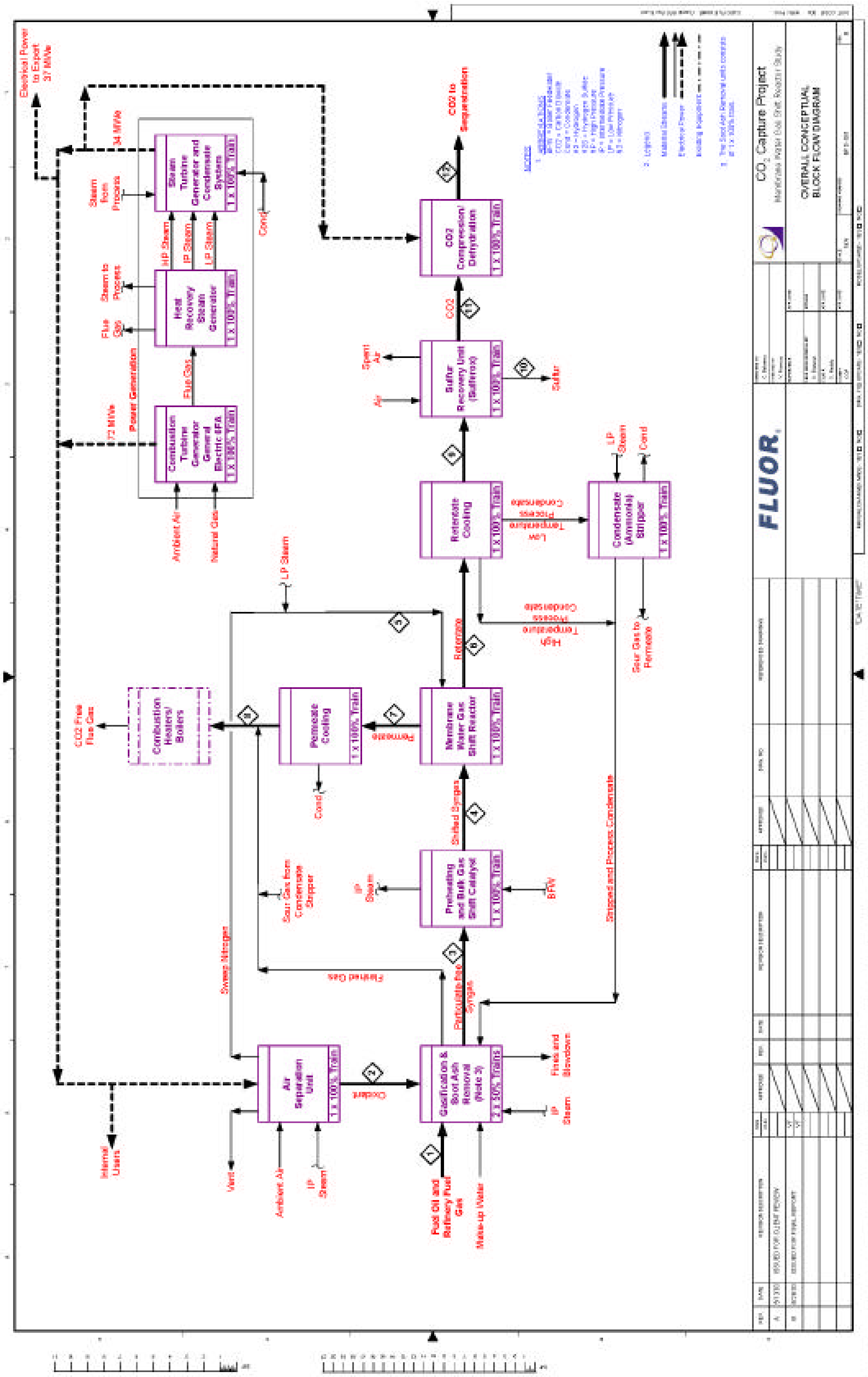

CO2 Capture Project
Manitoba Pyper Coal Shift Reactor Study
OVERALL CONCEPTUAL BLOCK FLOW DIAGRAM
FLUOR
Electrical Power to Export 37 MWe
34 MWe
72 MWe
Power Generation
Steam Turbine Generator and Condensate System
1 x 100% Train
Heat Recovery Steam Generator
Combustion Turbine Generator General Electric 6FA
Ambient Air
Natural Gas
HP Steam
IP Steam
LP Steam
Flue Gas
Steam to Process
Steam from Process
Cond
CO2 to Sequestration
CO2 Compression/ Dehydration
CO2
Sulfur Recovery Unit (Sulferox)
Spent Air
Air
Sulfur
Retentate Cooling
Low Temperature Process Condensate
Condensate (Ammonia) Stripper
LP Steam
High Temperature Process Condensate
Sour Gas to Permeate
Retentate
Membrane Water Gas Shift Reactor
Permeate
Permeate Cooling
Combustion Heaters/ Boilers
CO2 Free Flue Gas
Sweep Nitrogen
Sour Gas from Condensate Stripper
Shifted Syngas
Preheating and Bulk Gas Shift Catalyst
IP Steam
BFW
Stripped and Process Condensate
Flashed Gas
Particulate-free Syngas
Air Separation Unit
Oxidant
Gasification & Soot Ash Removal (Note 3)
2 x 50% Trains
Fines and Blowdown
IP Steam
Fuel Oil and Refinery Fuel Gas
Make-up Water
Internal Users
Vent
Ambient Air
IP Steam
Notes
2. Legend
Material Streams
Electrical Power
Existing Equipment
ISSUED FOR CLIENT REVIEW
ISSUED FOR FINAL REPORT

Table 5-2 – Overall Heat and Material Balance (Total Plant Basis)

Stream Description		Fuel Gas and Fuel Oil to Gasification Island		Oxygen from Air Separation Unit to Gasification Island		Syngas from Gasification Island to Preheating and Bulk Gas Shift Catalyst		Shifted Syngas To Membrane Water Gas Shift Reactor		Sweep Gas to Membrane Water Gas Shift Reactor	
