Liquid CO_2/Coal Slurry for Feeding Low Rank Coal to Gasifiers

Final Technical Report

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Abstract

This study investigates the practicality of using a liquid CO_2/coal slurry preparation and feed system for the E-Gas™ gasifier in an integrated gasification combined cycle (IGCC) electric power generation plant configuration.

Liquid CO_2 has several property differences from water that make it attractive for the coal slurries used in coal gasification-based power plants. First, the viscosity of liquid CO_2 is much lower than water. This means it should take less energy to pump liquid CO_2 through a pipe compared to water. This also means that a higher solids concentration can be fed to the gasifier, which should decrease the heat requirement needed to vaporize the slurry. Second, the heat of vaporization of liquid CO_2 is about 80% lower than water. This means that less heat from the gasification reactions is needed to vaporize the slurry. This should result in less oxygen needed to achieve a given gasifier temperature. And third, the surface tension of liquid CO_2 is about 2 orders of magnitude lower than water, which should result in finer atomization of the liquid CO_2 slurry, faster reaction times between the oxygen and coal particles, and better carbon conversion at the same gasifier temperature. EPRI and others have recognized the potential that liquid CO_2 has in improving the performance of an IGCC plant and have previously conducted systems-level analyses to evaluate this concept. These past studies have shown that a significant increase in IGCC performance can be achieved with liquid CO_2 over water with certain gasifiers.

Although these previous analyses had produced some positive results, they were still based on various assumptions for liquid CO_2/coal slurry properties. This low-rank coal study extends the existing knowledge base to evaluate the liquid CO_2/coal slurry concept on an E-Gas™-based IGCC plant with full 90% CO_2 capture. The overall objective is to determine if this technology could be used to reduce the cost and improve the efficiency of IGCC plants. The study goes beyond the systems-level analyses and initial lab work that formed the bases of previous studies and includes the following tasks: performing laboratory tests to quantify slurry properties; developing an engineering design of a liquid CO_2 slurry preparation and feed system; conducting a full IGCC plant techno-economic analysis for Powder River Basin (PRB) coal and North Dakota lignite in both water and liquid CO_2 slurries; and identifying a technology development plan to continue the due diligence to conduct a comprehensive evaluation of this technology.

The initial task included rheology tests and slurry data analyses that would increase the knowledge and understanding of maximum solids loading capability for both PRB and lignite. Higher coal concentrations have been verified in liquid CO_2 over water slurries, and a coal concentration of 75% by weight in liquid CO_2 has been estimated to be achievable in a commercial application. In addition, lower slurry viscosities have been verified in liquid CO_2 at the same solids loading, where the liquid CO_2/coal slurry viscosity has been measured to be about a factor of 10 lower than the comparable water slurry and estimated to be less than 100 centipoise in a commercial application.

In the following task, an engineering design of a liquid CO_2/coal slurry preparation and mixing system has been developed for both a batch and continuous system. The capital cost of the design has also been estimated so that it could be used in the economic analysis. An industry search and survey has been conducted to determine if essential components required to construct the feed system are available from commercial sources or if targeted R&D efforts are required. The search and survey concluded that commercial sources are available for selected components that comprise both the batch and continuous type systems.

During normal operation, the fuel exits the bottom of the coal silo and is fed to a rod mill for grinding to the desired particle size. From the rod mill, the coal is transported in a dense phase pneumatic transport system to the top of a solids heat exchanger, wherein the ground coal is chilled to a low temperature (in the range of -23.3°C (-10°F)) prior to mixing with liquid CO_2. This temperature was selected based on evaluating trade-offs between refrigeration work and the cost of the system pressure boundary at various combinations of pressure and temperature that correspond to the gas/liquid phase boundary for CO_2. Electrical loads to drive the equipment comprising the liquid CO_2 feed system are significantly greater than those for a water slurry system, and this effect has been captured in the technical performance analysis.

In the next task, a plant-wide techno-economic analysis has been conducted for PRB coal and lignite in both liquid CO_2 and water slurry feed. The IGCC cases using a liquid CO_2 slurry system show reduced plant output and higher heat rate for PRB coal and for ND lignite at 90% CO_2 capture. Some of these performance differences can be attributed to the higher requirement for steam for the liquid CO_2 slurry cases to drive the water-gas shift reaction, thereby reducing steam turbine power generation. Other factors contributing to the calculated performance differences are the increase in parasitic loads attributable to refrigeration to produce liquid CO_2 and chilled coal and the reduction in enthalpy of the inlet streams to the gasifier associated with the low temperature liquid CO_2 slurry feed.

The capital costs for the complete plant are slightly higher for the liquid CO_2 slurry cases for PRB coal but somewhat reduced for ND lignite relative to the corresponding water slurry cases. Differences in dollar/kWe costs are higher for both coals due to the reduction in net output. The cost of electricity computed for the liquid CO_2/coal slurry cases is greater for both PRB and ND Lignite coals. It does not appear that there is any benefit to using liquid CO_2/coal slurries for feeding low rank coals to the E-Gas™ gasifier. Any incidental benefits in improved cold gas efficiency are more than compensated for in higher overall plant costs, increased complexity, and reduced power output and efficiency.

The results of the study are compared with previous published analyses, and the differences in model assumptions, approach and basis are summarized. It has been concluded that the use of liquid CO_2 may still prove to have a significant advantage in a different type of gasifier, i.e., single-stage entrained flow with radiant quench section, but some key questions remain unanswered that can validate the potential improvement of gasifier performance using liquid CO_2 slurries. In order to provide a path to answering these questions, a technology development roadmap has been developed to resolve fundamental issues and to better define the operation aspects of using liquid CO_2/coal slurries. The fundamental issues could be resolved by conducting additional laboratory analyses consisting of:

- A rheological test program to quantitatively evaluate slurry preparation and handling for liquid CO_2 including experiments to evaluate preparation systems.
- An experimental program on CO_2-assisted gasification in order to obtain the most relevant experimental data from drop tube furnace studies to aid in verifying the potential advantages of direct feed of liquid CO_2/coal as gasifier feedstocks.

Quantifying the operational aspects of liquid CO_2 slurries can best be achieved with:

- An experimental program using a flow test loop to evaluate equipment performance and handling properties of liquid CO_2/coal slurries for gasifier feedstocks on a scale sufficient to predict full scale operating parameters.
- Spray atomization studies necessary to evaluate the effect of atomization properties of liquid CO_2/coal slurries that could be significantly different than those of water/coal slurries.

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Acknowledgments

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List of Acronyms and Abbreviations

AGR	Acid gas removal
ASTM	American Society for Testing and Materials
ASU	Air separation unit
atm	Atmosphere
BEC	Bare erected cost
Btu	British thermal unit
Btu/hr	British thermal unit per hour
C	degrees Centigrade
CCF	Capital charge rate factor
CDR	Carbon dioxide recovery
CCS	Carbon capture and storage
CF	Capacity factor
cm	Centimeter
CM	Construction management
CO_2	Carbon dioxide
COE	Cost of electricity
CoP	ConocoPhillips Company
COS	Carbonyl sulfide
CS	Carbon Steel
CT	Combustion turbine
CWT	Cold water temperature
DAF	Dry ash free
DB	Dry basis
DCS	Distributed control system
DIPE	Dooher Institute of Physics and Energy
DOE	Department of Energy
EIA	Energy Information Administration
EOR	Enhanced oil recovery
EPA	Environmental Protection Agency
EPC	Engineering, procurement, construction
EPRI	Electric Power Research Institute
ERC	Emission reduction credits
ft	Foot, Feet
FO&M	Fixed operations and maintenance
FSI	Free swilling index
gal	Gallon
gpm	Gallon per minute
GT	Gas turbine
HAZOP	Hazard and operability
HGI	Hardgrove Grindability Index
HHV	Higher heating value
HO	Home office
hp	Horsepower

HP	High pressure
HPRV	High pressure rotary valve
hr	Hour
HRSG	Heat recovery steam generator
HVAC	Heating, ventilating, and air conditioning
HWT	Hot water temperature
Hz	Hertz
IGCC	Integrated coal gasification combined cycle
IRROE	Internal rate of return on equity
ISO	International Organization for Standardization
ISS	Industry search and survey
kg/hr	Kilogram per hour
kJ	Kilojoules
kJ/hr	Kilojoules per hour
kW	Kilowatt
kWe	Kilowatts electric
kWh	Kilowatt-hour
kWt	Kilowatts thermal
lb	Pound
lb/hr	Pounds per hour
lb/ft^2	Pounds per square foot
LCOE	Levelized cost of electricity
LHV	Lower heating value
LIBOR	London Interbank Offered Rate
LRC	Low rank coal
m	Meters
m/min	Meters per minute
m^3/min	Cubic meter per minute
million $	Millions of dollars
MMBtu	Million British thermal units (also shown as 10^6 Btu)
MMBtu/hr	Million British thermal units (also shown as 10^6 Btu) per hour
mole%	Mole percent (percent by mole)
MPa	Megapascals absolute
mPa-s	Millipascal seconds (or centipoise)
MSDS	Material safety data sheet
MWe	Megawatts electric
MWh	Megawatt-hour
MWt	Megawatts thermal
ND	North Dakota
NDE	Non-Destructive Examination
NETL	National Energy Technology Laboratory
N/A	Not applicable
Nm^3	Normal cubic meter
NOx	Oxides of nitrogen
O&M	Operations and maintenance
OC	Operating cost

pph	Pounds per hour
ppm	Parts per million
PRB	Powder River Basin
PSFM	Power Systems Financial Model
psia	Pounds per square inch absolute
psid	Pounds per square inch differential
psig	Pounds per square inch gauge
QGESS	Quality Guidelines for Energy System Studies
Qty	Quantity
Ref.	Reference
scf	Standard cubic feet
scfd	Standard cubic feet per day
scfm	Standard cubic feet per minute
SGS	Sour gas shift
SMD	Sauter mean diameter
SRU	Sulfur recovery unit
ST	Steam turbine
STG	Steam turbine generator
TAG	[EPRI] Technical Assessment Guide
TASC	Total as-spent cost
TDH	Total dynamic head
TEG	Tri-ethylene glycol
TOC	Total overnight cost
TPC	Total plant cost
tpd	Tons per day
tph	Tons per hour
TPI	Total plant investment
tonne	Metric ton (1000 kg)
VO&M	Variable Operations and maintenance
vol%	Volume percent (percent by volume)
wt%	Weight percent (percent by weight)
$M	Millions of dollars

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Executive Summary

Introduction

This report summarizes the results of an investigation into the practicality of a liquid CO_2/coal slurry preparation and feed system for the E-Gas™ gasifier in an integrated gasification combined cycle (IGCC) electric power generation plant configuration. The study also evaluates the technical and economic performance impacts of substituting a liquid CO_2/coal slurry feed for the E-Gas™ gasifier in lieu of a water/coal slurry feed. The study evaluates the liquid CO_2 slurry performance and costs for two coals: Powder River Basin sub-bituminous (PRB) and North Dakota lignite.

Background

The present study is based on work performed and documented in the bituminous and low rank coal baseline reports [1 and 2]. These two reports document the evaluation of the E-Gas™ gasifier firing Illinois 6 and PRB using a water/coal slurry as feed. The present liquid CO_2/coal slurry evaluation is based on the same configuration as that used in the Baseline Reports.

System Description (Total Plant)

The overall plant configuration evaluated for this study is an IGCC electric generating plant based on two General Electric Frame 7F gas turbines receiving clean low Btu syngas from two E-Gas™ entrained flow oxygen blown gasifiers and their gas cleanup trains. The plant configuration incorporates nominal 90% CO_2 capture. The overall plant configuration is presented in Figure ES-1 below.

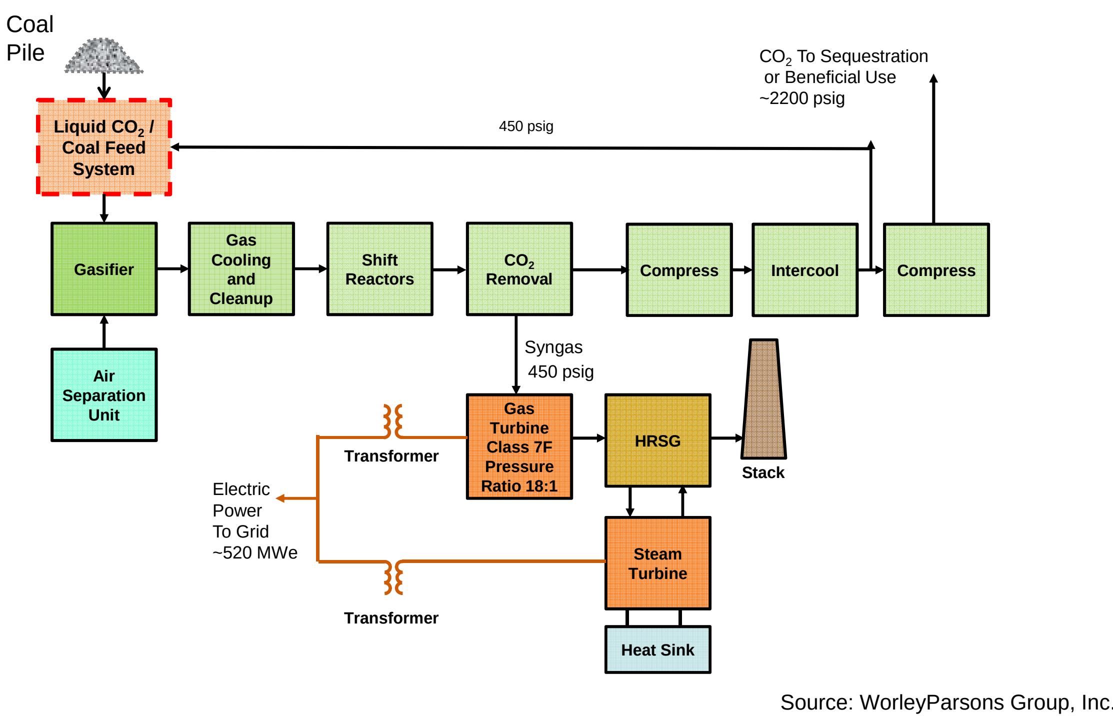


Figure ES-1. Gasification System with CO_2 Capture

System Description (Liquid CO_2)

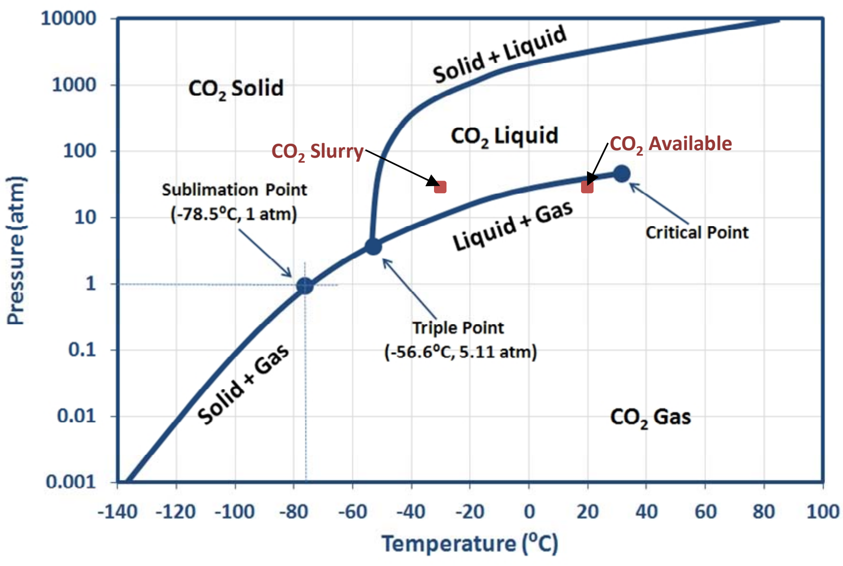
The liquid CO_2/coal slurry system was evaluated for both a batch type and a continuous flow type system. The differences between the two types of systems are much less significant compared to the difference between a liquid CO_2 and a water slurry system.

The scope of the liquid CO_2/coal slurry preparation and feed system is accounted for in Account 2 of the EPRI Technical Assessment Guide (TAG) capital cost account structure. The system boundaries begin at the top of the fuel day silo, which holds a nominal 24 hours of coal. During normal operation, the fuel exits the bottom of the silo and is fed to a rod mill for grinding to the desired particle size. From the rod mill, the coal is transported in a dense phase pneumatic transport system to the top of a solids heat exchanger, wherein the ground coal is chilled to a low temperature (in the range of -23.3°C (-10°F)) prior to mixing with liquid CO_2.

CO_2 in the gas phase is extracted from the stream of cleaned and dried CO_2 part way through the compression process (after capture). The CO_2 gas is at a nominal 3.10 MPa (450 psia) and 37.8°C (100°F). The gas pressure is reduced in a gas expander, producing about 533 kWe and reducing the pressure and temperature to 1.90 MPa/6.1°C (275 psia/43°F). The CO_2 is then cooled and condensed in a shell-and-tube heat exchanger to the range of -25°C (-13°F).

A commercial mechanical vapor compression refrigeration system is employed to produce a circulating loop of glycol-based coolant, which is used to chill the coal and the CO_2 to the desired temperature. This temperature is selected based on evaluating trade-offs between refrigeration work and the cost of the system pressure boundary at various combinations of pressure and temperature that correspond to the gas/liquid phase boundary for CO_2. A small design margin of subcooling is incorporated to minimize the potential for flashing.

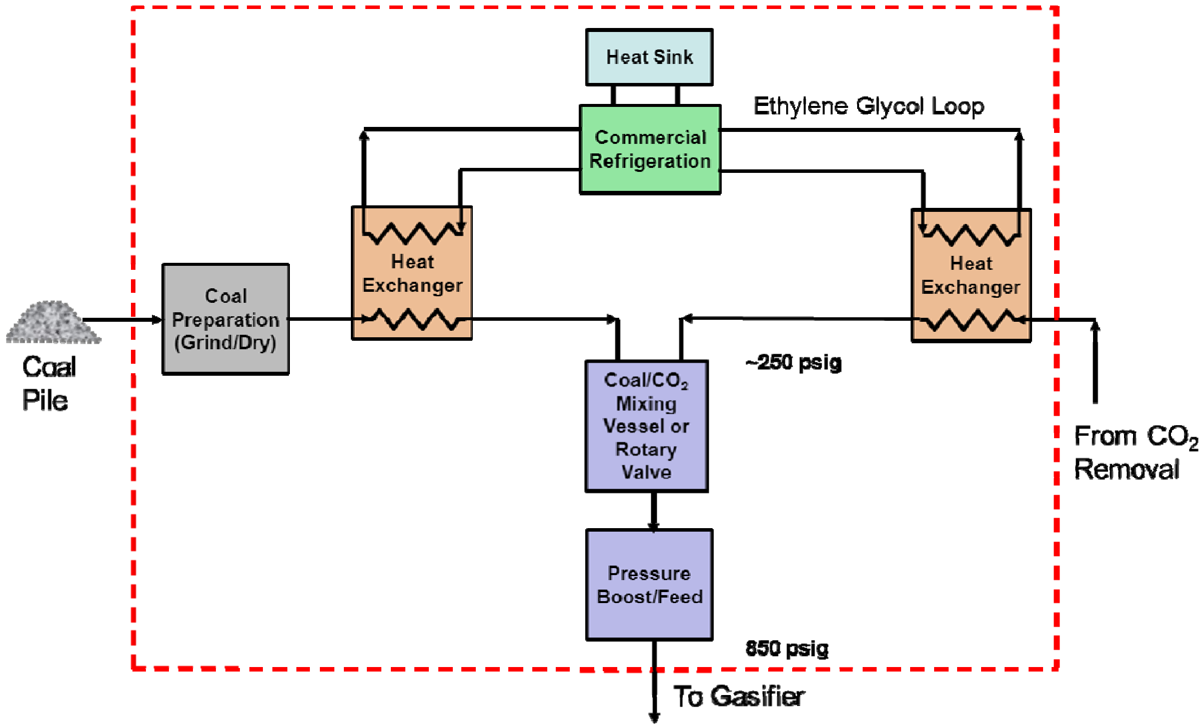
The phase diagram for CO_2 is illustrated below with starting point and end use point of the CO_2.



Source: WorleyParsons Group, Inc.

Figure ES-2. CO_2 Phase Diagram

The next figure is a simplified block diagram for the liquid CO_2/coal slurry prep and feed system.



Source: WorleyParsons Group, Inc.

