLAND
DEAERATOR
TO AMINE UNIT
FROM GASIFIER ISLAND
PARSONS
PARSONS INFRASTRUCTURE & TECHNOLOGY GROUP INC.
U.S. DEPARTMENT OF ENERGY
HYDROGEN PLANT
WYODAK COAL
CONVENTIONAL HYDROGEN FROM COAL WITHOUT CO_2 CAPTURE
SCALE NONE
XHZC-1-DW-021-360-002
DRAWN BY MAA 03/12/02

Overall performance for the entire plant is summarized in Table 3-1, which includes auxiliary power requirements. The net plant output power, after plant auxiliary power requirements are deducted, is nominally 42 MW_e. The overall plant thermal effective efficiency (thermal value of hydrogen and power produced) is 59.7 percent, on an HHV basis.

Table 3-1
Plant Performance Summary
Hydrogen Production from Wyodak Coal

Plant Output		
Steam Turbine Power	81,450	kW_e
Total	**81,450**	kW_e
Hydrogen Production		
Hydrogen Product	21,600	lb/h
Auxiliary Load		
Gasifier O_2 Compressor	9,590	kW_e
ASU Air Compressor	21,470	kW_e
Gasifier Slurry Pump	80	kW_e
Coal Handling	270	kW_e
Slag Handling	400	kW_e
Amine Unit	300	kW_e
Recycle Compressor	180	kW_e
H_2SO_4 Plant	100	kW_e
H_2S Furnace Air Blower	230	kW_e
Boiler Feedwater Pumps	1,420	kW_e
Steam Turbine Auxiliaries	250	kW_e
Cooling Tower	1,140	kW_e
Circulating Water Pumps	1,830	kW_e
Miscellaneous Balance of Plant	750	kW_e
Condensate Pumps	200	kW_e
Flue Gas Burner Air Blower	910	kW_e
Wastewater Treatment	500	kW_e
Total	39,620	kW_e
Plant Performance		
Net Auxiliary Load	39,620	kW_e
Net Plant Power	41,830	kW_e
Net Plant Efficiency (HHV)[1]	59.7%	
Net Plant Heat Rate (HHV)	5,820	Btu/kWh
Coal Feed Flowrate	283,833	lb/h
Thermal Input[2]	717,872	kW_e
Condenser Duty	593.7	MMBtu/h

1 – Efficiency calculation includes thermal value of hydrogen and power produced.
2 – HHV of as-fed Wyodak coal is 8,630 Btu/lb.

Figure 3-2 is a block flow diagram for the plant, and is accompanied by Table 3-2, which includes detailed process stream composition and state points.

Figure 3-2
Process Block Flow Diagram
E-Gas™ Gasifier-Based Hydrogen Production Plant – Wyodal Coal