Stream Number		1		2		3		4		5	
Temperature, °C		93		29		207		315		315	
Pressure, bars		39.4		49.0		37.8		35.0		3.0	
Component Flows	MW	kgmol/hr	mol %	kgmol/hr	mol %	kgmol/hr	mol %	kgmol/hr	mol %	kgmol/hr	mol %
CH4	16.04	1,571	67.8%	0	0.0%	2	0.0%	2	0.0%	0	0.0%
H2O	18.02	0	0.0%	0	0.0%	13,449	51.1%	9,313	35.4%	8,800	49.2%
CO2	44.01	47	2.0%	0	0.0%	673	2.6%	4,809	18.3%	0	0.0%
H2	2.02	182	7.9%	0	0.0%	7,010	26.6%	11,145	42.3%	0	0.0%
N2	28.02	18	0.8%	8	0.2%	35	0.1%	35	0.1%	9,100	50.8%
CO	28.01	0	0.0%	0	0.0%	5,131	19.5%	995	3.8%	0	0.0%
H2S	34.08	2	0.1%	0	0.0%	18	0.1%	19	0.1%	0	0.0%
COS	60.07	0	0.0%	0	0.0%	1	0.0%	0	0.0%	0	0.0%
NH3	17.03	0	0.0%	0	0.0%	3	0.0%	3	0.0%	0	0.0%
AR	39.95	0	0.0%	8	0.2%	8	0.0%	8	0.0%	0	0.0%
O2	32.00	0	0.0%	3,237	99.5%	0	0.0%	0	0.0%	0	0.0%
C2H6	30.07	219	9.4%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
C3H8	44.09	172	7.4%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
C4H10	58.12	98	4.2%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
C5H12	72.14	8	0.4%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total kgmol/hr		2,318	100.0%	3,254	100.0%	26,330	100.0%	26,330	100.0%	17,900	100.0%
Total kg/hr (solids not included)		48,657		552		431,805		431,805		413,514	
Molecular Weight		21.00		0.17		16.40		16.40		23.10	
Density, kg/m3		28.3		63.2		16.1		11.8		1.4	
Liquid Flow, m3/hr		-		-		-		-		-	
Vapor Flow, m3/hr		1,717		9		26,820		36,594		295,367	
Solids, kg/hr		39,384		-		-		-		-	

Table 5-2 – Overall Heat and Material Balance (Continued)
(Total Plant Basis)