Figure ES-3. Liquid CO_2/coal Slurry Preparation and Feed System

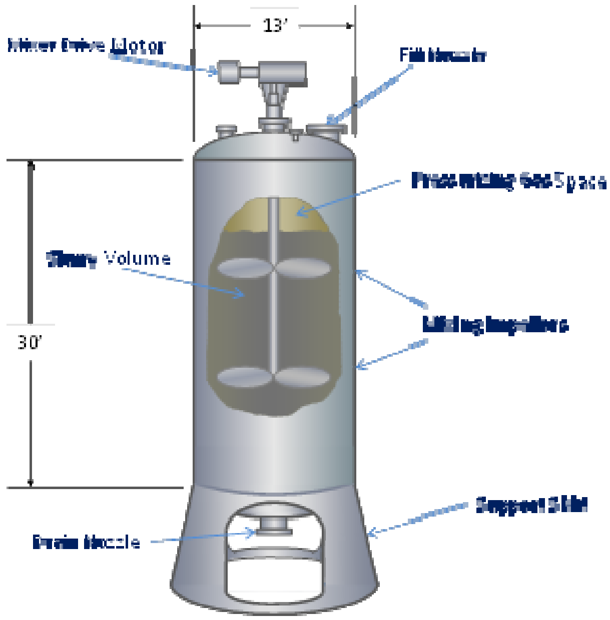
The following text describes several key components that comprise the liquid CO_2/coal slurry prep and feed system. These components are essential for assembling a functional system that mixes and transports liquid CO_2 and coal.

Key Components

One of the subordinate objectives of the study was to perform an industry search and survey to determine if essential components required to construct a liquid CO_2/coal slurry system were available from commercial sources or if targeted R&D efforts were required. The search and survey concluded that commercial sources were available for selected components that comprised both the batch type and continuous type systems. These components are identified and briefly described in the following text.

Mixing Tank

The batch type system requires a mixing tank capable of receiving ground coal at 1 atmosphere and then pressurizing to the mixing pressure of a nominal 17 atmospheres. The tank must be capable of holding an inventory that can support gasifier operation for a meaningful span of time. For this study, a mixing tank capacity of a nominal 30 minutes was selected. A tank with this capability is shown in the figure below.



Source: WorleyParsons Group, Inc.

Figure ES-4. Proposed Mixing Vessel

Rotary Valve

The continuous flow type system requires a continuous means of transporting ground coal from 1 atmosphere to a pressure of nominally 17 atmospheres. Most rotary valves simply meter coal (or some other granular solid) across a small pressure differential. Two manufacturers were identified that can provide rotary valves capable of working across the required pressure differential. One of these is illustrated in the figure below.

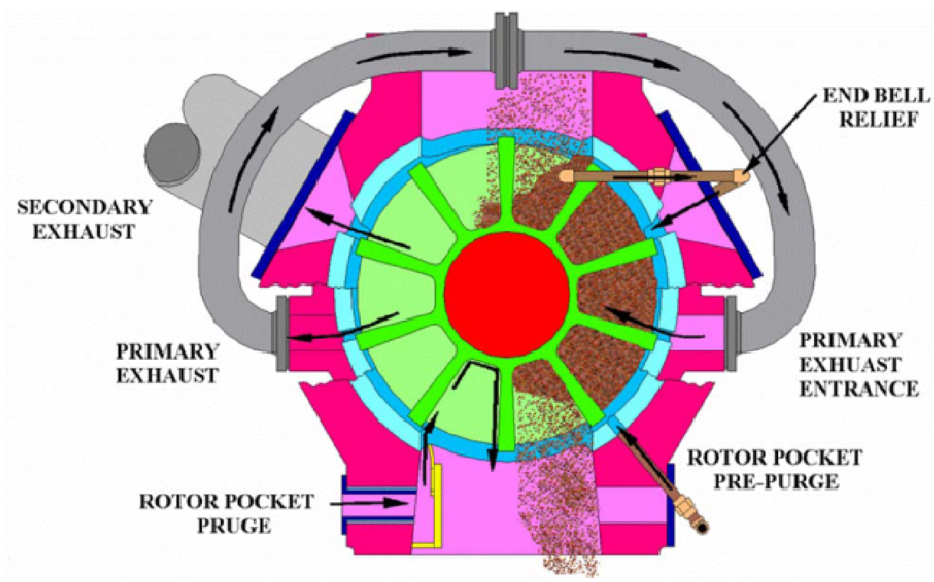


Figure ES-5. Andritz High Pressure Rotary Valve

Solids Cooler

A solids cooler is required that can chill ground coal on a continuous basis from normal ambient temperatures to the desired slurry temperature. The coal must be pre-chilled prior to mixing with liquid CO_2 to avoid flashing the CO_2. A commercial supplier of this type of cooler was found, and a typical example of this piece of equipment is shown in Figure ES-6.

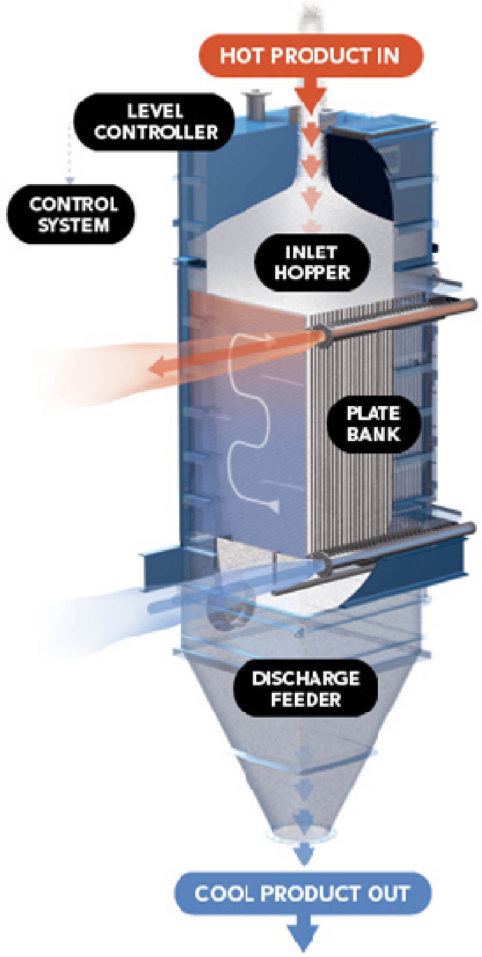


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Figure ES-6. Bulk Solids Cooler

Slurry Feed Pump

A pump capable of pumping the liquid CO_2/coal slurry from the mixing temperature to the final pressure required for gasifier feed (58 atmospheres) is required. A pump meeting this requirement is available and is manufactured by Putzmeister Solid Pumps GmbH. This type of pump is commonly used in pumping concrete, and it has also been pumping a water/coal slurry (or paste) into a pressurized combustor at a power plant site in Stockholm, Sweden for over 20 years. This type of pump is illustrated in Figure ES-7.

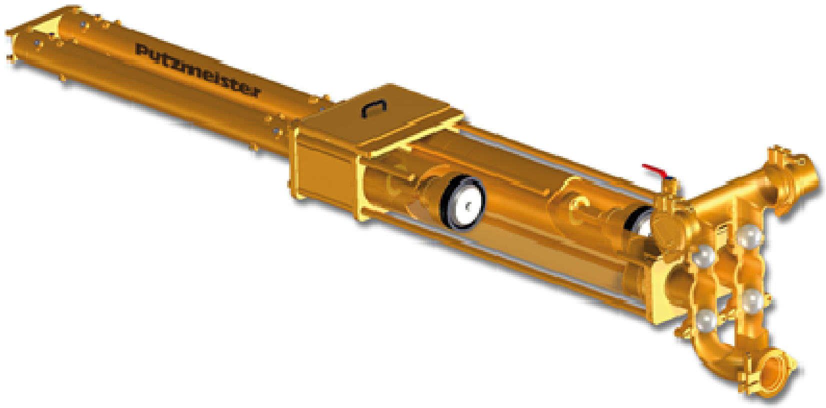

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Figure ES-7. Putzmeister High Density Solids Pump

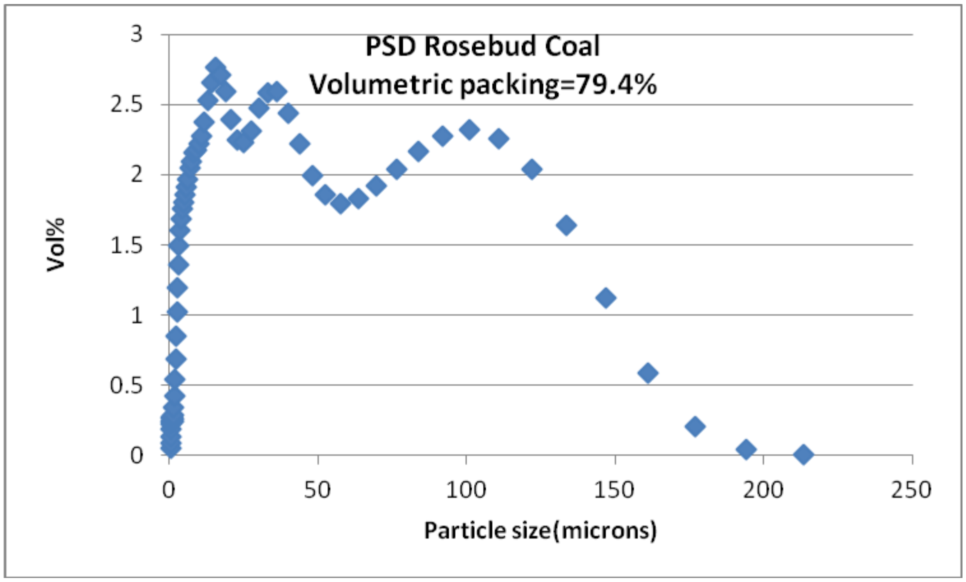
CO_2 Slurry Rheological Testing

The rheological testing of the PRB coal and North Dakota lignite took place at the laboratories of ATS RheoSystems (ATS) in Bordentown, NJ. Both coal in liquid CO_2 slurries and coal in water slurries were tested. A technique was developed for testing which minimized water absorption in the CO_2 slurries, and successful test runs on both coals were performed. Water/coal slurries were prepared at Columbia University and were also tested. It was found that the CO_2-based slurries had viscosities almost an order of magnitude lower than similar solids content water/coal slurries. In addition, the maximum water/coal slurry solids content was 60% by weight (only 55% for the PRB coal), whereas the maximum liquid CO_2/coal slurry solids content was 68% by weight. These results were consistent with earlier tests on two sub-bituminous coals which were carried out by the Dooher Institute of Physics and Energy (DIPE) at ATS in 2009. Slurryabilities were calculated from the data and used to estimate maximum solids for slurries in a full-scale slurry fed gasification system.

Powder River Basin (Rosebud) and North Dakota lignite (Freedom) coals

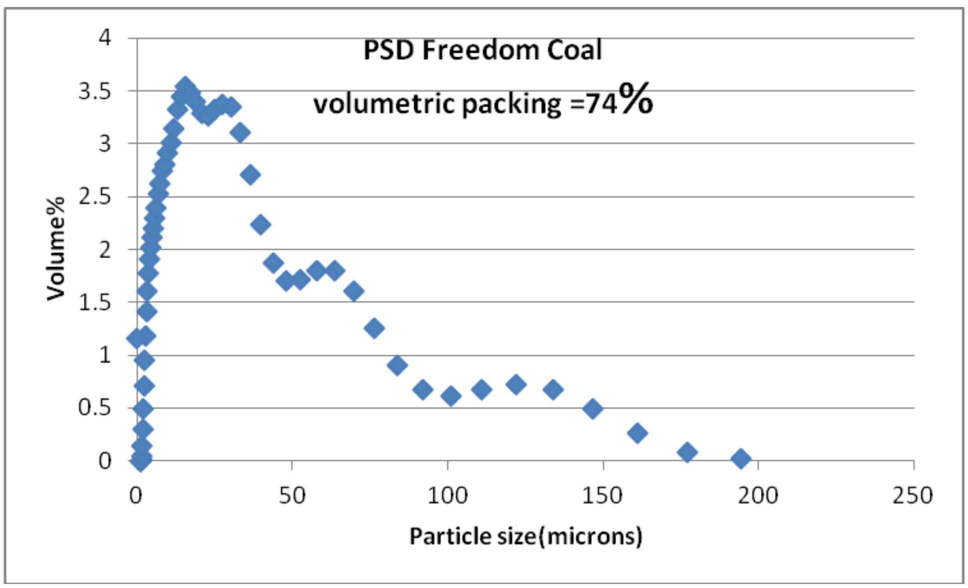
Coal and Sample Preparation

The Rosebud and Freedom coals were ground and sieved to specific particle size distributions supplied by the DIPE packing model in order to obtain geometric volumetric packings in the 74-80% range. This was necessary since the top size of the distributions was cut off at about 150 microns in order to avoid any bridging in the narrow gap in the bob and cup system employed by ATS for the rheological testing. In an actual coal gasifier, the top size is generally much larger, which can produce higher packings. However, once the slurryability is determined from the rheological tests results, the actual coal concentrations expected in a commercial gasifier can be determined. The particle size distributions for the two coals are depicted below.



Source: John Dooher, Adelphi University

Figure ES-8. Particle Size Distribution for Powder River Basin Sub-bituminous



Source: John Dooher, Adelphi University

Figure ES-9. Particle Size Distribution for North Dakota Lignite

Coal Analyses

Analyses of these coals were performed by SGS Minerals according to ASTM standards. Results are presented in Table ES-1 and Table ES-2.

Table ES-1. PRB-Rosebud Coal Analyses

Property	As Received, wt%	Dry, wt%	DAF, wt%
Moisture, Total	24.4		
Ash	8.72	11.54	
Volatile Matter	47.14	62.36	70.50
Fixed Carbon	19.74	26.10	29.50
Sulfur	1.37	1.81	
Carbon		55.07	
Hydrogen		5.85	
Nitrogen		0.77	
Oxygen		24.96	
Gross calorific Value, Btu/lb	8,978	11,876	13,424

Tests: HGI = 50, HGMoisture = 2.55, Equilibrium moisture = 24.00%
Free swelling index (FSI) = 0.0

Table ES-2. North Dakota Lignite-Freedom Coal Analyses

Property	As Received, wt%	Dry, wt%	DAF, wt%
Moisture, Total	25.93		
Ash	14.15	19.10	
Volatile Matter	47.94	64.73	80.01
Fixed Carbon	11.98	16.17	19.99
Sulfur	1.02	1.38	
Carbon		48.07	
Hydrogen		4.98	
Nitrogen		0.66	
Oxygen		25.81	
Gross calorific Value, Btu/lb	7,658	10,339	12,780

Tests: HGI = 53, HGMoisture = 2.39, Equilibrium moisture = 29.50%,
Free swelling index (FSI) = 0.0

Coal Water Slurries

Coal water slurries for the PRB and lignite coals were prepared according to the prescriptions shown in Table ES-3 and Table ES-4.

Table ES-3. Coal-Water Slurry Sample Prescription for PRB

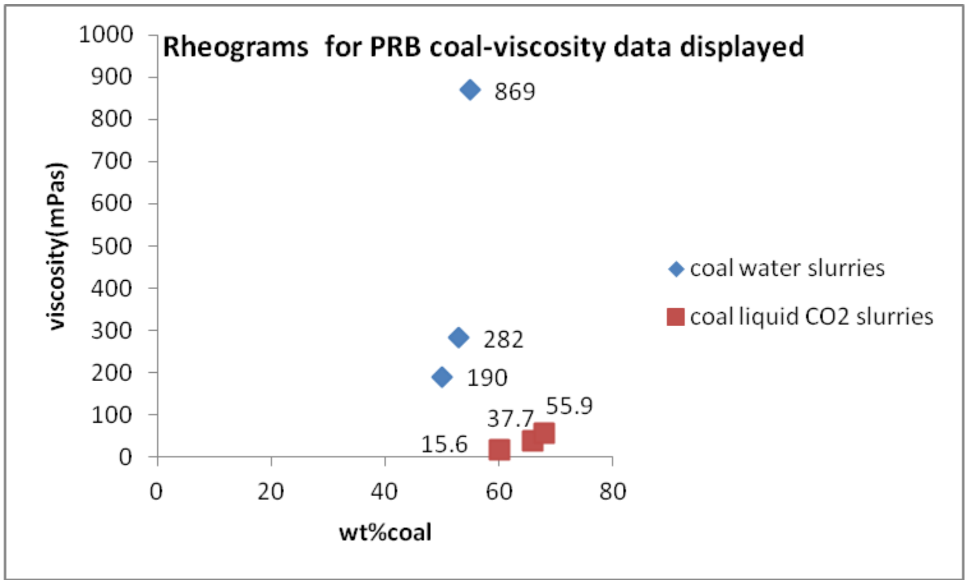
Mass Concentration (%)	Coal (gm)	Water (ml)	Amount of surfactant added (μL)
50	20.00	20	50
53	22.53	20	56.4
55	24.44	20	61.1

Table ES-4. Coal-Water Slurry Sample Prescription for Lignite

Mass Concentration (%)	Coal (gm)	Water (ml)	Amount of surfactant added (μL)
45	16.36	20	41
47	17.73	20	43
50	20	20	50
60	30	20	75

Rheological Testing

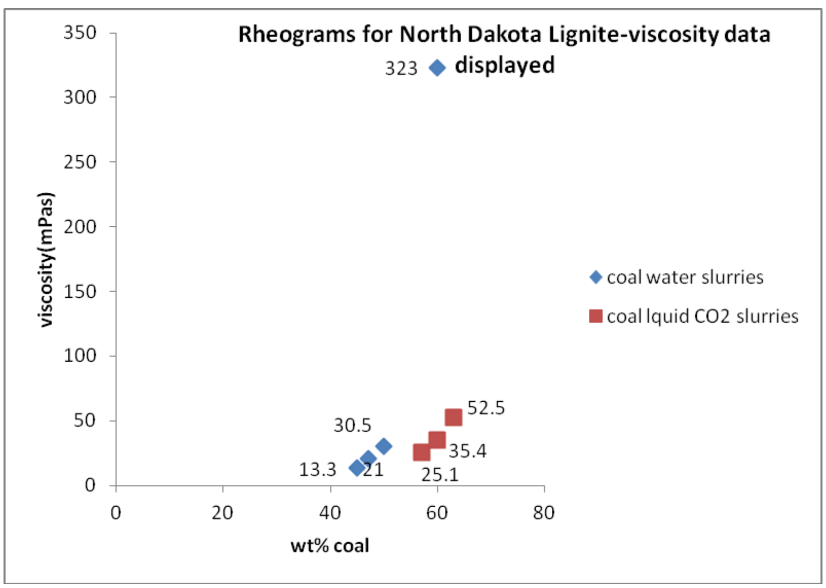
In Figure ES-10 and Figure ES-11, the results of the testing on CO_2/coal slurries and the water/coal slurries are displayed including the specific viscosities that were obtained by averaging all data points for each slurry in the same shear rate range of 1000 s^{-1}. The water/coal slurries were tested using a conventional bob and cup system. Liquid CO_2 by itself was also measured yielding a result of 0.3 mPa·s, which was in general agreement with published values. The data fit the DIPE model reasonably well. The slurryability of both low rank coals in liquid CO_2 was 0.88-0.89, whereas in water it was 0.78 for lignite and 0.7 for PRB, indicating the potential of running close to 80% liquid CO_2/coal slurries in a commercial gasifier with broad coal PSD's with packing fractions close to 0.9 compared to coal concentrations less than 70% in water with the same PSD. Some liquid CO_2 slurries were prepared at higher concentrations with PRB (70,73, and 76%) but did not show the expected increase in viscosity, indicating that mixing at very high concentrations (approaching maximum packing) in the rheometer is problematic and can lead to reduced coal concentrations in the measuring gap of the rheometer. This problem was not apparent at coal concentrations up to 68% for PRB.



Source: John Dooher, Adelphi University

Viscosity units are mPa·s
Wt% coal in CO_2(l) slurries=60, 66, and 68
Wt% coal in water slurries=50, 53, and 55

Figure ES-10. Effect of Coal Concentration for Rheology of Rosebud Coal in Water and Liquid CO_2



Source: John Dooher, Adelphi University

Viscosity units are mPa·s
Wt% coal in CO_2(l) slurries=57, 60, and 63
Wt% coal in water slurries=45, 47, 50, and 60

Figure ES-11. Effect of Coal Concentration for Rheology of Freedom Coal in Water and Liquid CO_2

Performance Results

The performance for all eight cases is the result of an EPRI ASPEN modeling effort, with participation by WorleyParsons, reflecting the plant configuration represented in the Low Rank Coal Baseline Report.

Some historical perspective is necessary in order to understand how the performance modeling was done. The history of these calculations is as follows:

In the 2005 to 2007 time frame, the US Department of Energy, National Energy Technology Laboratory (NETL) commissioned an evaluation of different types of fossil fired power plant technology. The performance modeling for that study was done by Research and Development Solutions, LLC (RDS), then the prime off-site support contractor for DOE-NETL. The results of the related modeling effort were published as the Cost and Performance Baseline for Fossil Energy Plants [2].