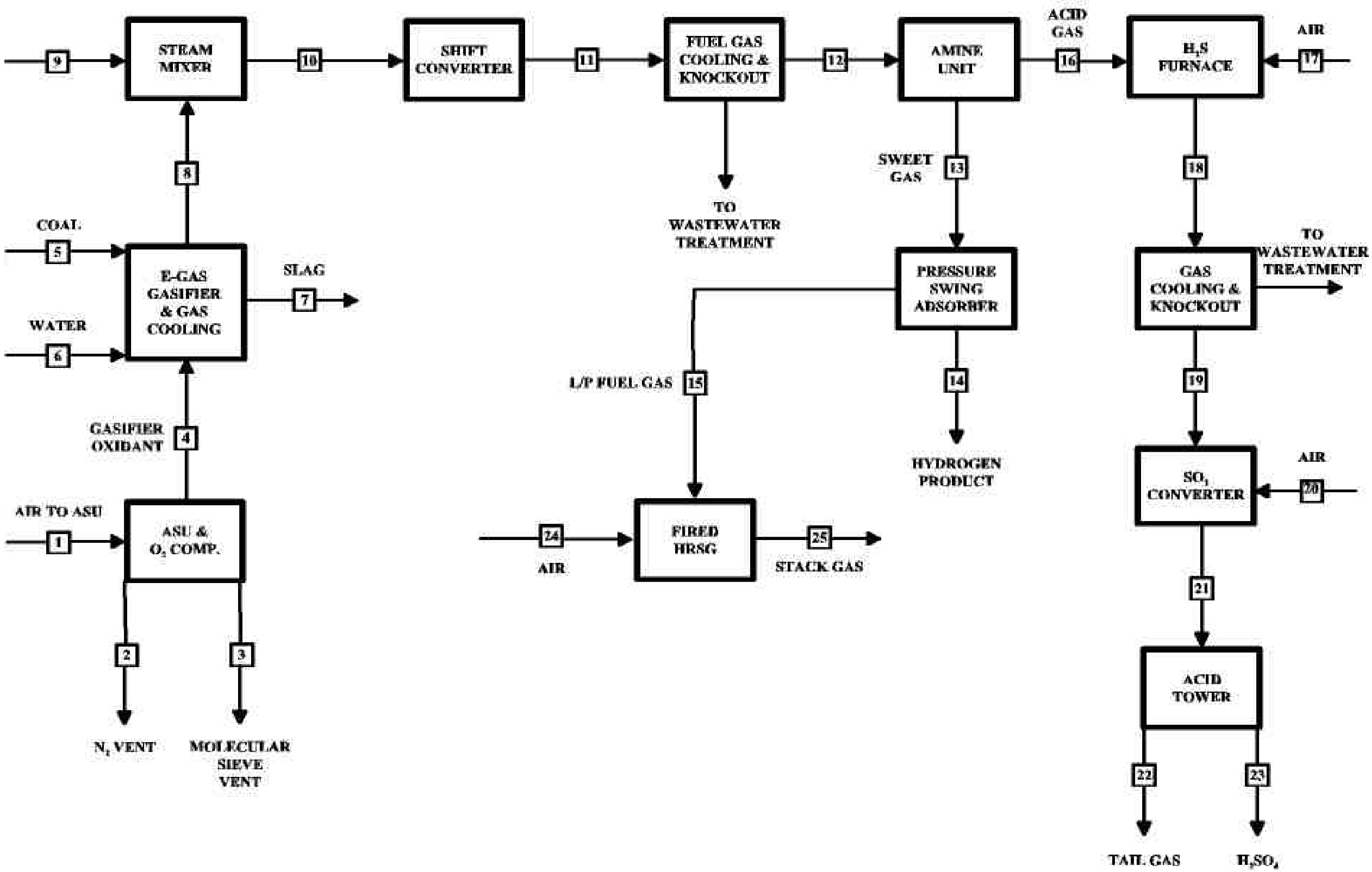


Table 3-2
Process Stream Compositions and State Points – Wyodak Coal

STREAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13
Vapor - Liquid													
Mole Fraction													
Ar	0.0094	0.0027	0.0000	0.0360	0.0000	0.0000	0.0000	0.0075	0.0000	0.0059	0.0059	0.0082	0.0092
CH_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0017	0.0000	0.0014	0.0014	0.0019	0.0021
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2661	0.0000	0.2111	0.0619	0.0852	0.0958
CO_2	0.0003	0.0000	0.0266	0.0000	0.0000	0.0000	0.0000	0.1604	0.0000	0.1272	0.2765	0.3795	0.3042
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2834	0.0000	0.2248	0.3740	0.5148	0.5792
H_2O	0.0108	0.0000	0.9734	0.0000	0.0000	1.0000	0.0000	0.2717	1.0000	0.4222	0.2730	0.0027	0.0031
H_2SO_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.7719	0.9973	0.0000	0.0140	0.0000	0.0000	0.0000	0.0052	0.0000	0.0041	0.0041	0.0057	0.0064
NH_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0021	0.0000	0.0016	0.0016	0.0000	0.0000
O_2	0.2076	0.0000	0.0000	0.9500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COS (ppmv)	0	0	0	0	0	0	0	69	0	55	0	0	0
H_2S (ppmv)	0	0	0	0	0	0	0	1,870	0	1,483	1,538	2,082	5
SO_2 (ppmv)	0	0	0	0	0	0	0	0	0	0	0	0	0
SO_3 (ppmv)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total V-L Flow (lb_{mol}/hr)	26,184	20,173	291	5,715	0	6,064	0	28,705	7,455	36,162	36,160	25,243	22,350
Total V-L Flow (lb/hr)	755,405	565,766	5,439	184,200	0	109,249	0	588,045	134,298	722,343	722,346	522,283	399,498
Solids Flow													
Coal	0	0	0	0	283,833	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Slag	0	0	0	0	0	0	17,091	0	0	0	0	0	0
Temperature (°F)	63	60	100	316		60		500	500	500	792	105	123
Pressure (psia)	14.4	14.7	87.5	620.0	14.7	14.7	15.0	391.0	470.0	391.0	381.0	353.0	338.0