Stream Description		Retentate from Membrane Water Gas Shift Reactor to Cooling		Permeate from Membrane Water Gas Shift Reactor to Cooling		Hydrogen Rich Fuel Gas to Existing Heaters/Boilers		Cooled Retentate to Sulfur Recovery Unit		Sulfur Product	
Stream Number		6		7		8		9		10	
Temperature, °C		328		347		41		35		50	
Pressure, bara		35.0		3.0		2.1		31.6		1.0	
Component Flows	MW	kgmol/hr	mol %	kgmol/hr	mol %	kgmol/hr	mol %	kgmol/hr	mol %	kgmol/hr	mol %
CH4	16.04	2	0.0%	0	0.0%	0	0.0%	2	0.0%	0	0.0%
H2O	18.02	8,333	56.3%	8,800	29.9%	711	3.3%	16	0.3%	21	54.1%
CO2	44.01	5,789	39.1%	0	0.0%	39	0.2%	5,751	89.5%	0	0.0%
H2	2.02	584	3.9%	11,541	39.2%	11,542	53.9%	584	9.1%	0	0.0%
N2	28.02	35	0.2%	9,100	30.9%	9,100	42.5%	35	0.5%	0	0.0%
CO	28.01	15	0.1%	0	0.0%	1	0.0%	15	0.2%	0	0.0%
H2S	34.08	19	0.1%	0	0.0%	1	0.0%	19	0.3%	0	0.0%
COS	60.07	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
NH3	17.03	3	0.0%	0	0.0%	3	0.0%	0	0.0%	0	0.0%
AR	39.95	8	0.1%	0	0.0%	0	0.0%	8	0.1%	0	0.0%
Sulfur	32.06	0	0.0%	0	0.0%	0	0.0%	0	0.0%	18	45.9%
Total kgmol/hr		14,789	100.0%	29,441	100.0%	21,396	100.0%	6,429	100.0%	39	100.0%
Total kg/hr		408,545		436,781		292,860		256,953		960	
Molecular Weight		27.63		14.84		13.69		39.97		24.46	
Density, kg/m3		20.0		0.9		1.1		56.1		-	
Liquid Flow, m3/hr		-		-		-		-		-	
Vapor Flow, m3/hr		20,427		485,313		270,141		4,580		-	

Table 5-2 – Overall Heat and Material Balance (Continued)
(Total Plant Basis)

Stream Description		CO2 Product from Sulferox Unit to CO2 Compressor/Dehydration		CO2 Product to Sequestration				
Stream Number		11		12				
Temperature, °C		68		30				
Pressure, bara		30.6		80.0				
Component Flows	MW	kgmol/hr	mol %	kgmol/hr	mol %			
CH4	16.04	2	0.0%	2	0.0%			
H2O	18.02	70	1.1%	0	0.0%			
CO2	44.01	5,738	89.0%	5,738	89.9%			
H2	2.02	583	9.0%	583	9.1%			
N2	28.02	35	0.5%	35	0.5%			
CO	28.01	15	0.2%	15	0.2%			
H2S	34.08	0	0.0%	0	0.0%			
COS	60.07	0	0.0%	0	0.0%			
NH3	17.03	0	0.0%	0	0.0%			
AR	39.95	8	0.1%	8	0.1%			
Total kgmol/hr		6,450	100.0%	6,380	100.0%			
Total kg/hr		256,683		255,424				
Molecular Weight		39.80		40.04				
Density, kg/m3		47.2		213.2				
Liquid Flow, m3/hr		-		-				
Vapor Flow, m3/hr		5,438		1,198				

5.1 Air Separation Unit

The purpose of the Air Separation Unit (ASU) is to provide high purity oxygen (99.5 mol%) for gasification and nitrogen as sweep gas to the Membrane Water Gas Shift (MWGS) Reactor. The oxygen and nitrogen are produced from ambient air and compressed to the pressures required by the process units. The unit consists of one 100% train and is considered a package unit, which is supplied by a vendor. The following is a description of a typical ASU plant.

Ambient air is compressed in a compressor intercooled with cooling water. Residual water vapor, carbon dioxide and other atmospheric contaminants are removed from the air in a molecular sieve adsorber. (Intermediate Pressure (IP) steam is used for regeneration.) The dry air is further compressed and sent to the cold box where oxygen and nitrogen are separated at cryogenic temperatures.

Gaseous oxygen exits the cold box (at low pressure) and is compressed with intercooling provided by cooling water. The pressurized gaseous oxygen is fed to the gasifiers.

The nitrogen from the low pressure cold box is also routed to a dedicated compressor. The compressed nitrogen is sent to the MWGS reactor for sweep gas (to lower the hydrogen partial pressure on the permeate side of the membrane thus promoting hydrogen transport). Excess nitrogen is vented from the cold box.