The study was conducted in two parts as documented in Volume 1, Bituminous Coal and Natural Gas to Electricity, Final Report, November 2010 and Volume 3a, titled Low Rank Coal to Electricity: IGCC Cases. Volume 3a documents the firing of low rank coals (PRB and lignite) in different types of gasifiers that are integrated in an IGCC plant configuration. The Volume 3a report was completed in May 2011. It should be noted that Volume 3a did not include a case for the E-Gas™ gasifier firing lignite.

For the Low Rank Coal Cases documented in Volume 3a, the performance modeling was performed by Booz Allen Hamilton, the present incumbent site support contractor at NETL and the successor to RDS. Booz Allen succeeded RDS at the end of activities associated with FY 2009.

All of the performance modeling discussed above involving the E-Gas™ gasifier was based on a ***water/coal slurry*** as feedstock. The present study evaluates the same gasifier supplied with a ***liquid CO_2/coal slurry.*** The liquid CO_2/coal slurry case modeling was performed in the following manner:

The Electric Power Research Institute (EPRI) developed heat/mass balance models for the E-Gas™ gasifier firing a water/coal slurry. EPRI benchmarked these models against those presented in Volumes 1 and 3a of the Baseline Report to match the performance, using the same design inputs, ambient conditions, gas turbine characteristics, etc. The performance models were then adjusted to reflect ISO ambient conditions (the Low Rank coal report cases were performed at higher altitude and lower ambient temperatures relative to ISO conditions).

WorleyParsons then modified the EPRI ASPEN models to reflect current E-Gas™ gasifier performance expectations. Phillips 66 and WorleyParsons gasifier output data were compared and deemed to be in good agreement. The WorleyParsons modified EPRI model results were used as a basis for cost modeling and subsequent levelized cost of electricity modeling.

Understanding the history and chronology of the performance modeling is important because the thermal performance bears heavily on the determination of economic performance as expressed in the calculation of the cost of electricity (COE).

In performing the analysis, the various cases were bound by several physical constraints:

- Site ambient conditions are set at ISO and are the same for all cases.
- Gas turbine generator electrical output is set at 232 MWe.
- CO_2 capture is set at 90 percent.

The principal governing parameter that calibrates the ASPEN model for the entire IGCC plant for each case is that the gas turbine power output is maintained at 232 MWe, which is based on the shaft torque limit for the GE Frame 7F engine that is an integral part of each case. This in turn dictates the syngas Btu input to the engine, which then influences a large number of upstream parameters in the gasifier and its ancillary systems. The ASPEN models for each case calculate the necessary stream parameters that derive from the above constraints.

The table below presents the performance for each case evaluated based on 90 percent capture, in accordance with the original scope of work.

Table ES-5. Selected Performance Data for the Four Study Cases - 90% Capture

	Case 1	**Case 2**	**Case 3**	**Case 4**
Coal type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Coal In (lb/hr)	679,576	672,160	976,416	912,612
Gross MW	741	718	822	762
ST Output (MW)	277	254	358	298
GT Output @ ISO (MW) - each	232	232	232	232
Aux Load (MW)	204	213	246	245
Net Plant Power	537	504	577	517
Net Plant Heat Rate (Btu/kWh)	10,836	11,420	11,210	11,680

In March 2012, the US EPA had issued for comment rules that require sufficient CO_2 capture to result in emissions potential of 1000 lb CO_2/MWh (gross) for new construction. For the cases evaluated in this study, this level of emissions corresponds to roughly ***36 percent to 42 percent capture***. Reducing the CO_2 capture from 90 percent to these levels significantly improves the performance results of all four cases.

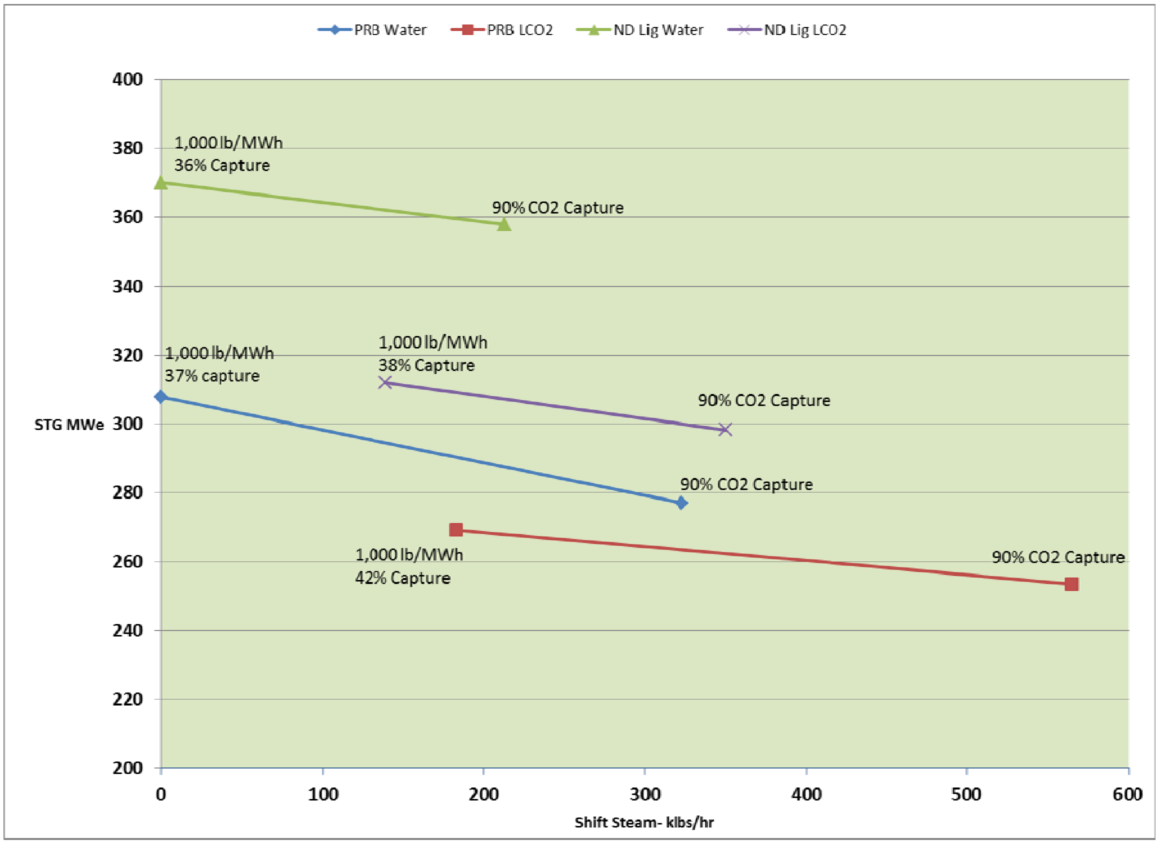
The next table presents performance for the 1000 lb/MWh (gross) cases. The percent capture varies somewhat from case to case. Overall, plant performance improves significantly with the reduction in the burden of capturing a significant portion of the CO_2 produced.

Table ES-6 Selected Performance Data for the Four Study Cases - 1000 lb CO_2/MWh (gross)

	Case 5	Case 6	Case 7	Case 8
Coal type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Coal In (lb/hr)	647,225	640,544	938,000	868,831
Percent CO_2 Capture	37	42	36	38
Gross MW	772	733	834	776
ST Output (MW)	308	269	370	312
GT Output @ ISO (MW) - each	232	232	232	232
Aux Load (MW)	163	173	195	199
Net Plant Power	609	560	640	577
Net Plant Heat Rate (Btu/kWh)	9,130	9,796	9,700	9,960

The water slurry cases inherently introduce more hydrogen to the gasifier than do the CO_2 slurry cases as a consequence of the hydrogen in the water that constitutes the slurry. Therefore, the water slurry cases tend to require less shift steam, resulting in increased steam turbine generator output. The reduction in CO_2 capture to meet the 1000 lb CO_2/MWh EPA target further reduces the amount of shift steam and also reduces auxiliary loads to a significant degree. Overall plant performance is improved commensurately. This reduction in shift steam flow contributes to the differential in performance between the water and liquid CO_2 slurry cases for each fuel. Other factors that impact performance are the higher parasitic loads for the refrigeration process that chills the coal and the CO_2 for slurry preparation, and the reduction in enthalpy of the feed streams (coal and slurry fluid) entering the gasifier.

Figure ES-12 below shows shift steam impact on steam turbine generator (STG) output for the eight cases evaluated. The results indicate the general trend that increases in shift steam tend to decrease electrical generation. Comparison between coal types and slurry types is not as readily made, as other factors influence STG output besides shift steam, such as steam generation in the gas cooler.



Source: WorleyParsons Group, Inc.

Figure ES-12 Effect of Shift Reactor Steam Flow on Steam Generator Power Output

Capital Cost & COE Results

The following presents the financial results of the evaluation of the liquid CO_2/coal slurry feed IGCC cases compared with the water/coal slurry cases. The financial results are calculated based on the methodology described in Cost Estimation methodology for NETL Assessments of Power Plant Performance [3].

The calculation includes an amortization of the plant capital costs along with a complete accounting of Operation & Maintenance (O&M) costs and fuel costs. For this report, first year cost of electricity is presented, although the methodology also enables calculation of a levelized COE.

The capital costs used in the COE calculation begin with the Total Plant Costs (TPC). Owners Costs and Financing costs are added to the TPC costs to arrive at Total Overnight Cost (TOC), which is the basis for the annualized capital cost component of the total COE. Additional financing costs are included by factoring the TOC to generate the Total As-Spent Cost (TASC) estimate.

Table ES-7 Capital Cost Build-up - 90% Capture Cases

	Case 1	Case 2	Case 3	Case 4
Coal Type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Total Plant Cost (TPC)	$1,876	$1,890	$2,177	$2,107
Pre-Production Cost	$63	$63	$73	$70
Inventory Capital	$23	$23	$29	$28
Initial Catalysts & Chemicals	$29	$30	$31	$33
Land	$1	$1	$1	$1
Other Owners Cost	$281	$284	$327	$314
Financing Costs	$51	$51	$59	$57
Total Overnight Cost	$2,324	$2,342	$2,697	$2,612
TASC Multiplier	1.14	1.14	1.14	1.14
Total As Spent Cost	$2,649	$2,670	$3,074	$2,977

Costs in million 2012 dollars

Table ES-8 Capital Cost Build-up - 1000 lb CO_2/MWh Capture Cases

	Case 5	Case 6	Case 7	Case 8
Coal Type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Total Plant Cost (TPC)	$1,759	$1,786	$2,031	$1,983
Pre-Production Cost	$59	$59	$68	$66
Inventory Capital	$21	$21	$27	$26
Initial Catalysts & Chemicals	$13	$17	$14	$17
Land	$1	$1	$1	$1
Other Owners Cost	$264	$268	$305	$297
Financing Costs	$48	$48	$55	$54
Total Overnight Cost	$2,164	$2,202	$2,500	$2,444
TASC Multiplier	1.14	1.14	1.14	1.14
Total As Spent Cost	$2,467	$2,510	$2,850	$2,788

Costs in million 2012 dollars

With the Total Overnight Cost values calculated, and the O&M costs and fuel costs from the appropriate tabulation (Section 11 of this report), the DOE methodology enables calculation of the all-in COE values for each case. Table ES-9 presents the values of COE and other pertinent parameters of interest. Table ES-10 presents values for the 1000 lb CO_2/MWh cases.

Table ES-9 Cost of Electricity and Cost of CO_2 Captured/Avoided - 90% Capture

	Case 1	Case 2	Case 3	Case 4
Coal Type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Net MWe	537.1	504.2	576.6	517.0
Total Overnight Cost $/kW	4,327	4,645	4,677	5,051
COE, $/MWh	125.26	133.92	138.90	149.09
COE, $/MWh (inc. T&S)	147.52	157.29	153.86	164.88
CO_2 emitted, lb/MWh (gross)	169.0	172.1	168.6	162.0
Cost of CO_2 Captured, $/metric ton	54.48	60.54	58.08	64.86
Cost of CO_2 Avoided, $/metric ton	98.56	112.34	90.37	105.02

Costs in 2012 dollars

Cost of CO_2 captured/avoided reference is baseline supercritical pulverized coal plant without CO_2 capture using the same fuel.

Table ES-10 Cost of Electricity and Cost of CO_2 Captured/Avoided - 1000 lb CO_2/MWh (gross)

	Case 5	Case 6	Case 7	Case 8
Coal Type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Net MWe	607.2	560.0	641.0	578.4
Total Overnight Cost $/kW	3,564	3,932	3,900	4,225
COE, $/MWh	102.60	112.90	115.66	124.05
COE, $/MWh (inc. T&S)	109.85	121.37	121.21	129.86
CO_2 emitted, lb/MWh (gross)	1000	1000	1000	1000
Cost of CO_2 Captured, $/metric ton	94.32	109.03	92.72	110.57
Cost of CO_2 Avoided, $/metric ton	129.52	181.72	124.80	161.75

Costs in 2012 dollars

Evaluation Results Summary

It is feasible to design and build a practical liquid CO_2/coal slurry preparation and feed system for use with an E-Gas™ gasifier. However, capital and O&M costs of the liquid CO_2/coal slurry preparation and feed system are somewhat higher than for a water/coal slurry system of comparable capacity.

The liquid CO_2 preparation and feed system can be assembled using commercially available components, and the system requires about the same amount of space as for a water slurry system. Electrical loads for the liquid CO_2 system equipment are greater than those for a water slurry system, but they are still relatively modest compared to other IGCC plant auxiliary loads.

Overall plant performance results are mixed. The IGCC cases using a liquid CO_2 slurry system show reduced plant output and higher heat rate for PRB coal and for ND lignite at 90% CO_2

capture and at lower capture rates commensurate with an emissions output of 1,000 lb CO_2/MWh (gross).

Some of these performance differences can be attributed to the variation in the amount of steam that must be diverted from the steam turbine expansion path (thereby reducing power generation). This is the consequence of increased need for steam to drive the water gas shift reaction, which drives the production of hydrogen and CO_2 in the syngas stream in lieu of water vapor and CO, which is present in the gasifier off-gas. Other factors contributing to the calculated performance differences are the increase in parasitic loads attributable to refrigeration to produce liquid CO_2 and chilled coal, and the reduction in enthalpy of the inlet streams to the gasifier associated with the low temperature liquid CO_2 slurry feed.

The capital costs for the complete plant are slightly higher for the liquid CO_2 slurry cases for PRB coal, but about somewhat reduced for ND lignite relative to the corresponding water slurry cases. Differences in dollar/kWe costs are higher for both coals due to the reduction in net output.

The cost of electricity computed for the liquid CO_2/coal slurry cases is greater for both PRB and ND Lignite coals.

It does not appear that there is any benefit to using liquid CO_2/coal slurries for feeding low rank coals to the E-Gas™ gasifier. Any incidental benefits in improved cold gas efficiency are more than compensated for in higher overall plant costs, increased complexity, and reduced power output and efficiency.

Comparison of Results with Previous Studies

There is a very small increase in cold gas efficiencies with the model that was used in this report as compared with the MIT study [4] and the 1st EPRI study [5]. The model that was used here was based in part on a revised Phillips 66 model of the E-Gas™ technology battery limit. The new model differed significantly from the model that was used in the earlier DOE Low Rank Coal baseline report in that the oxygen use for the water slurry feed was reduced and the cold gas efficiency increased from 70% to 74%. Coal concentration in the water slurry was significantly higher in the newer model and was almost the same as for the CO_2 slurry.

1. Introduction

This report documents an investigation into the practicality of designs for a system that prepares a slurry comprised of ground coal and liquid CO_2 for feed and injection to an oxygen blown, entrained flow gasifier. The report also documents comparative thermal performance and capital, O&M, and LCOE estimates for a series of cases firing different coals in water and liquid CO_2 slurry form. The gasifier is intended to be part of an Integrated Gasification Combined Cycle (IGCC) electric power plant that incorporates CO_2 capture for sequestration or beneficial use. A portion of the CO_2 separated from the plant exhaust stream is recycled to the liquid CO_2/coal slurry preparation system.

The aim of the first part of the investigation is to devise configurations for the liquid CO_2/coal slurry preparation and feed system that utilize commercially available components while relying on compliance with known physical properties of CO_2 and sound basic engineering principles. The balance of the report documents the comparative performance and costs of the two types of slurry (water versus liquid CO_2).

The report is developed in the following manner:

The first section after the introduction (2) describes a commercial size IGCC plant that incorporates oxygen blown entrained flow gasification preparing a low Btu syngas that is fired in a state of the art combustion turbine (GE Frame 7F or Siemens equivalent). The configuration used herein as a basis for the liquid CO_2/coal slurry system requires two gasifiers, two Air Separation Units, two combustion turbines, two Heat Recovery Steam Generators (HRSGs), and one steam turbine generator with accompanying balance of plant.

The IGCC configuration defined sets the parametric design values for the rest of the facility, including coal flows, CO_2 flows, required slurry delivery pressure, etc. These parameters then govern the design of the various subsystems that comprise the complete slurry system.

The next two sections (3 and 4) discuss the physical properties of CO_2 (the phase diagram, triple point, etc.), and the chemical and physical properties of the coals used herein. Section 5 describes the physical properties of the liquid CO_2/coal slurry in the range of interest (75 percent coal / 25 percent CO_2).

The next section, (6), provides a discussion of how the physical properties of CO_2 influence the design of the slurry system. The liquid region on the phase diagram has definitive boundaries, and these must be respected in the design of the system.

Section 7 describes the design of both batch type and continuous flow liquid CO_2/coal slurry preparation and feed systems. Sufficient detail is provided to enable commercial components to be specified and selected (typical vendors, not necessarily exclusive) and the costs of the two systems estimated. Schematic and general arrangement drawings are provided, the former in the report proper, and the latter in Appendix A. Equipment lists for each alternative are provided in Appendix B.

Section 8 describes reference designs for water/coal slurry systems for each coal that correspond to the liquid CO_2/coal cases. This section also describes a dry lock hopper type system capable of feeding a gasifier with the same nominal capacity as the E-Gas™ unit used herein as the basis for this study. This alternative gasifier must be capable of receiving a dry feed.

Section 9 presents the results of an Industry Search and Survey (ISS), which was aimed at discovering if the key components of the liquid CO_2/coal slurry system are available as commercial items, or potentially as modified commercial items. The ISS concludes that all of the components required to construct a complete liquid CO_2/coal slurry preparation and feed system are available commercially, with no development required.

Sections 10 and 11 present capital and operations and maintenance (O&M) cost estimates, respectively, for the different types of preparation and feed slurry systems described in the report: liquid CO_2/coal; water/coal; and dry feed. The liquid CO_2 system estimates are for both the batch and continuous versions of the system (Account 2 in the EPRI TAG accounting). The water and dry feed estimates are only for batch type systems, as continuous feed type systems are not relevant for these approaches.

Sections 12 and 13 present capital and O&M cost estimates for the entire IGCC plant with 90% carbon capture using liquid CO_2 slurries and water/coal slurries as feed to the gasifier. The performance impacts of the liquid CO_2 prep and feed system are reflected in the cost estimates for various components throughout the plant for each case. These total plant estimates are provided for the batch type system but not for the continuous type system. The differences between the batch and continuous type system are of minimal consequence in the context of the estimates for the entire plant.

Section 14 presents performance results for the four cases: two prep and feed systems (liquid CO_2 and water) and two coals (PRB and North Dakota lignite) per feed system.

Section 15 presents Cost of Electricity estimates for the four cases noted above. This section also presents Owners costs and costs of CO_2 captured and avoided.