Table 3-2 (Cont'd)
Process Stream Compositions and State Points – Wyodak Coal

STREAM NUMBER	14	15	16	17	18	19	20	21	22	23	24	25
Vapor - Liquid												
Mole Fraction												
Ar	0.0000	0.0171	0.0000	0.0094	0.0012	0.0012	0.0094	0.0019	0.0020	0.0000	0.0094	0.0142
CH_4	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.1780	0.0003	0.0000	0.0003	0.0003	0.0000	0.0003	0.0003	0.0000	0.0000	0.0000
CO_2	0.0010	0.5641	0.9791	0.0003	0.8640	0.8811	0.0003	0.8125	0.8260	0.0000	0.0003	0.3735
H_2	0.9976	0.2205	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0057	0.0000	0.0108	0.0194	0.0000	0.0108	0.0009	0.0000	0.0103	0.0108	0.1237
H_2SO_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9897	0.0000	0.0000
N_2	0.0014	0.0107	0.0000	0.7719	0.0978	0.0997	0.7719	0.1580	0.1606	0.0000	0.7719	0.4679
NH_3	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.2076	0.0008	0.0008	0.2076	0.0108	0.0110	0.0000	0.2076	0.0207
COS (ppmv)	0	0	0	0	0	0	0	0	0	0	0	0
H_2S (ppmv)	0	9	18,618	0	0	0	0	0	0	0	0	0
SO_2 (ppmv)	0	0	0	0	16,429	16,754	0	46	47	0	0	0
SO_3 (ppmv)	0	0	0	0	0	0	0	15,403	0	0	0	0
Total V-L Flow (lb_{mol}/hr)	10,316	12,034	2,849	403	3,263	3,200	289	3,486	3,328	52	14,400	24,034
Total V-L Flow (lb/hr)	21,596	377,901	122,785	11,623	134,408	133,294	8,351	141,645	137,417	5,100	415,444	793,224
Solids Flow												
Coal	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0
Slag	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	70	70	123	331	750	650	180	300	315	315	89	280
Pressure (psia)	310.0	17.0	338.0	45.0	42.0	29.5	25.0	20.0	19.0	19.0	17.0	14.7

3.2 PROCESS DESCRIPTION

Following are more detailed descriptions of the key process elements:

3.2.1 Gasifier

For this application to produce hydrogen, a dual-train E-Gas™ gasifier of the Wabash River configuration, consisting of two 50 percent gasifiers, is utilized. The net temperature for gas leaving the gasifier is 1900°F 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 gasifier at 1900°F goes through an internal cyclone that separates entrained particles from the gas for recycle to the gasifier, followed by a fire-tube boiler and gas cooler to reduce gas temperature to 645°F (341°C). Following the cooler, remaining particulates are removed from the gas with a metallic filter and are returned to the gasifier.

3.2.2 Air Separation Unit

Oxygen supply for this plant is also provided through a conventional cryogenic ASU. The air separation plant is designed to produce a nominal output of 2,200 tons/day of 99 percent pure O_2. The high-pressure plant is designed with one production train, with liquefaction and liquid oxygen storage providing an 8-hour backup supply of oxygen.

3.2.3 Particulate Removal

The particulate removal device is a sintered metal candle configuration, operating at the relatively low temperature of 645°F (341°C). The vessel and candle array is similar to the configuration used at the Wabash River demonstration plant. A particulate removal vessel is provided for each gasifier train.

3.2.4 CO Shift

After leaving the particulate control unit, steam is injected into the gas stream and the CO in the syngas is shifted to hydrogen and CO_2 in the shift converter utilizing a sulfur-tolerant shift catalyst. The shift catalyst also promotes the COS hydrolysis reaction. Heat is removed from the gas stream following the shift, the gases are cooled, sour water is condensed, and the gas stream is sent to the sulfur removal unit.

The CO shift converter consists of four fixed-bed reactors with two reactors in series and two in parallel. Two reactors in series with cooling between the two are required to control the exothermic temperature rise. The two reactors in parallel are required due to the high gas mass flow rate. Feed to the shift converter is first preheated by hot effluent from the second converter, heated by hot effluent from the first converter, and fed to the top of the two first-stage converters in parallel. Effluent from the first stage is cooled and fed to the top of the second-stage converters. Effluent from the second stage is cooled by exchanging heat with incoming feed, by an air cooler and finally by a water cooler.