The ASU also supplies the plant and instrument (P&I) air to the gasification plant. In the event the P&I air is not available from the ASU, a back-up P&I air system is provided in the utility systems.

5.2 Gasification Island

The purpose of the Gasification Island (GI) is to produce raw syngas from residual fuel oil and refinery fuel gas gasified with high purity oxygen in a low pressure total quench gasifier. The unit consists of two 50% trains and is considered a package unit. The following is a process description for a typical Gasification Island.

Residual fuel oil and refinery fuel gas with Intermediate Pressure (IP) steam are fed to the GI where they are partially oxidized with high purity oxygen supplied by the Air Separation Unit. The resulting raw syngas is primarily a mixture of hydrogen and carbon monoxide with smaller quantities of nitrogen, water vapor, carbon dioxide, hydrogen sulfide, carbonyl sulfide, methane, and argon. The raw syngas is then cooled by quenching in water in the gasifier quench chamber. Particulates entrained in the raw syngas are removed via wet scrubbing, and the syngas is routed to the Preheating and Bulk Gas Shift Catalyst unit. The particulates exit the GI as fines for disposal and wastewater from the unit is also sent offsite for disposal.

Flashed gas from the water treating area in the GI is combined with the hydrogen rich fuel to the existing combustion heaters/boilers. Process condensate from gas cooling is returned to the GI for syngas scrubbing, and make-up water is supplied to maintain the GI water balance.

5.3 Preheating and Bulk Gas Shift Catalyst Unit

The purpose of the Preheating and Bulk Gas Shift Catalyst Unit is to convert the majority of the carbon monoxide and water existing in the syngas from the Gasification Island (GI) to carbon dioxide and hydrogen via the following reaction:

$$CO + H_2O \leftrightarrow H_2 + CO_2 \text{ (shift reaction)}$$

By converting approximately 80% of the carbon monoxide prior to the Membrane Water Gas Shift (MWGS) reactor, the amount of carbon dioxide recovered in the MWGS reactor is maximized. The ideal process disposition for the high temperature shift reactor is immediately after the GI because the syngas is fully saturated with sufficient water for the shift reaction.

The process configuration for the Preheating and Bulk Gas Shift Catalyst unit is shown in the Process Schematic (DWG-001) in Section 6, and corresponding stream data are shown in Section 7. This unit consists of one 100% train.

The feed to the unit is a particulate-free, raw syngas from the GI. The raw syngas enters the Shift Reactors Unit saturated with water at 207°C and 37.8 bara. A Shift Feed/Effluent Exchanger preheats the syngas to 288°C. A Start-up Heater is required to provide initial heat to a partial flow of syngas using High Pressure (HP) steam. This initial heat is necessary to preheat the gas to the desired temperature of operation of the catalyst during start-up.

The syngas enters the Bulk Shift Reactor and, due to the exothermic nature of the shift reaction, exits at 453°C. Sweep gas to the MWGS reactor is preheated by cooling the shift effluent to 352°C in the Sweep Gas Heater. Further cooling of the syngas to 315°C is accomplished by producing Intermediate Pressure (IP) steam in the Shift IP Steam Generator. Preheated IP Boiler Feedwater (BFW) at 197°C is fed to the Shift IP Steam Drum and saturated steam at 29.9 bara and blowdown are produced.

The shifted syngas is sent to the MWGS Reactor unit for further shifting and separation of hydrogen and carbon dioxide.

5.4 Membrane Water Gas Shift Reactor

The purpose of the Membrane Water Gas Shift (MWGS) Reactor is to convert the remaining carbon monoxide and water in the syngas from the Bulk Gas Shift Catalyst unit to carbon dioxide and hydrogen via the shift reaction. The hydrogen is then separated from the carbon dioxide by selective permeation of the hydrogen through the membrane. See Section 3.0 for details on the MWGS Reactor.

The MWGS Reactor unit is shown in the Process Schematic (DWG-001) in Section 6, and corresponding stream data are shown in Section 7. This unit consists of one 100% train.

The feed to the unit is a shifted syngas at 315°C and 35.0 bara. Nitrogen from the Air Separation Unit is combined with superheated Low Pressure steam for the sweep gas, which is preheated against the effluent from the Bulk Shift Reactor to 315°C before entering the MWGS reactor.