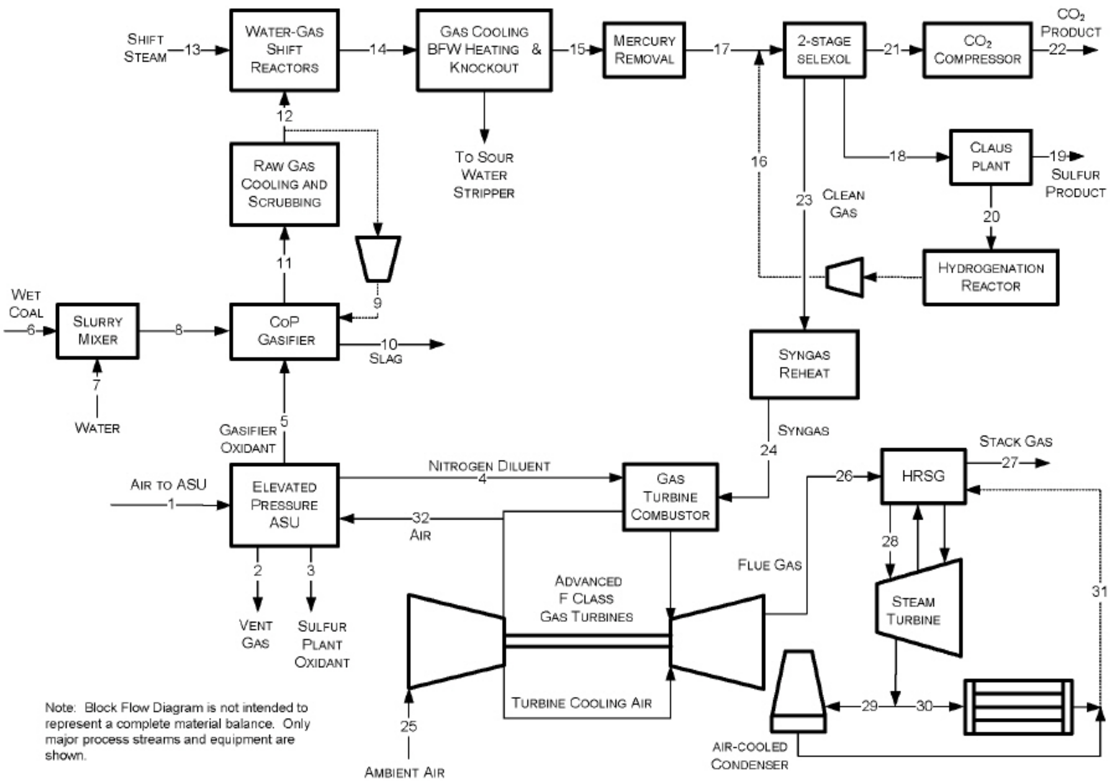
Section 16 summarizes the results of the evaluation.

Section 17 compares the results with previously published analyses.

Section 18 defines a technology development plan to continue the due diligence in performing a comprehensive technical evaluation of this technology.

2. IGCC System Design Basis and Design Parameters

The IGCC plant configuration is based on Case S4B presented in the “Cost and Performance Baseline for Fossil Energy Plants, Volume 3a: Low Rank Coal to Electricity: IGCC Cases” [1] by US DOE-NETL. The Case S4B process flow diagram and a brief summary of the plant process are excerpted from the NETL report and provided below for reference.



Source: NETL

Figure 2-1 IGCC Process Flow Diagram

In this plant configuration, PRB coal is prepared into a water slurry with approximately 49 percent solids and is injected in both the oxidizing and reducing sections of the E-Gas™ gasifier. Two parallel gasifiers operate at 4.2 MPa (615 psia) and process a total of 7,349 tonne/day (8,101 tpd) of as-received PRB. Oxygen is used to gasify a portion of the slurry in the horizontal cylinder portion with two horizontally opposed burners. The highly exothermic gasification/oxidation reactions take place rapidly at high temperatures of 1,316 to 1,427°C (2,400 to 2,600°F). The hot raw gas from the first stage enters the second (top) stage, which is a vertical cylinder perpendicular to the first stage. The remaining coal slurry is injected into this hot raw gas. The endothermic gasification/devolatilization reaction in this stage reduces the final gas temperature to about 1,038°C (1,900°F).

Raw Gas Cooling/Particulate Removal

High-temperature heat recovery in each gasifier train is performed by raw gas coolers in three sections (a superheater, an evaporator, and an economizer), which lower the raw gas temperature from 1,038°C (1,900°F) to 337°C (638°F). After passing through the raw gas coolers, the syngas passes through a cyclone and a raw gas candle filter where a majority of the fine particles are removed and returned to the gasifier using recycled syngas. The filter consists of an array of ceramic candle elements in a pressure vessel. Fines produced by the gasification system are recirculated to extinction. The ash that is not carried out with the gas forms slag and exits the gasifier in liquid form. The slag is solidified in a quench tank for disposal.

Sour Water Stripper

Water condensed during the cooling of the raw gas, along with all other sour water from the plant are sent to the sour water stripper, which removes NH_3, H_2S, HCN, and other impurities from the waste stream. The sour gas stripper consists of a sour drum that accumulates sour water that flows to the sour stripper, which consists of a packed column with a steam-heated reboiler. Sour gas is stripped from the liquid and sent to the sulfur recovery unit (SRU). Remaining water is sent to wastewater treatment.

Sour Gas Shift (SGS)

The water concentration in the syngas is adjusted upstream of the shift reactors by the injection of shift steam, extracted from the steam cycle. The hot syngas exiting the first stage of SGS is used to superheat steam. One more stage of SGS (for a total of two) results in approximately 97 percent overall conversion of CO to CO_2. The warm syngas from the second stage of SGS is cooled to preheat the syngas prior to the first stage of SGS. The SGS catalyst also serves to hydrolyze COS thus eliminating the need for a separate COS hydrolysis reactor. Following the second stage of SGS, the syngas is further cooled to 35°C (95°F) prior to the mercury removal beds.

Mercury Removal and AGR

The cooled syngas then passes through a carbon bed to remove 95 percent of the Hg.

The AGR process in Case S4B is a two stage Selexol process where H_2S is removed in the first stage and CO_2 in the second stage of absorption. The process results in three product streams, the clean syngas, a CO_2-rich stream, and an acid gas feed to the Claus plant. The acid gas contains about 17 percent H_2S and 68 percent CO_2 with the balance primarily H_2.

CO_2 Compression and Dehydration

CO_2 from the AGR process is generated at two pressure levels. The LP stream is compressed from 0.12 MPa (17 psia) to 1.03 MPa (150 psia) and then combined with the HP stream. The combined stream is further compressed to a supercritical condition at 15.27 MPa (2,215 psia) using a multiple-stage, intercooled compressor. During compression, the CO_2 stream is dehydrated to a dew point of -40ºC (-40°F) using a molecular sieve or a tri-ethylene glycol (TEG) unit. The raw CO_2 stream from the Selexol process contains over 99 percent CO_2. The dehydrated CO_2 is transported to the plant fence line and is sequestration-ready.

Note: The level of moisture removal incorporated into the S4B case of the "Baseline" Report, described in summary herein, is most likely not sufficient to meet the needs of the liquid CO_2/coal slurry system. It is likely that the Baseline configuration CO_2 compression and dehydration configuration will require modification to incorporate a TEG unit or a molecular sieve unit to achieve the necessary level of moisture removal.

Claus Unit

The SRU is a Claus bypass-type SRU utilizing oxygen instead of air. The Claus plant produces molten sulfur by converting approximately one third of the H_2S in the feed to SO_2, then reacting the H_2S and SO_2 to sulfur and water. The combination of Claus technology and tail gas recycle results in an overall sulfur recovery exceeding 99 percent.

Utilizing oxygen instead of air in the Claus plant reduces the overall cost of the sulfur recovery plant. Feed for each case consists of acid gas from both the acid gas cleanup unit and a vent stream from the sour water stripper in the gasifier section.

In the furnace waste heat boiler, steam is generated. This steam is used to satisfy all Claus process preheating and reheating requirements, as well as to provide some steam to the medium pressure steam header. The sulfur condensers produce 0.34 MPa (50 psig) steam for the LP steam header.

Power Block

Clean syngas from the AGR plant is reheated to 196°C (385°F). The conditioned syngas is diluted with nitrogen, and then enters the combustion turbine (CT) burner. The exhaust gas exits the CT at 561°C (1,042°F) and enters the HRSG where additional heat is recovered. The flue gas exits the HRSG at 132°C (270°F) and is discharged through the plant stack. The steam raised in the HRSG is used to power an advanced commercially available steam turbine using a nominal 12.4MPa/538°C/538°C (1,800 psig/1,000°F/1,000°F) steam cycle. There is no air integration between the CT and the ASU in the capture case.

Air Separation Unit

The ASU is designed to produce approximately 5,323 tonne/day (5,867 tpd) of 95 mole percent O_2 for use in the gasifier and SRU. The plant is designed with two production trains. The air compressors are powered by electric motors. Nitrogen is also recovered, compressed, and used as dilution in the CT combustor and for miscellaneous plant use (establishing a nitrogen blanket in vessels for layup, etc.) Air extraction is taken from the CT compressor to reduce the size of the main air compressor.

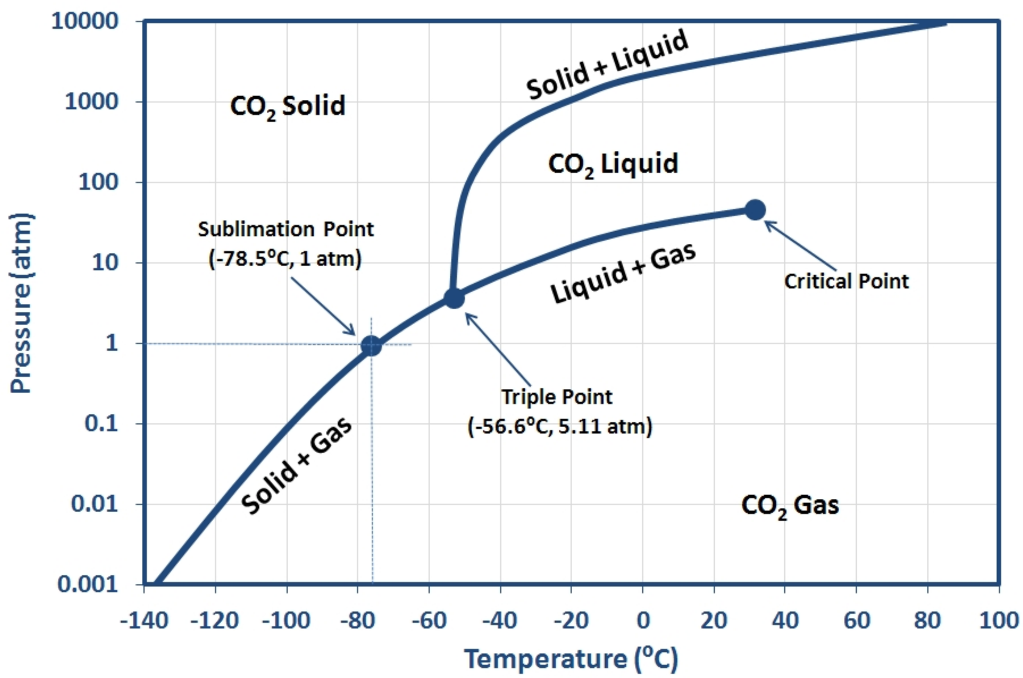
Case S4B Performance Results

Case S4B, based on the E-Gas™ IGCC plant with CO_2 capture and using PRB coal at the Montana site [elevation 1,036.3 m (3,400.0 ft)], produces a net output of 515 MWe at a net plant efficiency of 30.4 percent (HHV basis).

The ASU accounts for approximately 63 percent of the total auxiliary load, distributed between the main air compressor, the oxygen compressor, the nitrogen compressor, and ASU auxiliaries. CO_2 compression accounts for about 18 percent and the AGR process about 10 percent of the auxiliary load. All other individual auxiliary loads are less than 3 percent of the total.

3. Liquid CO_2 Physical Properties

The properties of liquid carbon dioxide are best understood by referring to the phase diagram shown in Figure 3-1. The liquid region starts at the triple point at 5.11 atm and -56.6°C (-70°F). Increasing the pressure while simultaneously increasing the temperature pushes carbon dioxide into the liquid region. For example, at a temperature of -20°C (-4°F) the pressure should be greater than 25 atm to stay in the liquid region. Density will decrease with increasing temperature from about 1100 kg/m^3 (68.7 lb/ft^3) to less than 900 kg/m^3 (56.2 lb/ft^3). The viscosity of the liquid according to published literature can range from 0.1-0.4 mPa-s. The supercritical region is shown in Figure 3-1.



Source: WorleyParsons Group, Inc.

Figure 3-1 CO_2 Phase Diagram

One of the general features of liquid CO_2 is that it is a refrigerated liquefied gas. The boiling point will depend on the pressure. The sublimation point of the solid phase, dry ice, is -78.5°C (-109.3°F) at 1 atm. The gas in vapor form is heavier than air and it is odorless and colorless and stable under normal circumstances.

Table 3-1 Specifications of Industrial Grade Carbon Dioxide

Gas / Property	Quantitative measure
Carbon dioxide	99.9%vol
Moisture	20 ppm
Oxygen	30ppm
Carbon monoxide	5ppm
NOx(each)	2.5ppm
Ammonia	2.5ppm
Total hydrocarbons	50ppm
Benzene	0.2ppm
Acetaldehyde	0.2ppm
Total sulfur(as S)	0.1ppm
Non volatile organic residues	5ppm
Non volatile residues	10ppm
Acidity	To pass JEFCA test
Taste and order in water	No foreign

Please note:

1. All figures are expressed in parts per million (ppm) by volume unless otherwise stated
2. This specification conforms with the EIGA guideline specification IGC 70/99/EFD "Carbon Dioxide Source Certification, Quality Standards and Verification"
3. Analysis methods comply, where applicable, with IGC/70/99 guidelines
4. The product complies with the requirements (E290) of EC Directive 2000/63/EC on food additives and with European Pharmacopeia.

Applications and Use

Carbon dioxide's properties give it a key role across many industries such as:

- **Food and Beverages**
  For chilling and freezing, for carbonation and dispensing of beverages, for food extraction, for Modified Atmosphere Packaging (MAP) and dry ice for in-transit refrigeration
- **Chemicals**
  As a replacement for CFC's in foamed plastics production
- **Electronics**
  Use of snow cleaning for devices
- **Agriculture**
  To boost production in greenhouses and pest control in grain silos
- **Healthcare**
  To treat respiratory disorders and for surgical dilation
- **Environment, water and waste**
  For drinking water treatment and waste water pH control

4. Coal Properties

Two sets of data were used to describe the coals used as a basis for this report. One set represents the as-tested samples of the coal material used in the rheological testing of the slurries described in the following section. The second set of coal property data represents typical values for the two types of coal (Powder River Basin Rosebud coal, and North Dakota Lignite) as analyzed in the Baseline Report and herein. The differences in coal analyses are not expected to represent significant impacts on thermal performance in the gasifier or rheological performance in the slurry property testing. The first set of tables below presents data for the fuel used in the rheological testing.

The analyses of both design coal samples were performed by SGS Minerals according to ASTM standards. Results are presented in Table 4-1 and Table 4-2.

Table 4-1 PRB-Rosebud Coal Analyses

Property	As Received, wt%	Dry, wt%	DAF, wt%
Moisture, Total	24.4		
Ash	8.72	11.54	
Volatile Matter	47.14	62.36	70.50
Fixed Carbon	19.74	26.10	29.50
Sulfur	1.37	1.81	
Carbon		55.07	
Hydrogen		5.85	
Nitrogen		0.77	
Oxygen		24.96	
Gross calorific Value, Btu/lb	8,978	11,876	13,424

Tests: HGI = 50, HGMoisture = 2.55, Equilibrium moisture = 24.00%
Free swelling index (FSI) = 0.0

Table 4-2 North Dakota Lignite-Freedom Coal Analyses

Property	As Received, wt%	Dry, wt%	DAF, wt%
Moisture, Total	25.93		
Ash	14.15	19.10	
Volatile Matter	47.94	64.73	80.01
Fixed Carbon	11.98	16.17	19.99
Sulfur	1.02	1.38	
Carbon		48.07	
Hydrogen		4.98	
Nitrogen		0.66	
Oxygen		25.81	
Gross calorific Value, Btu/lb	7,658	10,339	12,780

Tests: HGI = 53, HGMoisture = 2.39, Equilibrium moisture = 29.50%,
Free swelling index (FSI) = 0.0

The second set of tables presents the data characterizing the fuels used in the ASPEN performance analyses of the various cases. These analyses provide the thermal performance results and the stream data used as input for the capital and O&M cost estimates presented later in this report.

Table 4-3 Montana Rosebud PRB Coal Analyses

Proximate Analysis	Dry Basis, %	As Received, %
Moisture	0.0	25.77
Ash	11.04	8.19
Volatile Matter	40.87	30.34
Fixed Carbon	48.09	35.70
Total	100.0	100.0
Ultimate Analysis	**Dry Basis, %**	**As Received, %**
Carbon	67.45	50.07
Hydrogen	4.56	3.38
Nitrogen	0.96	0.71
Sulfur	0.98	0.73
Chlorine	0.01	0.01
Ash	11.03	8.19
Moisture	0.00	25.77
Oxygen[1]	15.01	11.14
Total	100.0	100.0
Heating Value	**Dry Basis**	**As Received**
HHV, kJ/kg	26,787	19,920
HHV, Btu/lb	11,516	8,564
LHV, kJ/kg	25,810	19,195
LHV, Btu/lb	11,096	8,252
Hardgrove Grindability Index	57	
Ash Mineral Analysis		**%**
Silica	SiO_2	38.09
Aluminum Oxide	Al_2O_3	16.73
Iron Oxide	Fe_2O_3	6.46
Titanium Dioxide	TiO_2	0.72
Calcium Oxide	CaO	16.56
Magnesium Oxide	MgO	4.25
Sodium Oxide	Na_2O	0.54
Potassium Oxide	K_2O	0.38
Sulfur Trioxide	SO_3	15.08
Phosphorous Pentoxide	P_2O_5	0.35
Barium Oxide	Ba_2O	0.00
Strontium Oxide	SrO	0.00
Unknown	---	0.84
	Total	100.0
Trace Components		**ppmd**
Mercury[2]	Hg	0.081

[1] By difference
[2] Mercury value is the mean plus one standard deviation using EPA's ICR data

Table 4-4 North Dakota Beulah-Zap Lignite, Freedom, ND Mine, Lignite Design Coal Analysis

Proximate Analysis	**Dry Basis, %**	**As Received, %**
Moisture	0.0	36.08
Ash	15.43	9.86
Volatile Matter	41.49	26.52
Fixed Carbon	43.09	27.54
Total	100.0	100.0
Ultimate Analysis	**Dry Basis, %**	**As Received, %**
Carbon	61.88	39.55
Hydrogen	4.29	2.74
Nitrogen	0.98	0.63
Sulfur	0.98	0.63
Chlorine	0.00	0.00
Ash	15.43	9.86
Moisture	0.00	36.08
Oxygen[1]	16.44	10.51
Total	100.0	100.0
Heating Value	**Dry Basis**	**As Received**
HHV, kJ/kg	24,254	15,391
HHV, Btu/lb	10,427	6,617
LHV, kJ/kg	23,335	14,804
LHV, Btu/lb	10,032	6,364
Hardgrove Grindability Index	Not applicable	
Ash Mineral Analysis		**%**
Silica	SiO_2	35.06
Aluminum Oxide	Al_2O_3	12.29
Iron Oxide	Fe_2O_3	5.12
Titanium Dioxide	TiO_2	0.58
Calcium Oxide	CaO	14.39
Magnesium Oxide	MgO	6.61
Sodium Oxide	Na_2O	5.18
Potassium Oxide	K_2O	0.64
Sulfur Trioxide	SO_3	16.27
Barium Oxide	Ba_2O	0.56
Strontium Oxide	SrO	0.27
Manganese Dioxide	MnO_2	0.02
Unknown	---	3.00
	Total	100.0
Trace Components		**ppmd**
Mercury[2]	Hg	0.116

[1] By Difference
[2] Mercury value is the mean plus one standard deviation using EPA's ICR data

5. Liquid CO_2/Coal Slurry Properties

This section summarizes the results of the rheological testing of Powder River Basin (PRB) sub-bituminous and North Dakota lignite coals which took place at the laboratories of ATS Rheosystems in Bordentown, NJ. Both coal in liquid carbon dioxide slurries and coal water slurries were tested. A technique was developed for testing which minimized water absorption in the CO_2 slurries, and successful test runs on all three coals were performed. Coal water slurries were prepared at Columbia University and were also tested. It was found that the CO_2 based slurries had viscosities almost an order of magnitude lower than similar solids content coal water slurries. In addition, the maximum coal water slurry solids content was 60% by weight (but only 55% for the PRB coal) whereas the maximum coal liquid CO_2 slurry solids content was 68% by weight. These results were consistent with earlier tests on two sub-bituminous coals which were carried out by the Dooher Institute of Physics and Energy (DIPE) at ATS in 2009. Slurryabilities were calculated from the data and used to estimate maximum solids for slurries in a full scale slurry fed gasification system. The details of the testing are delineated in the sections that follow.