3.2.5 Amine Unit/Acid Gas Concentrator

The purpose of the amine unit is to remove H_2S from the fuel gas stream. This step is necessary in order to minimize plant sulfur emissions. The solvent used in this case is a proprietary formulation based on MDEA. A traditional absorber/stripper arrangement will be used.

Cool, dry, and particulate-free synthesis gas enters the absorber unit at 353 psia and 105°F (41°C). In the absorber, H_2S along with some CO_2 is removed from the fuel gas stream. Clean fuel gas exits the top of the absorber and is then routed to the saturator column.

The rich solution leaving the bottom of the absorber is regenerated in a stripper through the indirect application of thermal energy via condensing low-pressure steam in a reboiler. The stripper acid gas stream, consisting of 16 percent H_2S and 78 percent CO_2 (with the balance mostly H_2O), requires further treatment before being sent to the sulfuric acid plant.

Typically, for good performance and operation, the minimum H_2S concentration in the acid gas feed to an acid plant should be above 27 percent. In this case, an acid gas concentrator was used to further concentrate the H_2S stream.

3.2.6 Hydrogen Purification

The product hydrogen stream exits the absorber and is sent to a PSA unit to purify the hydrogen. The product hydrogen leaves the PSA unit at 310 psia, and the PSA tail gas is sent to the HRSG to be fired with oxygen.

Treated gas from the amine unit absorber is fed directly to the PSA unit where hydrogen is purified up to approximately 99.9 percent. Carbon oxides are limited to 10 ppm in the final hydrogen product. The PSA process is based on the principle of adsorbent beds adsorbing more impurities at high gas-phase partial pressure than at low partial pressure.

The gas stream is passed through adsorbent beds at 338 psia, and then the impurities are purged from the beds at 17 psia. Purge gas is sent to the gas-fired heat recovery unit for steam generation. Purified hydrogen is produced at 310 psia. The PSA process operates on a cyclic basis and is controlled by automatic switching valves. Multiple beds are used in order to provide constant product and purge gas flows.

3.3 MAJOR EQUIPMENT LIST FOR WYODAK COAL CASE

This section contains the equipment list corresponding to the power plant configuration shown in Figure 3-1. This list, along with the heat and material balance and supporting performance data, was used to generate plant costs and used in the financial analysis. In the following, all feet (ft) conditions specified for process pumps correspond to feet of liquid being pumped.

ACCOUNT 1 COAL RECEIVING AND HANDLING

Equipment No.	Description	Type	Design Condition	Qty.
1	Bottom Trestle Dumper and Receiving Hoppers	N/A	100 ton	2
2	Feeder	Vibratory	300 tph	2
3	Conveyor 1	54" belt	450 tph	1
4	As-Received Coal Sampling System	Two-stage	N/A	1
5	Conveyor 2	54" belt	450 tph	1
6	Reclaim Hopper	N/A	40 ton	2
7	Feeder	Vibratory	150 tph	2
8	Conveyor 3	48" belt	300 tph	1
9	Crusher Tower	N/A	300 tph	1
10	Coal Surge Bin w/Vent Filter	Compartment	300 ton	1
11	Crusher	Granulator reduction	6"x0 - 3"x0	1
12	Crusher	Impactor reduction	3"x0 - 1"x0	1
13	As-Fired Coal Sampling System	Swing hammer	N/A	2
14	Conveyor 4	48" belt	300 tph	1
15	Transfer Tower	N/A	300 tph	1
16	Tripper	N/A	300 tph	1
17	Coal Silo w/Vent Filter and Slide Gates	N/A	600 ton	2

ACCOUNT 2 COAL-WATER SLURRY PREPARATION AND FEED

Equipment No.	Description	Type	Design Condition	Qty.
1	Feeder	Vibrating	100 tph	2
2	Weigh Belt Feeder		48" belt	2
3	Rod Mill	Rotary	100 tph	2
4	Slurry Water Pumps	Centrifugal	180 gpm @ 500 ft	2
5	Slurry Water Storage Tank	Vertical	1,500 gal	1
6	Rod Mill Product Tank	Vertical	35,000 gal	2
7	Slurry Storage Tank with Agitator	Vertical	150,000 gal	2
8	Coal-Slurry Feed Pumps	Positive displacement	700 gpm @ 1,250 ft	2
9	LT Slurry Heater	Shell and tube	20 x 10^6 Btu/h	2
10	HT Slurry Heater	Shell and tube	7 x 10^6 Btu/h	2