The permeate (hydrogen rich stream) leaves the MWGS reactor at 347°C and 3.0 bara and is routed to the Permeate Cooling unit. The retentate (carbon dioxide rich stream) leaves the MWGS reactor at 328°C and 35.0 bara and is cooled to 209°C against the feed to the Bulk Shift Reactor. The retentate is then further cooled to 205°C in the Shift Intermediate Pressure (IP) Boiler Feedwater (BFW) Heater by heating IP BFW from 151°C to 197°C before the water is fed to the Shift IP Steam Drum. The condensate in the cooled retentate is separated from the gas in the Retentate Knock-out Drum #1 and is routed to the Stripped Condensate Drum. The resulting gas is routed to the Retentate Cooling unit.

5.5 Permeate Cooling Unit

The purpose of the Permeate Cooling Unit is to cool the permeate so that the excess moisture resulting from the sweep gas is condensed and removed providing a hydrogen rich fuel with a lower heating value greater than 5.9 MJ/Nm^3 (150 Btu/SCF (LHV)).

The process configuration for the Permeate Cooling Unit is shown in the Process Schematic (DWG-002) in Section 6, and corresponding stream data are shown in Section 7. The unit consists of one 100% train.

The permeate from the Membrane Water Gas Shift (MWGS) Reactor is cooled to 162°C by generating Low Pressure (LP) Steam, at 4.8 bara, in the Permeate LP Steam Generator. LP Boiler Feedwater (BFW) from the Deaerator is sent to the Permeate LP Steam Drum and saturated LP steam and blowdown are produced.

The cooled permeate is then routed to the Permeate Air Cooler where the gas is cooled to 60°C. The condensate formed is separated from the gas in Permeate Knock-out Drum #1. The dry permeate is then cooled to 35°C with cooling water in the Permeate Trim Cooler. The resulting condensate is separated from the gas in Permeate Knock-out Drum #2 and combined with the condensate from the first permeate knock-out drum in the Permeate Condensate Drum. The condensate is relatively free of contaminants; and therefore, is combined with vacuum condensate from the combined cycle by the Permeate Condensate Pump.

The cooled permeate is combined with the flash gas from the Permeate Condensate Drum, flashed gas from the Gasification Island, stripper overhead from the Condensate Stripper and flashed gas from the Stripped Condensate Drum and routed to the existing heaters/boilers (battery limits). The resulting flue gas from the combustion of the hydrogen rich fuel has a low carbon dioxide content.

5.6 Retentate Cooling Unit

The purpose of the Retentate Cooling Unit is to cool the retentate from the Membrane Water Gas Shift (MWGS) Reactor to a suitable temperature for the Sulfur Recovery Unit.

The process configuration for the Retentate Cooling Unit is shown in the Process Schematic (DWG-002) in Section 6, and corresponding stream data are shown in Section 7. The unit consists of one 100% train.

The retentate from the Retentate Knockout Drum #1 is cooled to 162°C by generating Low Pressure (LP) Steam, at 4.8 bara, in the Retentate LP Steam Generator. LP Boiler Feedwater (BFW) from the Deaerator is sent to the Retentate LP Steam Drum and saturated LP steam and blowdown are produced. Condensate from the retentate is separated in the Retentate Knock-out Drum #2.

The dry, cooled retentate is then routed to the Vacuum Condensate Heater where the gas is cooled to 52°C by heating vacuum condensate and condensate from the cooling of permeate from 40°C to 148°C, which is routed to the Deaerator. The condensate formed is separated from the gas in Retentate Knock-out Drum #3. The dry retentate is then cooled to 35°C with cooling water in the Retentate Trim Cooler. Condensate is separated in Retentate Knock-out Drum #4 and combined with the condensate from knock-out drums #2 and #3 and routed to the Stripper Feed Drum.

The condensate produced from the cooling of the retentate is ultimately returned to the Gasification Island (GI) for syngas scrubbing. However, the condensate contains ammonia from the gasifier and to avoid build-up of ammonia in the scrubbing water, the ammonia is removed from the condensate before the water is returned to the GI. The majority of the ammonia condenses from the gas at low temperatures; therefore, to minimize the size of the Condensate Stripper, only the water condensed at low temperatures is fed to the stripper while the water condensed at higher temperatures can by-pass the stripper and be returned directly to the GI.

The cooled retentate (carbon dioxide rich stream) is routed to the Sulfur Recovery Unit.

5.7 Condensate (Ammonia) Stripper Unit

The purpose of the Condensate (Ammonia) Stripper Unit is to remove ammonia, carbon dioxide and hydrogen sulfide present in the condensate produced in the Retentate Cooling Unit. The water is recycled back to the Gasification Island (GI) to minimize fresh water make-up to the system. Condensate stripping is provided to prevent the build up of ammonia in the syngas scrubbing section of the GI.