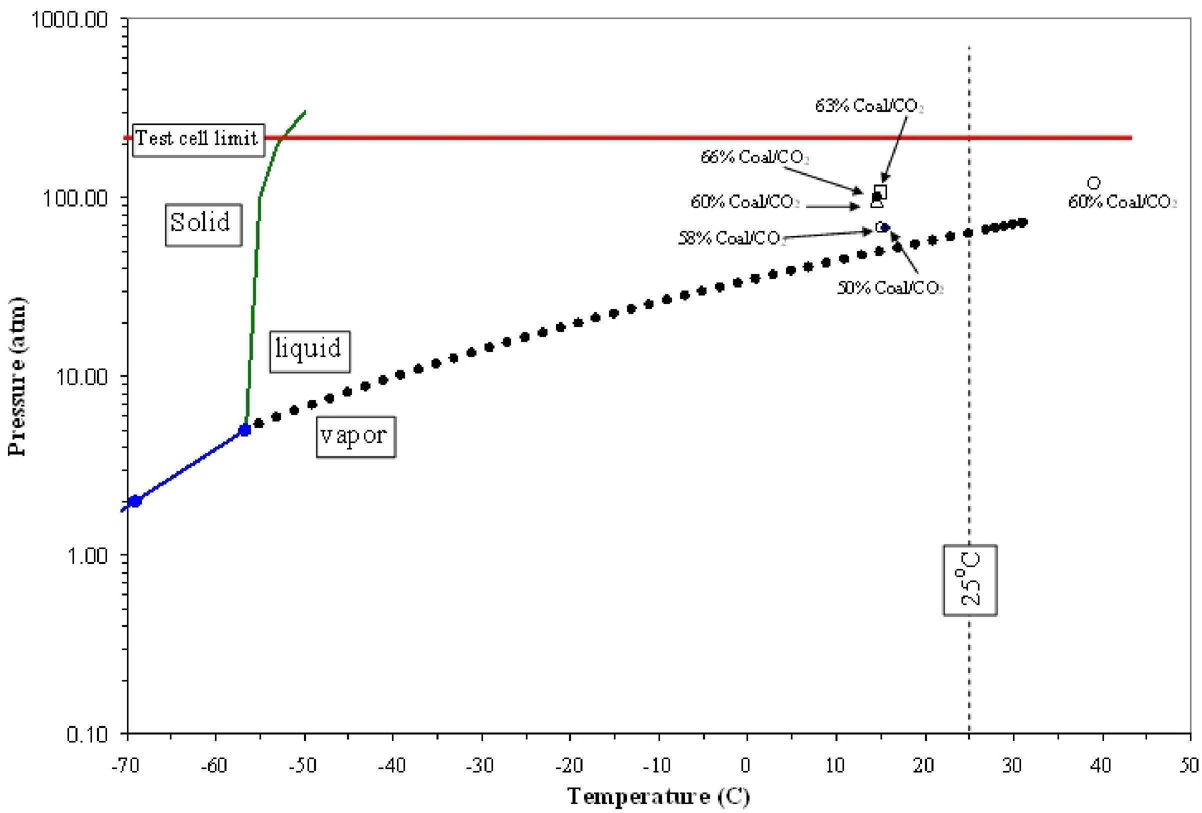
5.1 Coal and Liquid CO_2 Preparation

Two techniques were utilized to prepare liquid CO_2/coal slurries in the test cell which is shown in Figure 5-2.

In the first technique, after the cell has been cooled to about -20°C (-4°F) by spraying with dry ice, an amount of ground coal is added based on the estimated liquid level in the cell when the liquid state is attained. Then the cell is sealed and attached to the rheometer, liquid CO_2 is added, and the cell pressurized by nitrogen to over 6.89 MPa (1000 psig). The cell is then heated to 15°C (59°F) and the magnetically coupled rotor turned to attain high shear rates (>1000 s^{-1}) in the gap to mix the CO_2 and coal. This technique avoids water absorption and dry ice evaporation outside of the cell. Measurements on just liquid CO_2 alone yielded a viscosity in the 0 .4-0.5 cp, which though of the same order of magnitude as some of the values in the literature is generally higher, though none of those measured values utilized a bob and cup system with shear rates comparable to those analyzed here that include shear rates that may occur in plant handling (Fenghour). A calibration liquid with a known viscosity of 0.8 cp was tested in the system giving support to the value of the measurement with this first technique. A 50 wt% coal/CO_2 slurry was tested using this technique with a resulting viscosity of 30 cp at a shear rate in the 1000 s^{-1} range. When a higher concentration coal slurry (60 wt %) was attempted, it was not possible to obtain a consistent shear rate without decoupling of the rotor from the magnetic drive mechanism. This was mainly due to the fact that the cell was not large enough to avoid clogging at high concentrations.

This first technique was abandoned and a second technique was developed that consists of mixing dry ice and coal and then loading the cooled cell with a predetermined mixture, pressurizing, and heating. Measurements of the viscosity of liquid CO_2 using this dry ice loading yielded a viscosity in the 0.5 cp range, indicating much less water absorption than in the previous testing in 2009 where the viscosity was a factor of three higher. This could be due to lower relative humidity.

The graph below displays the conditions that where obtained for liquid CO_2 coal slurries. The temperature and pressure were recorded when viscosity measurements were stable. All slurries were well within the liquid regime, sufficiently above saturation. The PRB and lignite coal slurries were all tested in the same area in the CO_2 phase diagram.



Source: John Dooher, Adelphi University

Figure 5-1 Phase Diagram for Slurry Testing

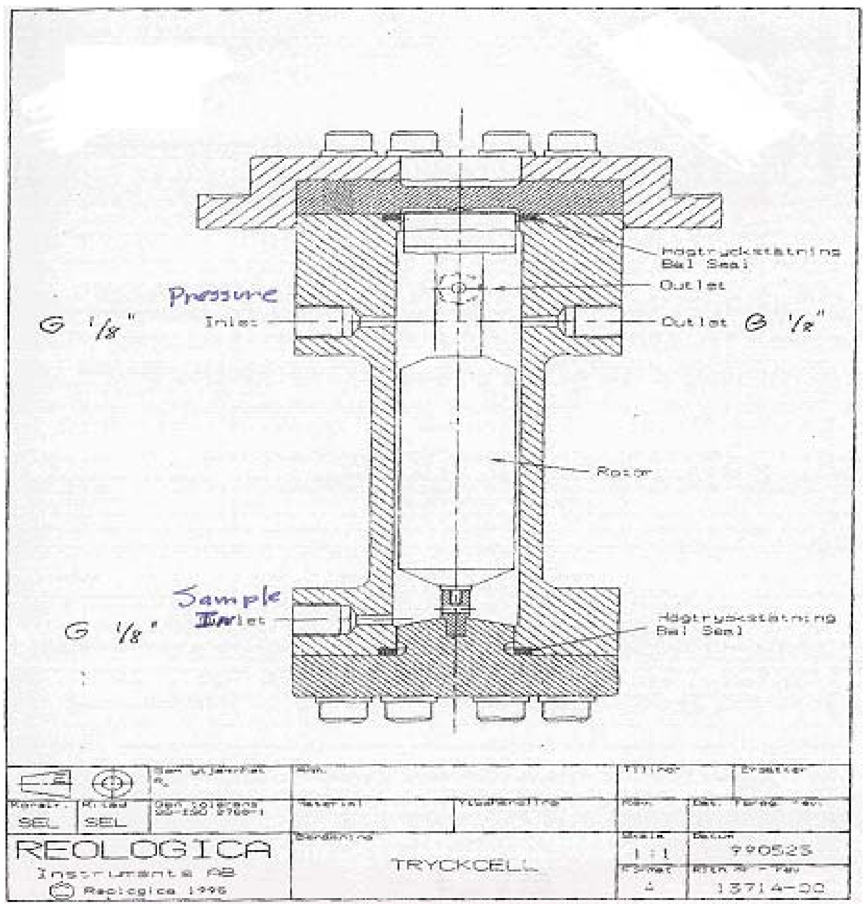
During the viscosity measurements taken at ATS, an attempt was made to determine the amount of CO_2 sublimation that could occur during transfer of the premade CO_2(s) coal mixture into the rheometer cup. A mixture of CO_2(s) and coal was prepared in a nitrogen purged glove bag. A scale in the bag was used to record weight loss rates for CO_2(s) sublimation from the mixture. This was compared to a CO_2(s) coal mixture prepared on the bench, not in a glove bag, in ambient conditions. The table below shows the rate of sublimation for both mixtures. A third test was done measuring pure CO_2(s) sublimation rates (i.e., no coal present) in a nitrogen purged glove bag. As evidenced in the table below, all rates were very similar.

Table 5-1 Sublimation Rates

Sample	Sublimation rate (grams sec^{-1} gram CO_2^{-1})
CO_2(s)/coal – in glove bag	0.0013
CO_2(s)/coal – on bench	0.0012
Pure CO_2(s) – in glove bag	0.0016

These sublimation rates were in-line with rates determined in literature (Caldwell et. al.) These results enabled determination of the actual slurry mixture that was loaded into the rheometer measurement cup. The loading procedure took approximately 3 minutes. Assuming CO_2 sublimed while in the rheometer cup, which is a worst case scenario since the cup was pre-cooled to approximately -20°C (-4°F), estimation was done to determine final slurry mixtures.

The targeted samples of 60, 63, and 66% were basically achieved. However, the 50 and 58% targets were significantly different from the final calculated ratios. This occurred because the first samples tested were the 50 and 58% that allowed determination of slurry preparation and loading protocols. Once all protocols were confidently established and sublimation rates accurately calculated, it was possible to compensate more precisely for the subsequent tests with the higher coal loadings.



Source: John Dooher, Adelphi University

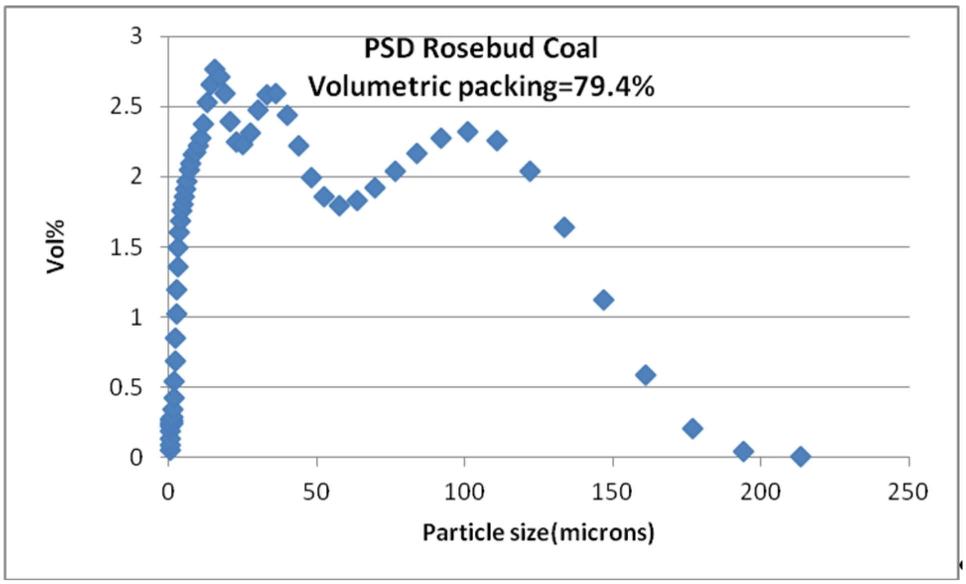
Figure 5-2 Test Cell Schematic

5.2 Powder River Basin (Rosebud) and North Dakota Lignite (Freedom) Coals

The analyses of both design coal samples were performed by SGS Minerals according to ASTM standards. Results are presented in Table 4-1 and Table 4-2.

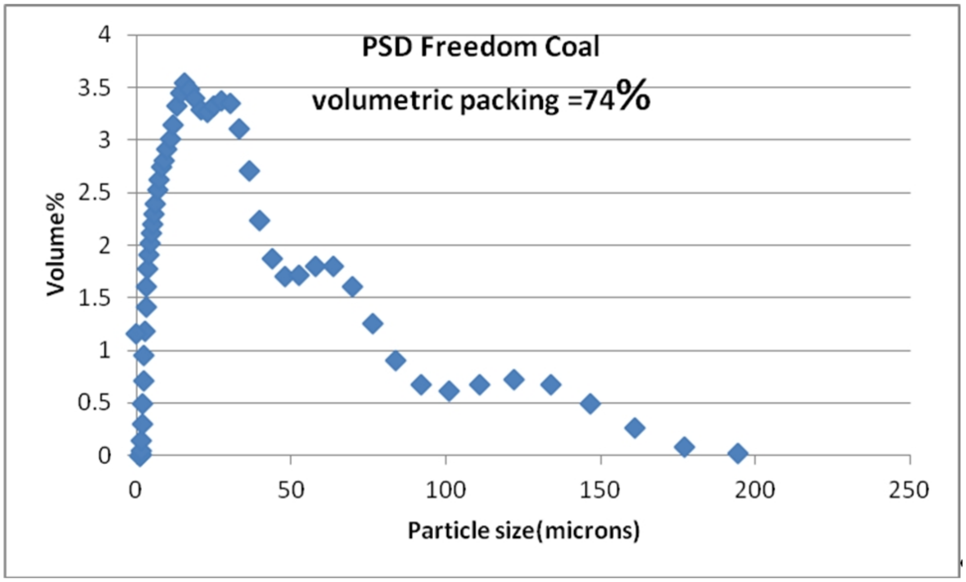
5.2.1 Coal and Sample Preparation

The Rosebud and Freedom coals were ground and sieved to specific particle size distributions supplied by the DIPE packing model in order to obtain geometric volumetric packings in the range of 74-80%. This was necessary since the top size of the distributions was cut off at about 150 microns in order to avoid any bridging in the narrow gap in the bob and cup system employed by ATS for the rheological testing. In an actual coal gasifier, the top size is generally much larger which can produce higher packings. However, once the slurryability is determined from the rheological tests results, the actual coal concentrations expected in a commercial gasifier can be determined. The particle size distributions for the two coals are depicted below.



Source: John Dooher, Adelphi University

Figure 5-3 Particle Size Distribution for PRB



Source: John Dooher, Adelphi University

Figure 5-4 Particle Size Distribution for North Dakota Lignite

5.2.2 Coal/Water Slurries

Coal/water slurries for the PRB and lignite coals were prepared according to the prescriptions shown in Table 5-2 and Table 5-3.

Table 5-2 Coal-Water Slurry Sample Prescription for PRB

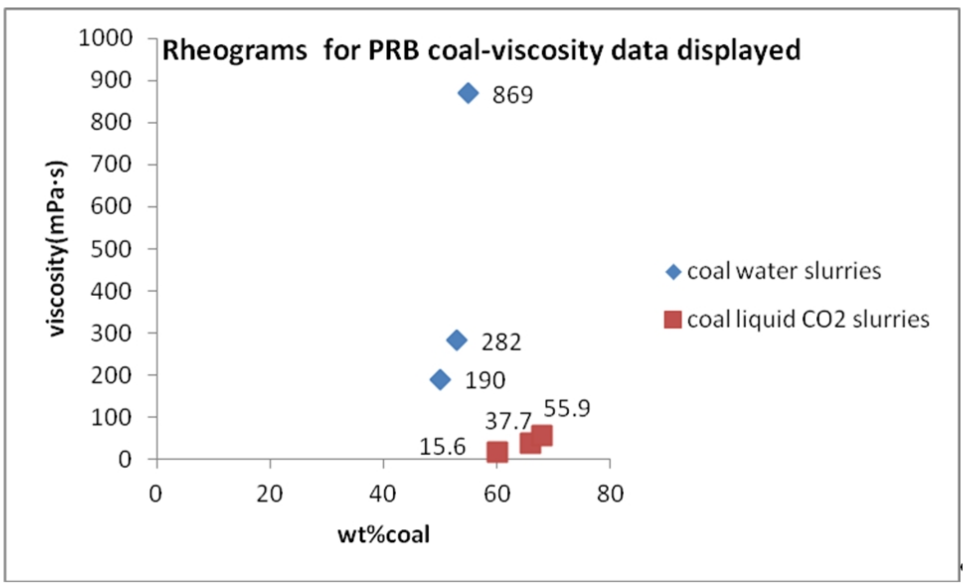
Mass Concentration (%)	Coal (gm)	Water (ml)	Amount of surfactant added (μL)
50	20.00	20	50
53	22.53	20	56.4
55	24.44	20	61.1

Table 5-3 Coal-Water Slurry Sample Prescription for North Dakota Lignite

Mass Concentration (%)	Coal (gm)	Water (ml)	Amount of surfactant added (μL)
45	16.36	20	41
47	17.73	20	43
50	20	20	50
60	30	20	75

5.2.3 Rheological Testing

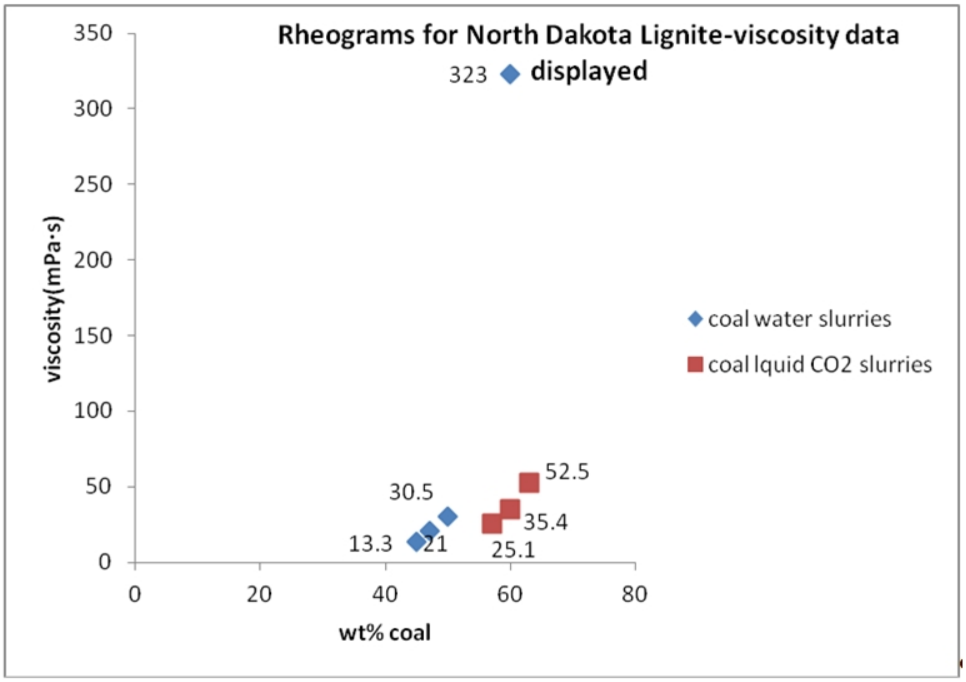
In Figure 5-5 and Figure 5-6, the results of the testing on coal/CO_2 slurries and the coal/water slurries are displayed including the specific viscosities which were obtained by averaging all data points for each slurry in the same shear rate range 1000 s^{-1}. The coal water slurries were tested using a conventional bob and cup system. Liquid CO_2 by itself was also measured yielding a result of 0.3 mPa·s, which was in general agreement with published values. The data fit the DIPE model reasonably well. The slurryability of both low rank coals in liquid CO_2 was 0.88-0.89, whereas in water it was 0.78 for lignite and 0.7 for PRB, indicating the potential of running close to 80% coal/liquid CO_2 slurries in a commercial gasifier with broad coal PSD's with packing fractions close to 0.9 compared to coal concentrations less than 70% in water with the same PSD. Some liquid CO_2 slurries were prepared at higher concentrations (70, 73, and 76%) with PRB, but results did not show the expected increase in viscosity indicating that mixing at very high concentrations (approaching maximum packing) in the rheometer is problematic and can lead to reduced coal concentrations in the measuring gap of the rheometer. This problem was not apparent at coal concentrations up to 68% for PRB.



Source: John Dooher, Adelphi University

#Wt% coal in CO_2(l) slurries = 60, 66, and 68
*Wt% coal in water slurries = 50, 53, and 55

Figure 5-5 Effect of Coal Concentration for Rheology of Rosebud Coal in Water and Liquid CO_2



Source: John Dooher, Adelphi University

#Wt% coal in CO_2(l) slurries = 57, 60, and 63
*Wt% coal in water slurries = 45, 47, and 60

Figure 5-6 Effect of Coal Concentration for Rheology of Freedom Coal in Water and Liquid CO_2

5.3 Liquid CO_2/Coal Slurry Properties References

- Fenghour, A., Wakeham, W.A., Vesovic, V, The Viscosity of Carbon Dioxide, J.Phys.Chem.Ref.Data,Vol27,no.1,1998
- Caldwell, D.C. et. al., 2006, Sublimation Rate of Dry Ice Packaged in Commonly Used Quantities by the Air Cargo Industry, Federal Aviation Administration, DOT/FAA/AM-06/19, Office of Aerospace Medicine, Washington, DC 20591

6. Liquid CO_2/Coal Slurry System Design Considerations

The liquid CO_2/coal slurry system replaces the water slurry coal preparation and feed system documented in the Baseline report. In the Baseline configuration, coal is ground and mixed with water to form a slurry or paste. Approximately 80 percent of this slurry is pumped at elevated pressure into the gasifier mixing nozzles at the ends of the horizontal gasifier section. The remaining 20 percent is routed to the injection nozzle in the upper stage of the two-stage gasifier.