ACCOUNT 3 FEEDWATER AND MISCELLANEOUS BOP SYSTEMS

ACCOUNT 3A CONDENSATE AND FEEDWATER SYSTEM

Equipment No.	Description	Type	Design Condition	Qty
1	Cond. Storage Tank	Vertical, cylindrical, outdoor	200,000 gal	1
2	Condensate Pumps	Vert. canned	1,000 gpm @ 400 ft	2
3	Deaerator	Horiz. spray type	1,100,000 lb/h 205°F to 240°F	1
4	IP Feed Pump	Horiz. centrifugal single stage	200 gpm/1,850 ft	2
5	HP Feed Pump	Barrel type, multi-staged, centr.	500 gpm @ 4,000 ft	2

ACCOUNT 3B MISCELLANEOUS EQUIPMENT

Equipment No.	Description	Type	Design Condition	Qty
1	Auxiliary Boiler	Shop fabricated, water tube	400 psig, 650°F 70,000 lb/h	1
2	Service Air Compressors	Recip., single stage, double acting, horiz.	100 psig, 750 cfm	2
3	Inst. Air Dryers	Duplex, regenerative	750 cfm	1
4	Service Water Pumps	Horiz. centrifugal, double suction	200 ft, 1,200 gpm	2
5	Closed Cycle Cooling Water Pumps	Horizontal, centrifugal	70 ft, 1,200 gpm	2
6	Fire Service Booster Pump	Two-stage horiz. centrifugal	250 ft, 1,200 gpm	1
7	Engine-Driven Fire Pump	Vertical turbine, diesel engine	350 ft, 1,000 gpm	1
8	Raw Water Pumps	SS, single suction	60 ft, 300 gpm	2
9	Filtered Water Pumps	SS, single suction	160 ft, 120 gpm	2
10	Filtered Water Tank	Vertical, cylindrical	15,000 gal	1
11	Makeup Demineralizer	Anion, cation, and mixed bed	70 gpm	2
12	Sour Water Stripper System	Vendor supplied	200,000 lb/h sour water	1
13	Liquid Waste Treatment System	Vendor supplied	400 gpm	1

ACCOUNT 4 GASIFIER AND ACCESSORIES

ACCOUNT 4A GASIFICATION

Equipment No.	Description	Type	Design Condition	Qty
1	Gasifier	Pressurized entrained bed/syngas cooler	2,500 std (dry-coal basis) @ 425 psia	2
2	Raw Gas Cooler Steam Generator	Fire tube boiler	1,500 psig/600°F 160.0 MMBtu/h	2
3	Raw Gas Cooler Steam Generator	Shell and tube	800 psig/518°F 163.3 MMBtu/h	2
4	Medium-Temperature Candle Filter	Sintered stainless	400 psia, 645°F	2
5	Flare Stack	Self-supporting, carbon steel, stainless steel top, pilot ignition	770,000 lb/h, medium-Btu gas	1

ACCOUNT 4B AIR SEPARATION PLANT

Equipment No.	Description	Type	Design Condition	Qty
1	Air Compressor	Centrifugal, multi-stage	75,000 scfm, 67 psia discharge pressure	2
2	Cold Box	Vendor supplied	2,200 ton/day O_2	1
3	Oxygen Compressor	Centrifugal, multi-stage	17,000 scfm, 600 psig discharge pressure	2
4	Liquid Oxygen Storage Tank	Vertical	60' dia x 80' vert	1

ACCOUNT 5 SYNGAS SHIFT AND CLEANUP

ACCOUNT 5A WATER-GAS SHIFT AND RAW GAS COOLING

Equipment No.	Description	Type	Design Condition	Qty
1	High Temperature Shift Reactor 1	Fixed bed	400 psia, 500°F	1
2	High Temperature Shift Reactor 2	Fixed bed	400 psia, 750°F	1
3	HP Steam Generator	Shell and tube	70×10^6 Btu/h @ 1700 psia and 613°F	1
4	IP Steam Generator	Shell and tube	45×10^6 Btu/h @ 800 psia and 518°F	1
5	LP Steam Generator	Shell and tube	30×10^6 Btu/h @ 200 psia and 382°F	1
6	Raw Gas Coolers	Shell and tube with condensate drain	100×10^6 Btu/h	2
7	Raw Gas Knock Out Drum	Vertical with mist eliminator	400 psia, 130°F	1

ACCOUNT 5B ACID GAS REMOVAL AND HYDROGEN PURIFICATION

Equipment No.	Description	Type	Design Condition	Qty
1	Amine Absorber 1	Column	90,000 scfm (4,400 acfm), 353 psia, 103°F	2
2	Amine Regenerator 1	Column	Vendor design	1
3	Sulfuric Acid Plant	Vendor design	61 tpd sulfuric acid	1
4	PSA Unit	Fixed bed	93 MMscfd H_2 @ 310 psia	1

ACCOUNT 6 COMBUSTION TURBINE/ACCESSORIES

Not applicable.