The condensate streams contain equilibrium concentrations of dissolved gases, which increase as the temperature of the streams decrease. Therefore, the lower temperature (cold) condensate is collected and sent to the condensate stripper for removal of ammonia.

The process configuration for the Condensate Stripper Unit is shown in the Process Schematic (DWG-003) in Section 6, and corresponding stream data are shown in Section 7. The unit consists of one 100% train.

The feed to the condensate stripper is the cold condensate from Retentate Knock-out Drums #2, #3 & #4. The condensate streams are collected in the Stripper Feed Drum. A minor (normally no flow) stream from the Sulfur Recovery Unit is also routed to the feed drum. Flash gas from the feed drum is sent to the overhead of the Condensate Stripper.

The condensate from the feed drum is routed to the top section of the Condensate Stripper (trayed column) where it is stripped by steam from the Stripper Reboiler. The stripped condensate exits the bottom of the condensate stripper and is routed to the Stripped Condensate Drum.

The Stripper Reboiler uses Low Pressure (LP) steam to generate stripping steam at 126°C for the column. The steam condensate is routed to the Stripper LP Condensate Pot and then returned to the steam system.

Most of the dissolved gases are removed from the condensate and sent overhead in the column. The overhead is cooled against cooling water in the Stripper Condenser, and the non-condensing sour gas from the Stripper Reflux Drum is combined with cooled permeate and sent to the existing fuel system. The liquid from the drum is routed by the Stripper Reflux Pump to the top of the stripper.

In addition to stripped condensate, hot temperature condensate from the Retentate Knock-out Drum #1 is also sent to the Stripped Condensate Drum. The total condensate is then returned to the GI syngas scrubber via the Stripped Condensate Pump. The temperature of this stream is 127°C. The flashed gas from this drum is also combined with the permeate stream and sent to the existing fuel system.

5.8 Sulfur Recovery (Sulferox) Unit

The purpose of the Sulfur Recovery Unit is to remove sulfur compounds from the cooled retentate stream. The unit is based on SulFerox® Process Technology, which uses a nonvolatile, aqueous solution of an iron chelate to covert gaseous hydrogen sulfide to solid elemental sulfur. The unit consists of one 100% train and is a packaged unit that is supplied by a vendor (Westfield Engineering & Services). The following is a description of a typical Sulferox plant.

The retentate with a content of 0.3 mol% of hydrogen sulfide is mixed with the SulFerox® solution (containing Fe^{+++}) by bubbling the gas up through the solution where the hydrogen sulfide is converted to elemental sulfur. The elemental sulfur drops into the liquid phase; thereby sweetening the gas and forming spent solution (containing Fe++). Air is then bubbled up through the spent solution which regenerates the solution (now contains Fe+++). The air and regenerated solution is sent to a settler where the air is vented and the sulfur agglomerates and settles. Clarified regenerated solution is pumped back to the gas/liquid contactor. Thickened sulfur from the settler is filtered, the sulfur product is removed and the cleaned filtrate is returned to the circulating loop.

5.9 CO2 Compression/Dehydration Unit

The purpose of the CO_2 Compression/Dehydration Unit is to compress and remove moisture in the product carbon dioxide stream. The process configuration for the unit is shown in the Process Schematic (DWG-004) in Section 6, and corresponding stream data are shown in Section 7. The unit consists of one 100% train.

The feed to the CO_2 Compression/Dehydration Unit is the sulfur free retentate from the Sulfur Recovery Unit. The carbon dioxide stream is cooled to 35°C with cooling water in the CO_2 Compressor Precooler. Any condensate formed is removed and routed to the Blowdown Sump. The stream is then compressed in the CO_2 Compressor Package to the required pressure and temperature of 80 bara and 30°C. At an interstage pressure of 49.6 bara, the compressed carbon dioxide is sent to a dryer package, which reduces the moisture level down to a –40°C dew point. Interstage and after-stage cooling are also provided by cooling water.

The carbon dioxide product is then sent for sequestration for Enhanced Oil Recovery (EOR) (battery limits).

5.10 Natural Gas Fired Combined Cycle

The purpose of the Natural Gas Fired Combined Cycle is to produce electrical power from a combustion turbine and steam turbine for consumers in the entire plant. To provide sufficient electrical power for plant users and minimize electrical power export, a General Electric (GE) Frame 6FA combustion turbine was utilized.