The CO_2/Coal Slurry System described herein provides a liquid CO_2/coal slurry comprised of approximately 75 percent coal and 25 percent liquid CO_2. The liquid CO_2/coal slurry is prepared on a batch or continuous basis and is then pumped to the gasifier feed nozzles. The following discussion applies to both batch and continuous systems, except as noted.

Design of this system must account for the physical properties of CO_2 as manifested in its phase diagram, along with practical considerations that arise from good design practices for pressure vessels, heat transfer and refrigeration equipment, and design of solid and fluid transport systems for power plant applications. The liquid CO_2 must be maintained at an elevated pressure in order to remain in the liquid state. Two essential areas of design are considered below.

6.1 Refrigeration Work and System Design

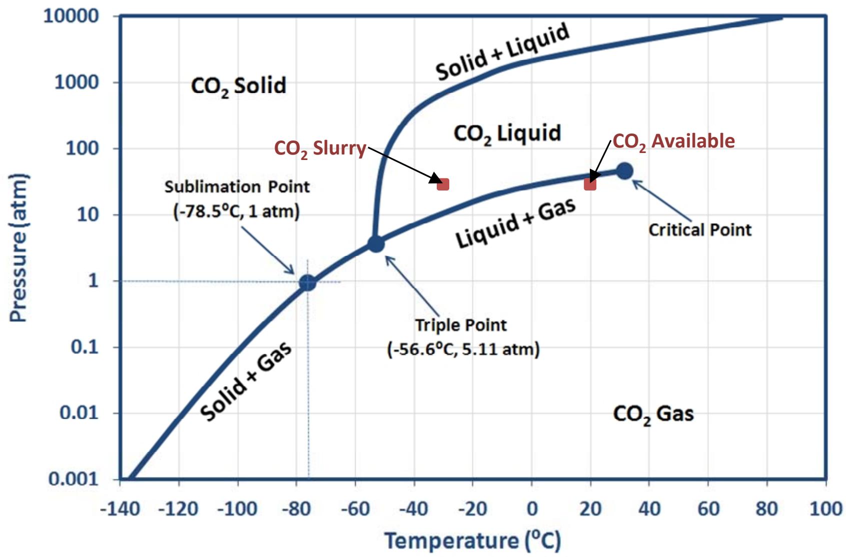
Figure 6-1 shows the phase diagram with the initial state of the CO_2 available and the final state of the CO_2 in the slurry. By definition, the slurry consists of coal particles mixed with the liquid CO_2. It is desirable to maintain some margin relative to the Liquid/Vapor phase boundary to avoid flashing of the CO_2 back to the vapor phase. For the purposes of this study, an operating CO_2 pressure and temperature for the preparation and feed system of 1.72 MPa (250 psig) and -23°C (-10°F) have been selected. This design condition was selected as a compromise between very low temperature and moderate pressure conditions and very high pressure but moderate (near normal ambient) pressures.

The condition selected provides a small design margin against the CO_2 vapor/liquid temperature boundary at this pressure of about 1.7°C (3°F). This is likely adequate due to the very large thermal mass of material (coal and CO_2) and the relatively low residence time in the mixing vessel (less than one hour) which will limit the potential for in-leakage of heat and consequent temperature rise of the contents. For the continuous flow type of system, heat transfer is less of a concern, due to the smaller residence time of material in the system.

This means that the coal and CO_2 must be chilled from their respective initial states; [3.10 MPa (450 psig) / 38°C (100°F) for the CO_2, and 0.10 MPa (14.7 psig) / 21°C (70°F) for the coal] to the desired temperature. The coal is taken from an outdoor coal pile and stored in an enclosed day silo. The coal is assumed to be drained and air dried prior to entry into the liquid CO_2 system (system boundary is at the tail pulley of the conveyor belt transporting the coal into the liquid CO_2 building at a point above the day silos).

The CO_2 is taken from an intermediate point in the CO_2 compression process at the tail end of the gasification plant CO_2 capture process. The CO_2 is assumed to be dried to very low moisture levels by a suitable drying process (TEG or molecular sieve). Based on their respective initial states, the refrigeration work required to chill these two slurry components can be calculated. Figure 6-2 shows the sensible heat that must be removed from the CO_2 to achieve a range of chilled temperatures (solid line). The dashed line shows the refrigeration work that must be expended to achieve the temperatures shown on the graph.

There are two separate concepts presented here: the solid line represents the amount of energy that must be removed from the CO_2 to change its temperature (a manifestation of the First Law of Thermodynamics); the dashed line represents the refrigeration work required to transfer this energy (heat) against an increasing adverse temperature gradient (a manifestation of the Second Law of Thermodynamics). The calculation of the data presented in the graph includes consideration of the coefficient of performance of a commercial refrigeration cycle, which is a function of the temperature gradient as well as individual component efficiencies and parasitic losses associated with typical commercial equipment.

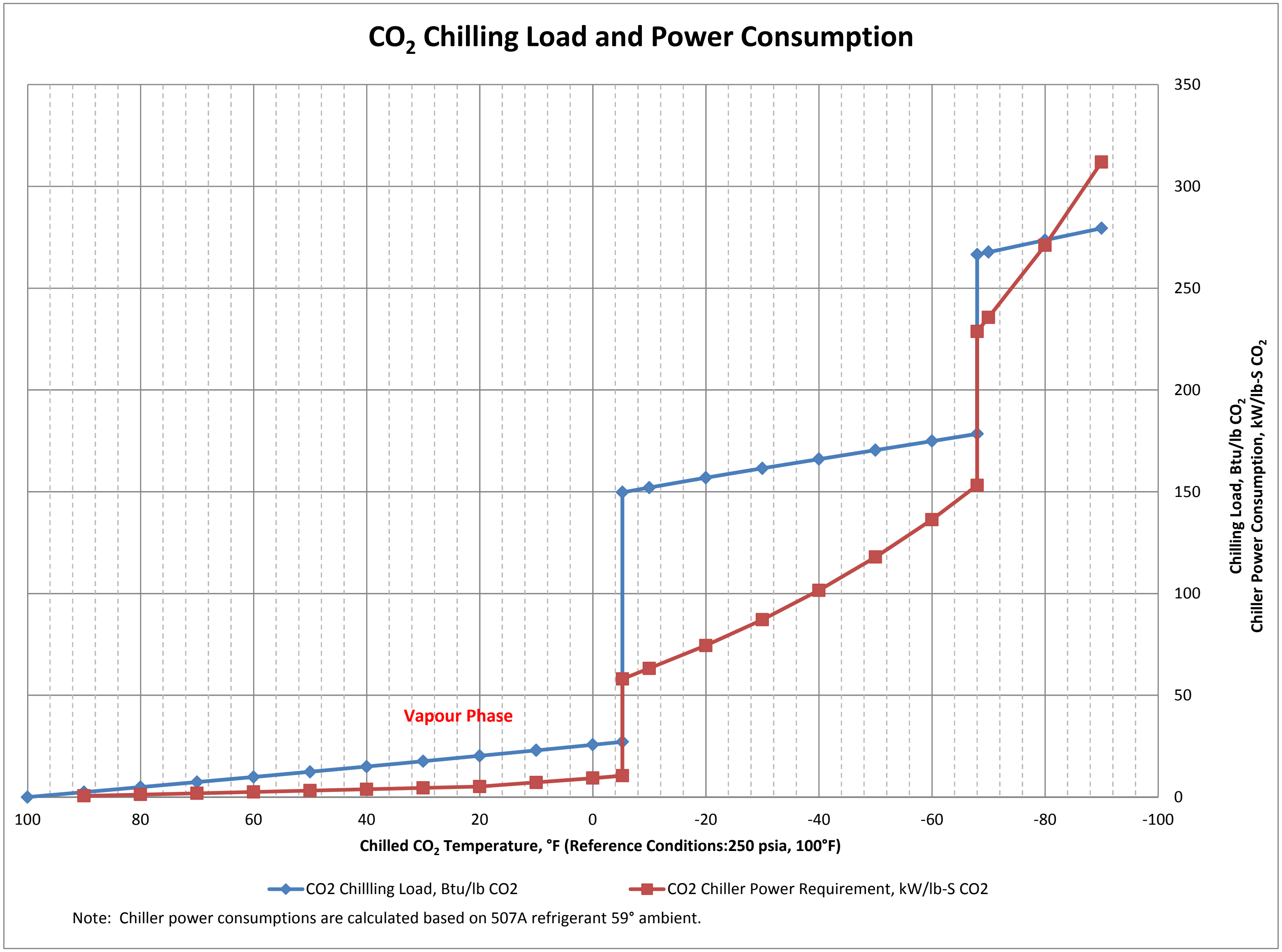


Source: WorleyParsons Group, Inc.

Figure 6-1 CO_2 Phase Diagram

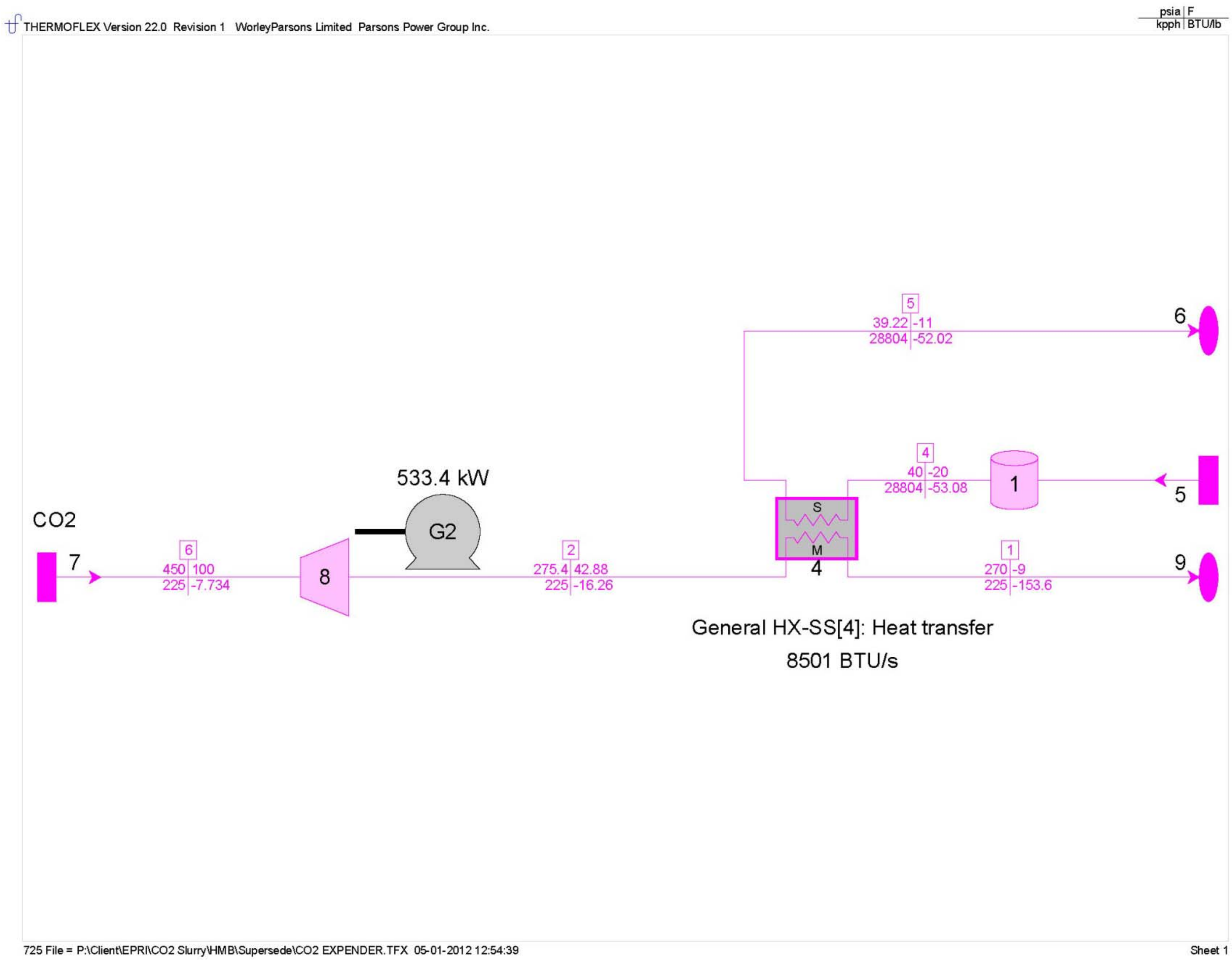
In order to reduce the amount of refrigeration work and the consequent capital and operating costs of the refrigeration system, the CO_2 is expanded in an industrial type gas expander to reduce its pressure and temperature and also to produce some useful power. The initial CO_2 pressure was selected based on its availability in the overall CO_2 capture system. The CO_2 at this node in the system has been partially compressed to its final pressure for pipeline injection, sequestration, or other beneficial use. At this node [3.10 MPa (450 psig) / 38°C (100°F)], the CO_2 has been cleaned and dried in a tri-ethylene glycol unit or a molecular sieve unit, and is without contaminants. The expansion produces a nominal 533 kWe in a suitable electrical generator. Figure 6-3 shows a simple schematic diagram with state point properties.

Figure 6-4 shows the sensible heat energy required to chill the coal from an initial state (taken as 21°C (70°F) to various temperatures of interest, and the corresponding refrigeration work required.



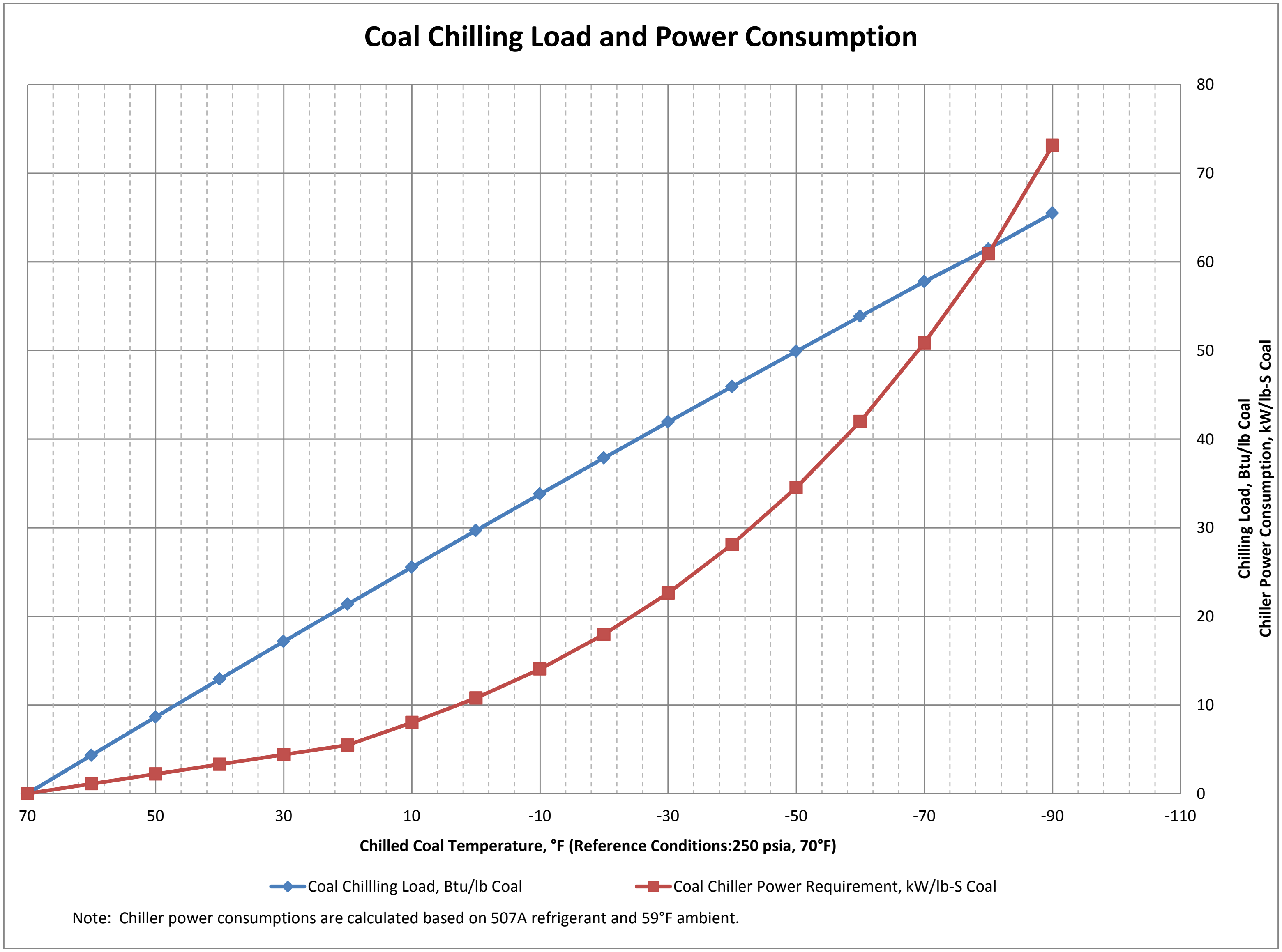
Source: WorleyParsons Group, Inc.

Figure 6-2 CO_2 Chilling Load and Power Consumption



Source: WorleyParsons Group, Inc.

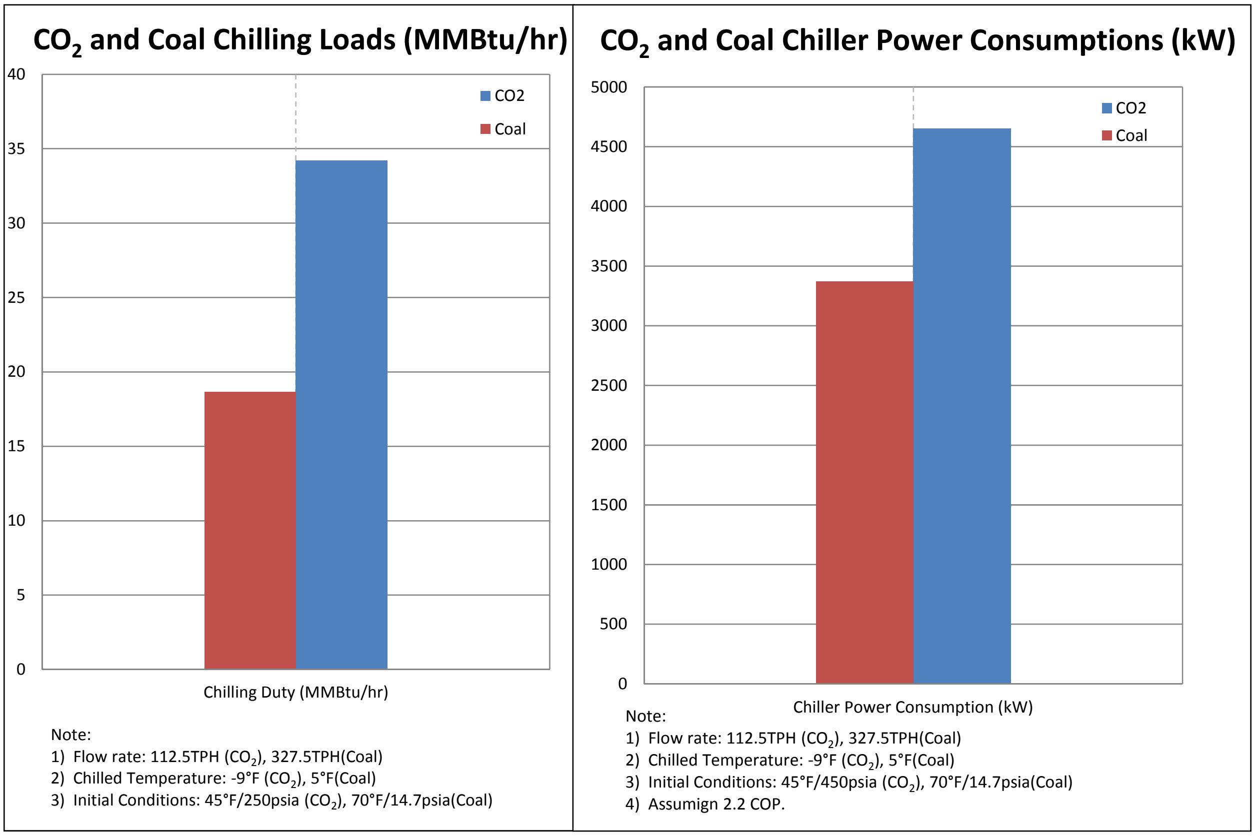
Figure 6-3 CO_2 State Point Properties with Expansion and Chilling



Source: WorleyParsons Group, Inc.