ACCOUNT 7 WASTE HEAT BOILER, DUCTING, AND STACK

Equipment No.	Description	Type	Design Condition Drums	Qty
1	Heat Recovery Steam Generator	Fired drum	1700 psig/1000°F 600,000 lb/h 200 x 10^6 Btu/h	1
2	Stack	Carbon steel plate, type 409 stainless steel liner	213 ft high x 28 ft dia.	1

ACCOUNT 8 STEAM TURBINE GENERATOR AND AUXILIARIES

Equipment No.	Description	Type	Design Condition (per each)	Qty
1	81 MW Steam Turbine Generator	TC2F26	1800 psig 1000°F/1000°F	1
2	Bearing Lube Oil Coolers	Plate and frame		2
3	Bearing Lube Oil Conditioner	Pressure filter closed loop		1
4	Control System	Digital electro-hydraulic	1600 psig	1
5	Generator Coolers	Plate and frame		2
6	Hydrogen Seal Oil System	Closed loop		1
7	Surface Condenser	Single pass, divided waterbox	880,000 lb/h steam @ 2.4 in. Hga	1
8	Condenser Vacuum Pumps	Rotary, water sealed	2500/25 scfm (hogging/holding)	2

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Design Condition (per each)	Qty
1	Circ. Water Pumps	Vertical wet pit	40,000 gpm @ 60 ft	2
2	Cooling Tower	Mechanical draft	100,000 gpm	1

ACCOUNT 10 ASH/SPENT SORBENT RECOVERY AND HANDLING

ACCOUNT 10A SLAG DEWATERING AND REMOVAL

Equipment No.	Description	Type	Design Condition	Qty
1	Slag Dewatering System	Vendor proprietary	205 tpd	1

3.4 CAPITAL AND OPERATING COSTS FOR HYDROGEN FROM WYODAK PRB COAL

The total plant cost for the plant producing 313 tons of hydrogen per day from Wyodak PRB coal is $364.6 million in 2001 dollars. The capital cost summary is included in Table 3-3.

Table 3-3
Capital Cost Summary – Hydrogen Production from Wyodak Coal

Client: DEPARTMENT OF ENERGY — Report Date: 03-Jun-2002 03:16 PM
Project: NETL H_2 Production Facility

TOTAL PLANT COST SUMMARY

Case: Sub-Bituminous H_2 Plant w/o CO_2 Capture
Plant Size: 259.2 H_2 TPD — Estimate Type: Conceptual — Cost Base (Dec) 2001 — ($X1000 & $X1000/TPD)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost $	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/TPD
1	COAL & SORBENT HANDLING	6,242	1,282	4,611	323		**$12,457**	997		1,345	**$14,799**	57
2	COAL & SORBENT PREP & FEED	10,581	1,539	5,776	404		**$18,299**	2,040		2,034	**$22,373**	86
3	FEEDWATER & MISC. BOP SYSTEMS	4,259	1,253	2,561	179		**$8,253**	660		891	**$9,804**	38
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E	54,709		23,270	1,629		**$79,607**	9,553		8,916	**$98,076**	378
4.2	Syngas Cooling	w/4.1		w/ 4.1	w/ 4.1			w/ 4.1		w/ 4.1		
4.3	ASU/Oxidant Compression	29,814		w/equip.			**$29,814**	2,385		3,220	**$35,419**	137
4.4-4.9	Other Gasification Equipment	7,665	5,742	5,067	355		**$18,829**	1,538		2,037	**$22,404**	86
	SUBTOTAL 4	*92,188*	*5,742*	*28,336*	*1,984*		***$128,250***	*13,476*		*14,173*	***$155,899***	*602*
5	HYDROGEN SEPARATION/GAS CLEAN	46,572	3,701	16,976	1,188		**$68,437**	8,005		7,644	**$84,086**	324
6	COMBUSTION TURBINE/ACCESSORIE											
6.1	Expander Turbine/Generator											
6.2-6.9	Combustion Turbine Accessories											
	SUBTOTAL 6											
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	4,533		551	39		**$5,123**	410		553	**$6,086**	23
7.2-7.9	HRSG Accessories, Ductwork and Stack	496	185	296	21		**$997**	80		108	**$1,185**	5
	SUBTOTAL 7	*5,029*	*185*	*847*	*59*		***$6,120***	*490*		*661*	***$7,271***	*28*
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	7,843		1,094	77		**$9,013**	721		973	**$10,707**	41
8.2-8.9	Turbine Plant Auxiliaries and Steam Pip	3,567	109	1,656	116		**$5,447**	436		588	**$6,471**	25
	SUBTOTAL 8	*11,409*	*109*	*2,749*	*192*		***$14,460***	*1,157*		*1,562*	***$17,178***	*66*
9	COOLING WATER SYSTEM	2,438	1,193	1,951	137		**$5,719**	458		618	**$6,795**	26
10	ASH/SPENT SORBENT HANDLING SYS	4,322	559	1,845	129		**$6,855**	745		760	**$8,360**	32
11	ACCESSORY ELECTRIC PLANT	4,974	2,052	4,028	282		**$11,335**	907		1,224	**$13,466**	52
12	INSTRUMENTATION & CONTROL	5,045	1,199	3,720	260		**$10,224**	818		1,104	**$12,146**	47
13	IMPROVEMENTS TO SITE	1,465	842	2,425	170		**$4,902**	392		529	**$5,824**	22
14	BUILDINGS & STRUCTURES		2,630	2,702	189		**$5,521**	442		596	**$6,559**	25
	TOTAL COST	**$194,524**	**$22,285**	**$78,527**	**$5,497**		**$300,832**	**$30,586**		**$33,142**	**$364,560**	**1407**