The process configuration for the Natural Gas Fired Combined Cycle is shown in the Process Schematics (DWG-005 & 006) in Section 6, and corresponding stream data are shown in Section 7. The unit consists of one 100% train.

Natural gas is heated to 185°C against Intermediate Pressure (IP) Boiler Feedwater (BFW) in the Fuel Gas Heater and fed to the Combustion Turbine (CT) Generator. Ambient air is compressed and combusted with the natural gas then expanded in the CT to produce 72 MWe.

The exhaust from the combustion turbine at 592°C is routed to a Heat Recovery Steam Generator (HRSG). The HRSG consists of the following coils (in the order of flue gas flow):

- High Pressure (HP) Steam Superheater II
- Reheater II
- HP Steam Superheater I
- Reheater I
- HP Steam Evaporator
- Intermediate Pressure (IP) Steam Superheater
- HP Boiler Feedwater (BFW) Economizer II
- IP Steam Evaporator
- Low Pressure (LP) Steam Superheater
- HP BFW Economizer I in parallel with IP BFW Economizer
- LP Steam Evaporator

At the exit of the HRSG, the flue gas enters the stack at 162°C. The steam balance showing steam consumers and producers is provided in Section 6.

5.10.1 High Pressure Steam/Boiler Feedwater

BFW from the Deaerator at 142°C is routed by the Boiler Feedwater Pump to the LP Steam Evaporator. The preheated BFW at 151°C is then sent by the HP/IP Feedwater Pump to the HP BFW Economizer I coil where it is heated 216°C. The HP BFW (94,038 kg/hr) is then heated to 313°C in the HP BFW Economizer II coil and sent to the HP Steam Evaporator, where saturated HP steam is produced at 118 barg and 324°C. HP blowdown (flow rate set to 2% of the HP steam produced in the evaporator) is routed to the IP steam drum.

Saturated HP Steam (92,194 kg/hr) is heated to 510°C in the HP Steam Superheater I and HP Steam Superheater II coils and routed to the steam turbine.

5.10.2 Intermediate Pressure Steam/BFW

A portion of the IP BFW from the HP/IP Boiler Feedwater Pump is routed to the Shift IP BFW Heater while the remaining flow is sent to the IP BFW Economizer coil where it is heated to 189°C. The IP BFW is divided and a fraction of the flow is routed to the Fuel Gas Heater while the rest is sent to the IP Steam Evaporator. Saturated IP steam is produced at 30.3 barg and 236°C, and IP blowdown (flow rate set to 2% of the IP steam produced in the evaporator) is routed to the LP steam drum. Saturated IP Steam (11,305 kg/hr) is combined with IP steam (18,023 kg/hr) produced in the Shift IP Steam Generator and steam (5,268 kg/hr) required for the Air Separation Unit is extracted from the IP steam header. The net IP steam produced is then heated to 260°C in the IP Steam Superheater coil and combined with steam from the HP stage of the steam turbine. The combined IP steam (89,732 kg/hr) is heated to 509°C in Reheater I and Reheater II coils and routed to the steam turbine.

5.10.3 Low Pressure Steam/BFW

LP BFW from the Deaerator is sent to the Permeate Cooling Unit (80,220 kg/hr), Retentate Cooling Unit (118,867 kg/hr) and LP Steam Evaporator (139, 112 kg/hr) where steam is produced at 3.8 barg. LP steam is used for BFW deaeration and in the Sulfur Recovery Unit (3,967 kg/hr), Condensate Stripper (18,790 kg/hr) and Wastewater Stripping (5,831 kg/hr) for regeneration and reboilers. The steam condensate from process users is routed to the deaerator.

Excess LP steam (166,959 kg/hr) is superheated to 210°C in the LP steam superheater coil. The majority of the steam (158,505 kg/hr) is routed to the Membrane Water Gas Shift (MWGS) reactor for sweep gas while the remaining portion is sent to the steam turbine.

5.10.4 Blowdown

To control the amount of solids in the steam drums, continuous blowdown is extracted from the LP steam drum in the HRSG and the steam drums in the process units and routed to the Blowdown Drum. Streams also fed to the Blowdown Drum include the HP, IP and LP intermittent blowdown from the HRSG steam drums. The liquid streams are all flashed at atmospheric pressure. The resulting vapor is vented to the atmosphere and the condensate is sent to the Cooling Tower Basin.