Figure 6-4 Coal Chilling Load and Power Consumption

Figure 6-5 compares the heat transfer and the refrigeration work required for chilling a unit amount (one pound) of coal and the same data for the same quantity of CO_2. It will be noted that the refrigeration power to chill the coal is approximately three quarters of that required for the CO_2.



Source: WorleyParsons Group, Inc.

Figure 6-5 Heat Transfer and Refrigeration

The implications of this are that both the coal and the CO_2 must be pre-chilled to near the desired slurry temperature. If just the CO_2 is chilled, the sensible heat in the coal at its initial temperature [21°C (70°F)] is so large that it will heat up the CO_2 as the two components are mixed, and heat transfer occurs as the mixture moves towards equilibrium. Higher coal temperatures, which might be experienced in summer conditions, will exacerbate this condition. This has the potential to cause significant flashing of the CO_2 back to the vapor state. Therefore, for this conceptual design, both the coal and the CO_2 will be pre-chilled to near the desired temperature.

6.2 Pressure Vessel Design Considerations (Batch Case)

Perusal of the CO_2 phase diagram (Figure 6-1 above) shows that the gas/liquid phase boundary slopes upward with increasing pressure and temperature. For the case of a vessel with a design pressure of 1.86 MPa (270 psig) and an operating pressure of 1.72 MPa (250 psig), to match the conditions cited above in the refrigeration discussion, consider the following:

An approximate value for the pressure vessel wall thickness can be calculated by the relationship:

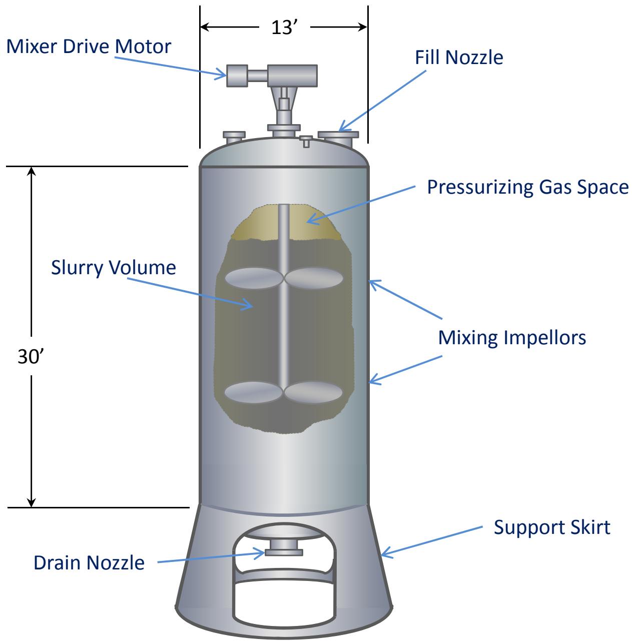
$$t_{wall} = \text{P (psig) X radius (inches)/allowable stress (psi)}$$

A vessel with a nominal 30 minute holding capacity must hold approximately 76 tonne (84 ton) of coal plus approximately 25 tonne (28 ton) of liquid CO_2 plus have some freeboard above the mixture surface. A reasonable set of dimensions for this vessel would be 4.0 m (13.0 ft) diameter with a height (straight side) of approximately 9.1 m (30.0 ft). The vessel would have dished heads and a nominal wall thickness of 2.8575 cm (1.125 in) if fabricated from a high performance plate material such as SA-516 Gr 70 (fine grained carbon steel,) qualified for low temperature applications.

By maintaining the wall thickness below 3.175 cm (1.25 in), post-weld heat treatment for stress relief can be avoided and the relatively thin wall is beneficial for avoiding nil ductility/brittle fracture issues. However, another major consideration for the specification and design of this vessel involves application of fatigue stress analysis. With a 40 year service life for the power plant, and an assumed 80 percent capacity factor for this type of unit, it can be predicted that each mixing vessel will be subjected to over 500,000 primary stress cycles in its useful life. This arises from the need to cycle from the empty condition at nominal 0.10 MPa (14.7 psia) (1 atm) pressure up to 1.72 MPa (250 psig) when ready to discharge. This cycling occurs at 30 minute intervals (see below). This is in contrast to assumptions made for typical power station piping and equipment in the ASME B&PV Code and the B31.1 piping code, which allow for several multiples of 10,000 cycles.

Therefore, a detailed fatigue stress analysis will be required for this vessel design. This analysis could result in a reduction in allowable stress for the plate material used to fabricate the vessel, with a consequent increase in wall thickness. Careful attention must be paid during design of the vessel to details of welding, nozzle reinforcement, etc. It is expected that all welds will require 100 percent radiography, along with application of other Non-Destructive Examination (NDE) methods, as appropriate. In addition, specification of Charpy V-notch testing of the materials of construction for fracture toughness at reduced temperatures will also be required.

A sketch of the proposed vessel is shown in Figure 6-6. The vessel dimensions account for providing proper geometry for the mixer mounted on top of the vessel, with a drive shaft reaching a nominal 7.6 m (25 ft) down into the slurry. This vessel has an operating capacity of a nominal 102 tonne (112 ton) of mixed coal and liquid CO_2 (3:1 mix by weight). At this size and capacity, two vessels are required for each gasifier train, or a total of four for the 550 MWe IGCC plant. The two vessels per train operated in a coordinated sequence, with one vessel feeding the gasifier while the second is filled and mixed. The cycle time is a nominal 30 minutes, after which the vessels switch roles by means of actuating a complement of leak-tight valves. The sizing allows for a dead band time of about 2 minutes for valve realignments, etc. For design of a commercial plant, it may be desirable to add a third vessel/mixer unit to each gasifier train. This will increase the time available for switching the duty phase of each vessel, and add some buffering time to the process. In addition, a surge bin between the chilled coal exiting the solids heat exchangers and the mixing vessel inlet may be required to temper fluctuations in coal flow rate when switching vessels. These decisions can be made during preliminary design of an actual plant.



Source: WorleyParsons Group, Inc.

Figure 6-6 Proposed Mixing Vessel

The selection of a higher operating and design pressure for the vessel will increase the operating temperatures based on the behavior of CO_2 (see Figure 6-1 above). For example, at a pressure of 5.69 MPa (825 psig or ~56 atm), for example, the phase boundary temperature is approximately 20°C (68°F). At this temperature, significantly reduced chilling or refrigeration is required. This would simplify the system design and reduce costs significantly. However, for a batch process, which requires a mixing vessel, the design pressure of this vessel must be around 5.86 to 6.03 MPa (850 to 875 psig).

With the same vessel OD, the wall thickness for this pressure will be in the range of 9.5 to 10.2 cm (3-3/4 to 4 inches). This clearly puts the vessel in a different category as far as materials of construction, design, welding, etc. are concerned. When the fatigue strength implications of the previous discussion are factored in along with potential brittle fracture considerations (which are significantly more involved for heavy wall vessels, but will also be considerably mitigated by the higher temperature), designing a vessel for this type of cyclic service at highly elevated pressures becomes more problematic. The weight and cost will increase very significantly.

It can be seen that there is an optimization process that is required to minimize the total cost of the system by selecting the best values for pressure and temperature and thereby influencing the refrigeration costs and pressure part costs (vessels, piping, valves, etc.).

For this conceptual design case, design parameters of 1.86 MPa (270 psig) / -23°C (-10°F) are selected, which support a vessel nominal wall thickness of 2.8575 cm (1.125 in).

6.3 Pressure Boundary Design Considerations (Continuous Flow Case)

The design of the continuous flow mixing system encounters considerations that are related to those that apply to the batch case. In order to maintain the CO_2 in a liquid state, the pressure and temperature must be held at compatible values. To mix the coal and the liquid CO_2, a suitable device must be found that can maintain a pressure boundary while accepting a moving stream of granular solids (coal) from one atmosphere to the required pressure (~17 atm). A search of available commercial devices revealed at least two manufacturers of suitable equipment. One such vendor was selected for application to this conceptual design study based on suitability and availability of technical and pricing information. Figure 6-7 shows a pictorial of a type of moving vane rotary valve manufactured by Andritz Inc.

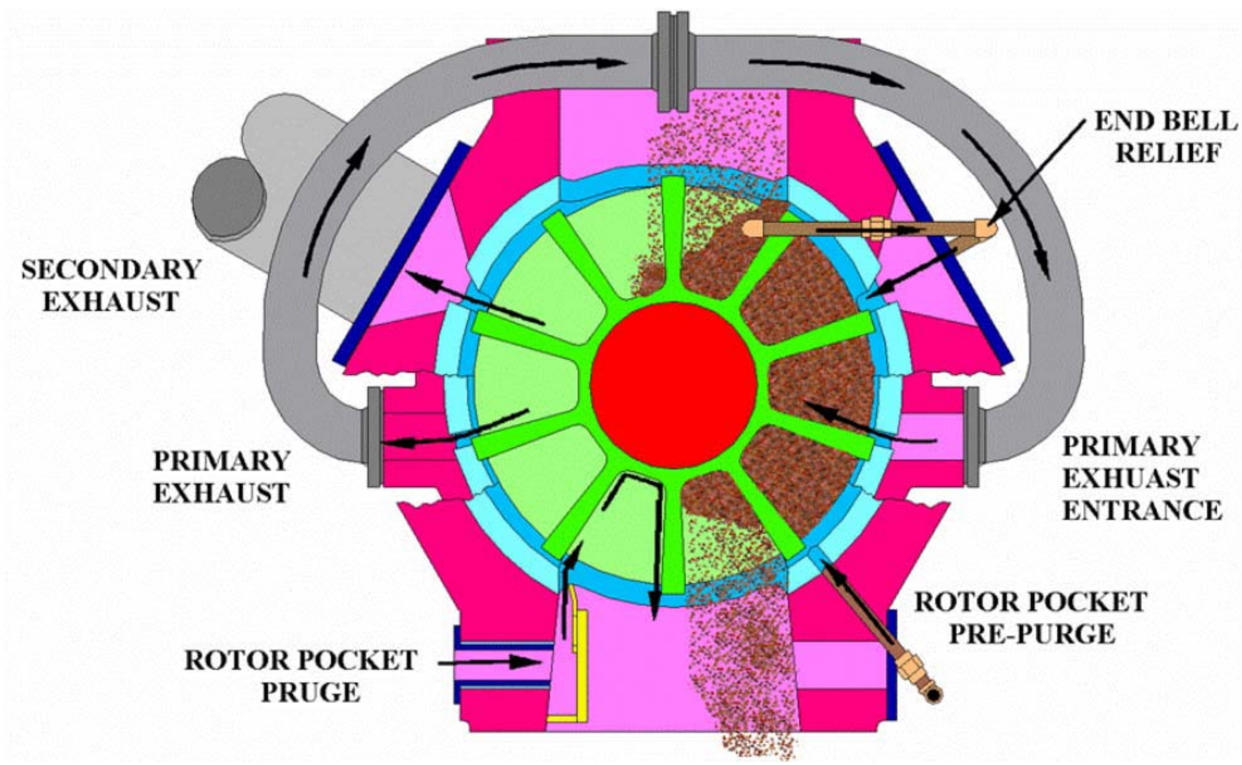


Figure 6-7 Andritz High Pressure Rotary Valve

The seal created by the moving vane against the casing that the valve rotates in provides the necessary pressure boundary. Dry, chilled coal is admitted at the top of the valve and occupies each valve pocket in succession as the valve rotates. The valve pockets discharge into a vertical pipe maintained at the required pressure by pumping liquid CO_2 in at a suitable rate. The same design pressure and temperature conditions are used herein for the continuous flow case as are used for the batch case. The Andritz High Pressure Rotary Valve is available now with a maximum operating pressure of about 1.72 MPa (250 psig) and a casing design pressure of about 2.41 MPa (350 psig). These parameters are exactly matched to the batch system requirements, and hence the same parameters are used for the continuous flow case. The system is described in more detail, along with the batch system design, in Section 7.

The continuous flow system design is very close to the batch system design. Most of the equipment and building structure remain as before, except that the mixing tanks are replaced in the flow diagram by the Andritz rotary valves, and a few additional ancillary components.

7. Liquid CO_2/Coal Slurry System Design Description (Batch and Continuous Cases)

7.1 Introduction

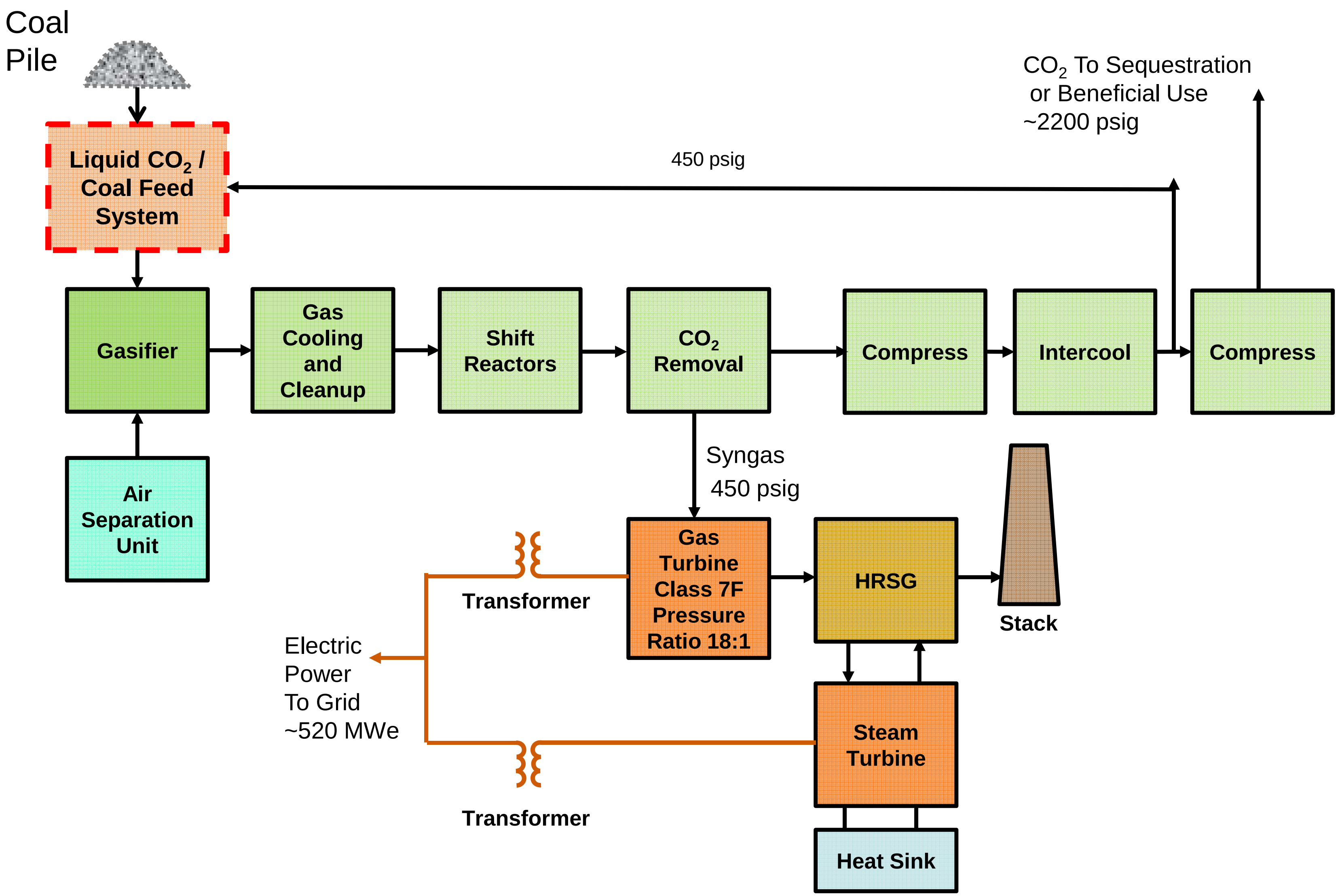
The liquid CO_2/coal slurry system prepares and feeds a slurry comprised of nominally 75 percent coal and 25 percent liquid CO_2 (by weight) to an oxygen blown entrained flow gasifier that is part of a complete gasification and electric power generation facility that also captures CO_2 and compresses it for pipeline injection. The overall gasification and power generation system is shown in Figure 7-1 below.

The liquid CO_2/coal slurry system is one of many systems comprising the entire facility. The scope of design for this description is limited to the liquid CO_2/coal system and related supporting subsystems. Figure 7-2 below presents a simplified block diagram of the liquid CO_2/coal prep and feed system.

The subject system is comprised of three subsystems that comprise the entire functional liquid CO_2/coal slurry system. These three subsystems are:

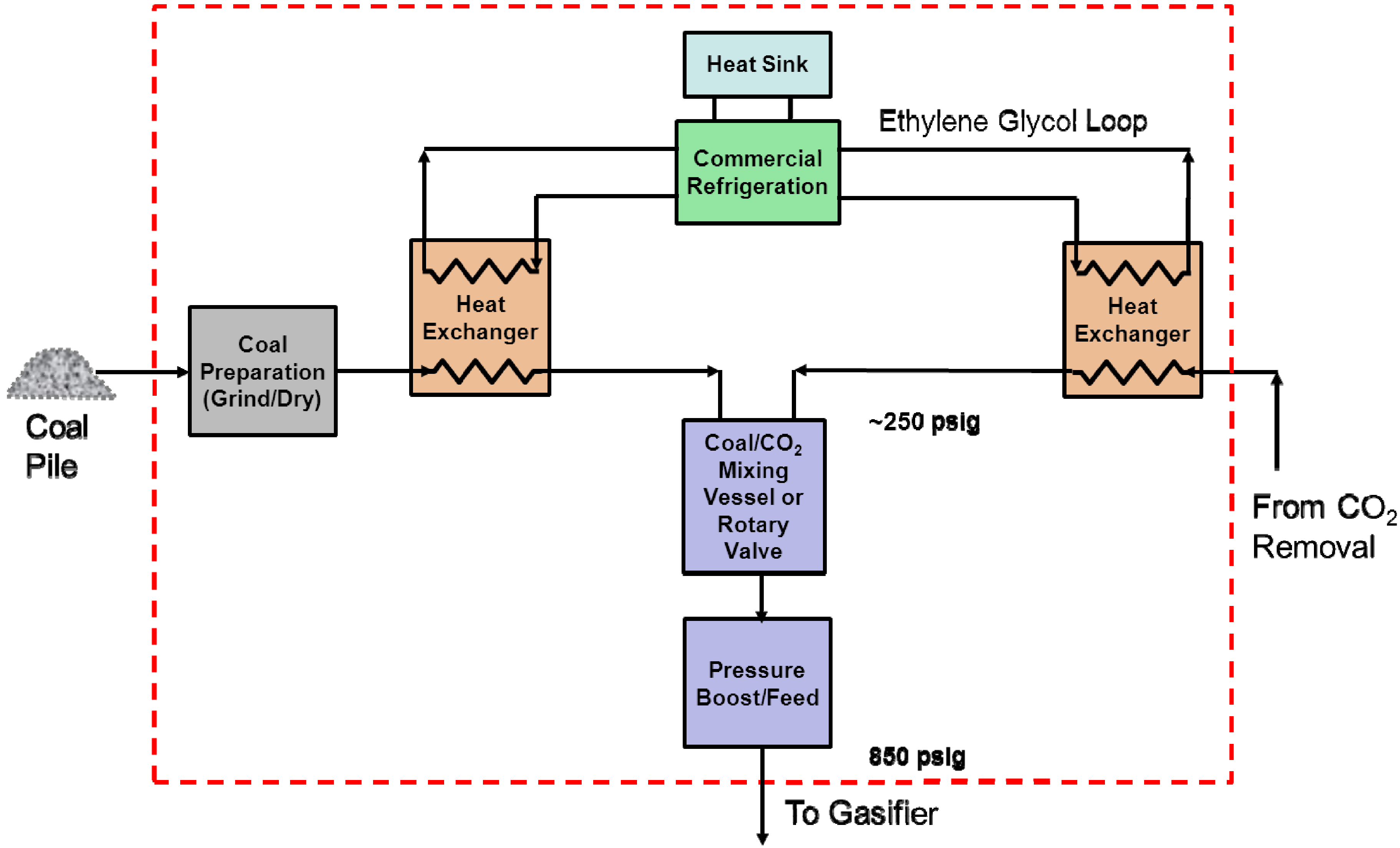
- Coal and CO_2 Chilling, Mixing, and Feed
- Refrigeration Package and Chiller Loop
- Gaseous CO_2 Transfer and Chilling System

Flow diagrams of each subsystem are presented at the end of this section. General arrangement drawings for the liquid CO_2/coal slurry building are presented in the Appendix to this report. The building is sized and configured to house the batch system; however, this design is also applicable to the continuous flow system as well. The principal difference lies in the elimination of the mixing vessels, and their replacement with the high pressure rotary valves. The same basic sub-processes are required with the mixing function performed in an in-line (pipeline) mounted mixer. The same storage, coal grinding, refrigeration, and other processes are required for both batch and continuous systems.