3.5 DETERMINATION OF COST OF HYDROGEN FROM WYODAK PRB COAL USING PRELIMINARY ASSUMPTIONS

For this economic analysis, the capital and operating costs for the two plants being evaluated have been upgraded to 2001 dollars. Coal cost has been estimated at $0.60 per MMBtu.

3.5.1 Approach to Cost Estimating

Economics in this report are stated primarily in terms of levelized cost of product, $/short ton ($/ton), or $/MMBtu. The cost of product is developed from the identified financial parameters in Table 3-4, and:

- Total capital requirement of the plant (TCR).
- Fixed operating and maintenance cost (fixed O&M).
- Non-fuel variable operating and maintenance costs (variable O&M).
- Consumables and byproducts costs and credits.
- Fuel costs.

Table 3-4
Operating Cost Data

OPERATING LABOR REQUIREMENTS		
BITUMINOUS H_2 PLANT W/O CO_2 CAPTURE		
Operating Labor Rate (base)	$26.15/hour	
Operating Labor Burden	30.00% of base	
Labor OH Charge Rate	25.00% of labor	
Operating Labor Requirements (OJ) per Shift		
Category	**1 Unit/Mod**	**Total Plant**
Skilled Operator	1.0	1.0
Operator	8.0	8.0
Foreman	1.0	1.0
Lab Techs, etc.	1.0	1.0
TOTAL – OJs	11.0	11.0

CONSUMABLES, BYPRODUCTS & FUELS DATA			
BITUMINOUS H_2 PLANT W/O CO_2 CAPTURE			
	Consumption		**Unit**
Item/Description	**Initial**	**/Day**	**Cost**
Water (/1,000 gal)		884	0.80
Chemicals			
Water Treatment (lb)	64,217	2,141	0.15
Limestone (ton)			16.25
Shift Catalyst (lb)	12,785	426.2	5.25
Amine (lb)	8,640	288.0	0.63
Other			
Supplemental Fuel (MMBtu)			
Purchased Power (MWh)			
LP Steam (/1,000 lb)			
Waste Disposal			
Sludge (ton)			
Slag (ton)		205	10.00
Byproducts & Emissions			
Sulfuric Acid (tons)		61	75.00
Excess Electric Generation (MWh)		1,004	30.00
Fuel (ton)		3,406	10.36

3.5.2 Production Costs (Operation and Maintenance)

The production costs for the plant consist of several broad categories of cost elements. These cost elements include operating labor, maintenance material and labor, administrative and support labor, consumables (water and water treating chemicals, solid waste disposal costs, byproducts such as power sales, and fuel costs). Note that production costs do not include capital charges and should not be confused with cost of product.