5.10.5 Deaerator

A deaerator is provided for the HRSG and operates at 2.8 barg. The deaerator removes any dissolved gases such as oxygen and carbon dioxide from the BFW make-up (demineralized water), vacuum condensate (from the surface condenser and preheated) and return condensate from the LP steam process users via LP stripping steam (7,451 kg/hr) generated in the HRSG and process units. The deaerator also provides a surge capacity for the BFW pumps.

5.10.6 Boiler Chemical Injection

The Boiler Chemical Injection System, includes an oxygen scavenger, amine solution and phosphate solution. The oxygen scavenger is injected into the deaerator to remove trace amounts of dissolved oxygen in the BFW. The amine solution is injected into the suction line of the BFW pumps as a preventative measure to neutralize carbonic acid that can form as result of any carbon dioxide present in the system. The phosphate solution is injected into the steam drums to minimize the formation of mineral scale in the boiler tubes.

The superheated HP steam at 109 barg and 507°C is fed to the Steam Turbine (ST) Generator to generate electrical power. Steam (25,600 kg/hr) is extracted from the HP stage for the Gasification Island. Steam from the HP stage exhaust is combined with superheated IP steam and reheated then fed to the IP section of the ST. Superheated LP steam is injected into the ST, which produces a net electrical power output of 34 MWe.

The steam and condensate from the steam turbine is sent to the Surface Condenser where the steam is condensed at -0.9 barg against cooling water. A Vacuum Condensate Pump transfers the vacuum condensate to the deaerator after preheating.

Process condensate from the Permeate Cooling Unit is combined with the vacuum condensate, heated to 148°C, combined with demineralized make-up water and routed to the deaerator.

5.11 Utilities & Supporting Systems

The utilities and support systems for the plant consist of the necessary general facilities to allow for the plant to operate as a stand-alone complex. Brief descriptions for selected systems are provided below.

- Natural gas supply – natural gas for the combined cycle is provided.
- Demineralized water package – demineralized water consists of 2x100% mixed-bed exchangers, one in operation and one in stand-by, filled with cation/anion resins, with internal-type regeneration. The package includes facilities for resin bed regeneration, chemical storage and neutralization basin.
- Cooling water package – cooling water is provided to the plant via a circulating loop and cooling towers. A closed circulating water loop is provided for cooling of the combustion turbine and steam turbine generators and combustion turbine auxiliary system.
- Potable water – water for personnel use is provided by a package, which adjusts the pH and sterilizes the water.
- Oily water separator - oily water from all process units is collected in the oily water sump, which separates the oil from the water by a corrugated plate oil/water separator. Contaminated storm water is also sent to the oily water sump for treatment.
- Fire protection and monitoring systems (firewater is supplied by the existing plant)
- Back-up plant and instrument air package – plant and instrument air is provided in the event the Air Separation Unit is down.
- Wastewater treatment package – waste water is collected and discharged from the plant. Storm water is also collected and oil is removed (if required) before being discharged for disposal. A sanitary waste water treating unit is included in this package.

- Flare – the flare system consists of collection headers for the process unit relief gases and a system of knockout drums prior to safe disposal in an elevated flare.
- Miscellaneous material (e.g. fines and sulfur) handling (unloading and loading facilities)
- Electric power distribution
- Uninterruptible power supply (UPS)
- Generator step-up transformer
- Continuous emissions monitoring (CEMS)
- Distributed control system (DCS)
- Interconnecting piping
- Other supporting facilities (e.g. Process analyzers; Hazardous gas detection system; Communications; Control room; Maintenance, warehouse and administration facility; Laboratory for inspection, certification and process control; Turbine building; Overhead turbine crane; Heating, ventilation and air conditioning (HVAC) systems; and Roads, parking, fencing and lighting)

6.0 PROCESS SCHEMATICS

Attached in this section are the process schematics for the CCP Membrane Water Gas Shift Reactor Study, Phase I. The purpose of the process schematics is to show the functionality of the equipment so that a third party can size and determine cost of the equipment (using the corresponding heat and material balance in section 7.0). The level of detail for the schematics are below that for Process Flow Diagrams.

Number	Title
DWG-001	Membrane Water Gas Shift Reactor
DWG-002	Gas Cooling
DWG-003	Condensate Stripping
DWG-004	Sulfur Recovery and CO_2 Compression
DWG-005	Combustion Turbine Generator and Heat Recovery Steam Generator
DWG-006	Steam Turbine Generator
	Steam Balance Diagram