3.5.3 Consumables

Shift Catalyst:

- Change-out every 3 years
- 0.0045 pounds of catalyst per 1,000 standard cubic feet of hydrogen
- 210 tons initial charge
- 70 tons per year annual cost

Proprietary Amine:

- 12 pounds per hour
- 100,000 pounds per year

PSA Sorbent:

- Periodic change-out with scheduled maintenance

SO_2 Conversion Catalyst:

- Periodic change-out with scheduled maintenance

3.5.4 Byproduct Credits

The production of 61 tons of sulfuric acid per day is taken as a byproduct credit at $75 per ton.

3.5.5 Financial Assumptions

The cost of hydrogen was determined based on financial assumptions typically used by Parsons. These are summarized in Table 3-5.

Table 3-5
Financial Parameters

Levelized capacity factor	90%
Design/construction period	4 years
Plant startup date	January 2005
Land area/Unit cost	100 acres @ 41,500/acre
Project book life	20 years
Project tax life	20 years
Tax depreciation method	Accelerated based on ACRS class
Property tax rate	1.0% per year
Insurance tax rate	1.0% per year
Federal income tax rate	34.0%
State income tax rate	4.2%
Capital structure	
Common equity	20% @ 16.50% annum
Debt	80% @ 6.30% annum
Weighted cost of capital (after tax)	6.49%

3.5.6 Cost Results

Applying the financial parameters from Table 3-5, the cost of hydrogen was estimated to be \$6.44/MMBtu (\$2.20/Mcf) for Wyodak PRB coal. The results of the cost estimating activity are summarized in Table 3-6. These results were used as the price of hydrogen input to the DOE IGCC financial model. The results are shown in Appendix B.

Table 3-6

CAPITAL INVESTMENT & REVENUE REQUIREMENT SUMMARY

TITLE/DEFINITION

Case:	Sub-Bituminous H_2 Plant w/o CO_2 Capture		
Plant Size:	259.2 TPD-Synga	HeatRate:	(Btu/kWh)
Primary/Secondary Fuel(type):	Wyodak	Cost:	0.60 ($/MMBtu)
Design/Construction:	3 (years)	BookLife:	20 (years)
TPC(Plant Cost) Year:	2001 (Jan.)	TPI Year:	2005 (Jan.)
Capacity Factor:	90 (%)		

CAPITAL INVESTMENT		**$x1000**	**$x1000/$H_2$TPD**
Process Capital & Facilities		300,832	1160.8
Engineering(incl.C.M.,H.O.& Fee)		30,586	118.0
Process Contingency			
Project Contingency		33,142	127.9
TOTAL PLANT COST(TPC)		$364,560	1406.7
TOTAL CASH EXPENDED	$364,560		
AFDC	$23,376		
TOTAL PLANT INVESTMENT(TPI)		$387,936	1496.9
Royalty Allowance			
Preproduction Costs		9,096	35.1
Inventory Capital		2,102	8.1
Initial Catalyst & Chemicals(w/equip.)			
Land Cost		150	0.6
TOTAL CAPITAL REQUIREMENT(TCR)		$399,284	1540.7

OPERATING & MAINTENANCE COSTS (2001 Dollars)	**$x1000**	**$x1000/$H_2$TPD**
Operating Labor	3,276	12.6
Maintenance Labor	2,549	9.8
Maintenance Material	3,824	14.8
Administrative & Support Labor	1,456	5.6
TOTAL OPERATION & MAINTENANCE	$11,105	42.8
FIXED O & M		38.56
VARIABLE O & M		4.28

CONSUMABLE OPERATING COSTS,less Fuel (2001 Dollars)	**$x1000**	**$/T H_2-yr**
Water	232	2.73
Chemicals	897	10.54
Other Consumables		
Waste Disposal	674	7.91
TOTAL CONSUMABLE OPERATING COSTS	$1,803	21.18
BY-PRODUCT CREDITS (2001 Dollars)	($11,401)	-133.93
FUEL COST (2001 Dollars)	$11,587	136.11

	1st Year (2005 $)	Levelized (Over Book Life $)
PRODUCTION COST SUMMARY	**$/T H_2-yr**	**$/T H_2-yr**
Fixed O & M	117.40	117.40
Variable O & M	4.28	4.28
Consumables	21.18	21.18
By-product Credit/Penalty	-133.93	-133.93
Fuel	132.87	121.20
TOTAL PRODUCTION COST	141.81	130.14
	12,072	
LEVELIZED CARRYING CHARGES(Capital)		656.63
	55,900	
LEVELIZED(Over Book Life)COST/Ton of Syngas		786.76
Equivalent 1st.Yr.$/MSCF / Lev'd $/MMBtu	2.202	6.44