Source: WorleyParsons Group, Inc.

Figure 7-1 Gasification System with CO_2 Capture



Source: WorleyParsons Group, Inc.

Figure 7-2 Liquid CO_2 / Coal Feed System

7.2 System Functions

The system receives and stores a one day supply of rough-sized coal, grinds the coal to the specified particle size, chills the coal to a low temperature (nominally -23°C [-10°F]), mixes the coal with liquid CO_2 in a mixing vessel or length of pipe, and finally, pumps the coal forward to the gasifier inlet connections at the required final pressure.

7.3 Design Scope and Design Criteria

The scope of the system design is from the top of the coal day bins to the slurry feed connections on the gasifiers.

Applicable codes and standards for the liquid CO_2/coal slurry prep and feed system include:

- System piping will be subject to ANSI B31.1, "Power Piping"
- The coal day silo will be subject to ACI 313, "Standard Practice for Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Material"
- The coal solids chilling heat exchangers will be designed and constructed in accordance with the ASME Boiler & Pressure Vessel Code, Section VIII, Division 1, but will not be Code Stamped or registered. These are essentially atmospheric pressure vessels.
- The mixing vessels will be subject to the ASME Boiler & Pressure Vessel Code, Section VIII, Division 2, and will be code stamped and registered. Detailed fatigue stress calculations are required, along with fracture toughness evaluation.

7.4 Performance Criteria

The system will be capable of storing 24 hours of fuel in two (2) day silos of 3,719 tonne (4100 ton) each.

The system will be capable of chilling the design firing rate of 307 tonne/hr (338 ton/hr) of PRB coal from ambient temperature (nominally 21 to -23°C (70 to -10°F)).

The system will be capable of chilling 103 tonne/hr (113 ton/hr) of CO_2 from a nominal pressure and temperature of 3.28 MPa (475 psig) / 38°C (100°F) (gaseous state) to an end point of 1.86 MPa (270 psig) / -26°C (-15°F) (liquid state).

The system will be capable of mixing the chilled coal and liquid CO_2 to a relatively homogeneous mixture with minimal rise in temperature, and pumping the mixture forward to the gasifier feed nozzles at a pressure of a nominal 5.86 MPa (850 psig).

The overall system is divided into two separate trains, each associated with one of the two gasifiers, with subsystem cross-ties provided to enhance reliability and availability.

7.5 System Description for Coal and CO_2 Chilling, Mixing, and Feed Subsystem

The subject system stores a one day supply of rough-sized coal reclaimed from the coal pile, and grinds it and chills it in preparation for making the liquid CO_2/coal slurry. This system also mixes the chilled coal and CO_2 and pressurizes and feeds it to the gasifiers.

7.5.1 Coal and CO_2 Chilling, Mixing, and Feeding Summary Description

Sized coal (1.3 cm [0.5 in] by zero) is supplied to the day silos by a conveyor from the plant coal reclaim and transport system. The system scope boundary is at the top of the day silo. The day silo is topped up at the end of each day shift and refilled as needed each day.

In normal operation of the facility at full rated load, the coal exits the bottom of the silo into a weigh feeder and metered to the inlet of a group of rod mills. The rod mills grind the coal to the required particle size and discharge same to the inlets of a complement of screw type solids pumps. An inert fluidizing gas, such CO_2 is supplied to the screw pumps to fluidize the coal and facilitate dense phase transport. A Fuller-Kovako Screw pump or equivalent type of pump provides motive means to transport the coal to the inlet of a cycle located above the inlet to the bulk solids coolers.

For each of two trains, the coal is discharged from the transport system to the top of two bulk solids heat exchangers. In the freeboard space at the top of these heat exchangers, the coal is disengaged from the CO_2 fluidizing gas, which is vented through a dust filter and returned to the IGCC CO_2 capture system. The bulk solids coolers pre-chill the coal, which avoids the necessity of chilling the CO_2 to the very low temperatures required to create the coal/CO_2 slurry mixture without presenting the potential for the CO_2 to flash back to vapor unless considerably higher pressures are maintained in the system (at 20°C [68°F], a pressure of approximately 5.69 MPa [825 psig] is required).

7.5.1.1 Batch System

For each train, the chilled coal falls by gravity into and through a rotary valve into one of two mixing vessels (see vessel sketch, Section 6, above) for each train in the two train system. The vessel is maintained at atmospheric pressure with an inventory of gaseous CO_2. As coal fills the vessel, gaseous CO_2 is vented to a collection system for recycling. When the desired coal inventory is established, the vessel is made pressure tight, and the fill of liquid CO_2 is initiated. The mixer is started early in the CO_2 fill cycle, to get an early start on mixing. When the desired CO_2 inventory has been loaded, the vessel is isolated and mixing continues. At the appropriate time in the overall chill-mix-feed cycle, the bottom discharge valve is opened, and the slurry injection pumps are started. These pumps provide the discharge head required for feed into the gasifier.

Note the arrangement in the batch system flow diagram in Figure 7-3. Coal flow is maintained through both of the bulk solids coolers simultaneously, but is then diverted into only one of the mixing vessels at a time. At any given time, one vessel will be in the fill and mix part of the cycle, while the other vessel is under pressure and is feeding the gasifier. After the feed vessel exhausts its inventory of slurry mix (nominally 30 minutes), the vessels switch roles and thus alternate between filling/mixing and feeding. Two vessels are required for each gasifier train for a total of four for the entire 550 MWe gasifier plant. As noted previously, a surge bin may be required between the bulk solids coolers and the mixing vessels.

7.5.1.2 Continuous Flow System

The continuous flow system operates in a similar manner to the batch system described above, except as follows: The coal is metered through a low pressure rotary feeder to the inlet of an Andritz feed bin. This bin is designed to accompany the Andritz metering screw and high pressure rotary valve that follow in series. The feed bin acts as a surge bin to smooth out the flow of solids. The high pressure rotary valve (HPRV) transports the coal across the pressure boundary between atmospheric pressure and the higher pressure 1.72 MPa (250 psig) required to maintain the CO_2 in a liquid state. The HPRV discharges into a horizontal mixing pipe section that incorporates several in-line mounted mixers in series. The mixing pipe section discharges to a suction header for the Putzmeister high pressure pumps for the final pressure boost to 5.86 MPa (850 psig). The Putzmeister discharge header conveys the mixed liquid CO_2 slurry to the gasifier feed nozzles.

The continuous flow system is illustrated in Figure 7-4.

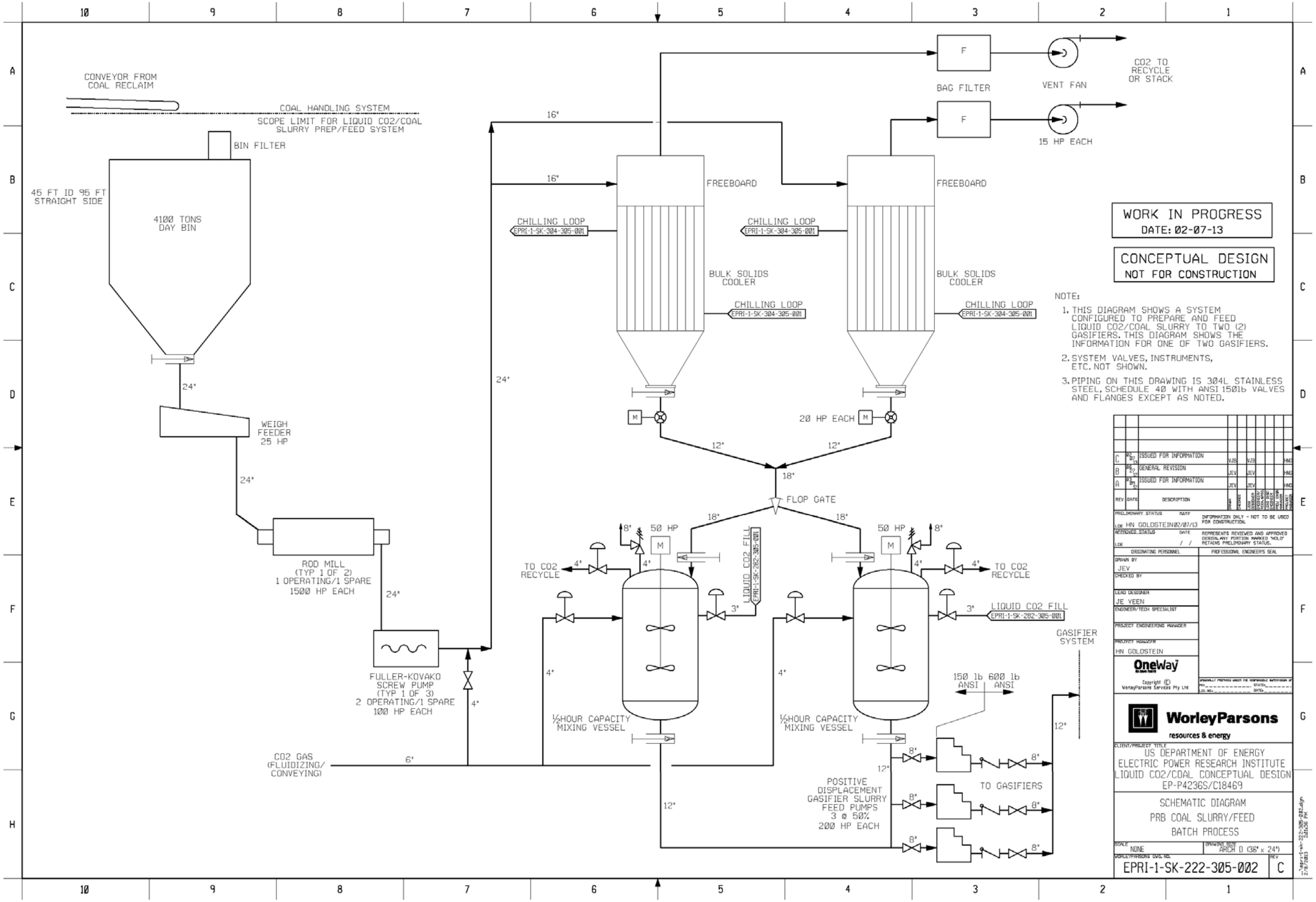


Figure 7-3 Batch System Flow Diagram

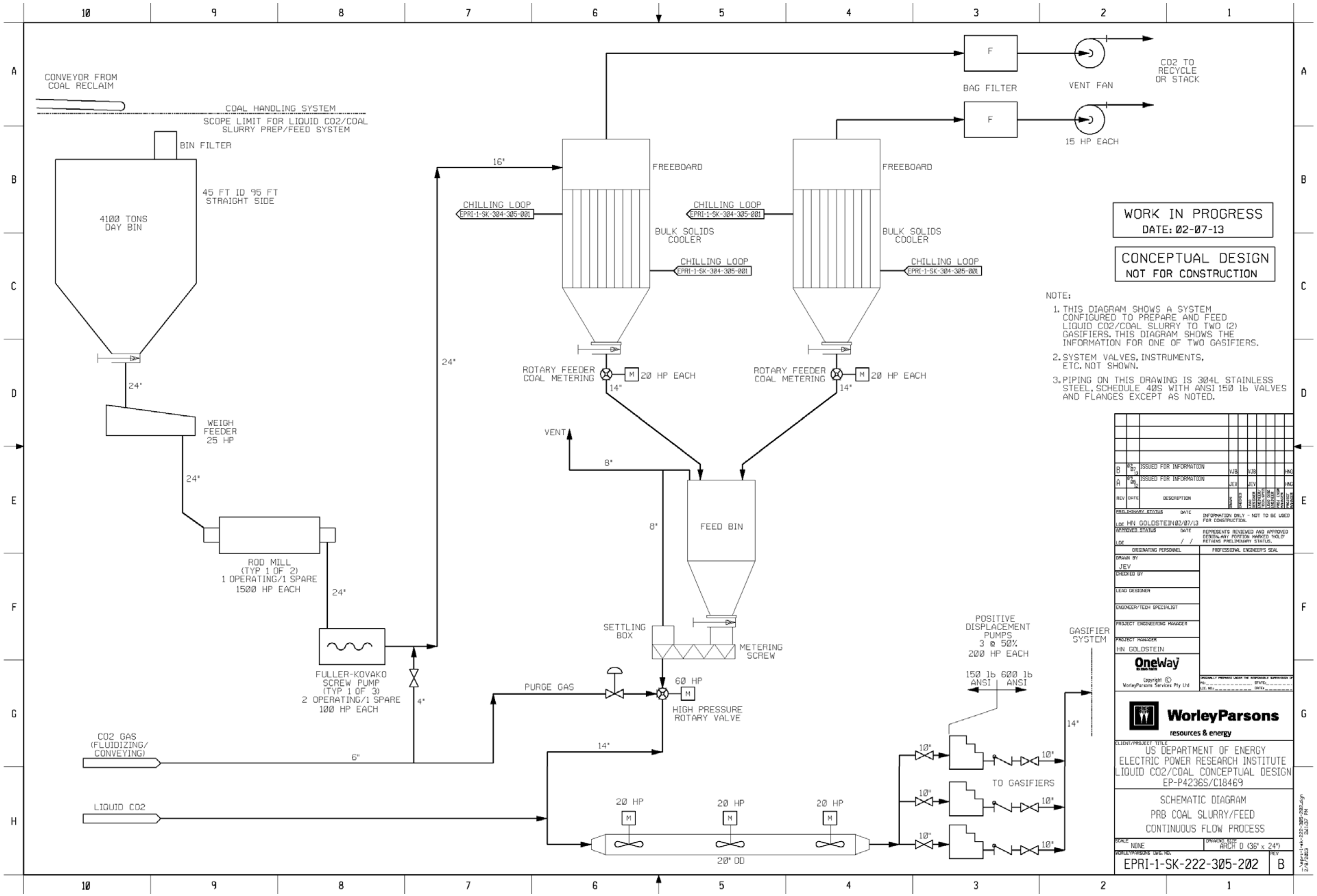


Figure 7-4 Continuous System Flow Diagram

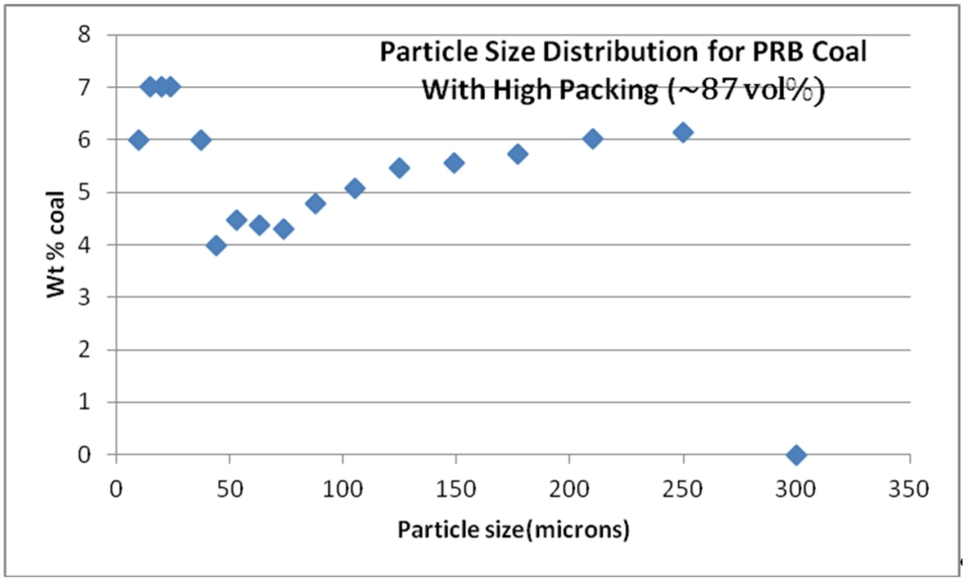
7.5.2 Coal and CO_2 Chilling, Mixing, and Feeding Subsystem-Major Components

Note: The following equipment is required for both batch and continuous feed systems.

Day Bins: One day bin is provided for each of two trains of equipment for a total of two for the entire 550 MWe IGCC plant. Each day bin is constructed as a slip-formed unlined concrete silo, with 13.7 m (45.0 ft) ID and 29.0 m (95.0 ft) height (straight side). A smooth finish is provided for the inside surface to minimize friction. The bottom cone is fabricated from carbon steel plate clad on the inside surface with 316 stainless steel. The inside surface is polished to minimize friction and allow the material to flow freely. Each silo has a working capacity of a nominal 3,719 tonne (4100 ton). The silos are provided with vent fans and filters for fugitive dust control.

Weigh Feeders: Each silo is equipped with a weigh type feeder to meter coal from the bottom of the silo to a downcomer that delivers the coal to the feed chute of each of two rod mills. Two weigh feeders are required, with capacities of nominal 154 tonne/hr (170 ton/hr) each. The weigh feeders require drive motors rated at 18.6 kW (25 hp) each.

Rod Mills: Each rod mill has a nominal capacity of 154 tonne/hr (170 ton/hr) of PRB coal. The coal is ground to meet the sizing requirements of the E-Gas™ gasifier, with particle size distribution as shown in Figure 7-5 below. Two rod mills at 100 percent capacity each are provided for each of two trains, (total of four mills), each driven by motors rated at approximately 1,119 kW (1500 hp) each.

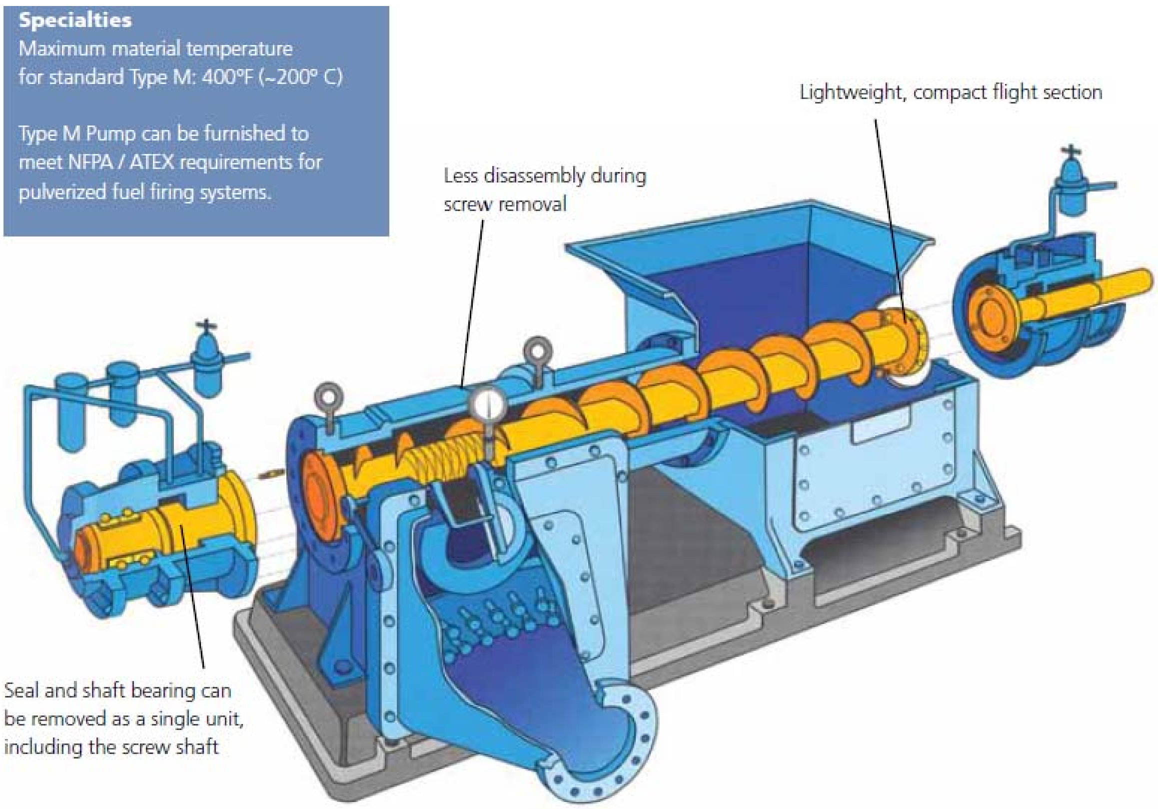


Source: John Dooher, Adelphi University

Figure 7-5 Particle Size Distribution for PRB Sub-bituminous

Note: This particle size distribution was used as a guide for rheological testing. The specified distribution for the actual gasifier operation is required.

Screw Pumps: These are positive displacement screw type pumps designed to receive granular solids and compact and advance this material into a pipeline. Three pumps at 50 percent capacity each are required for each of two trains, with drive motors rated at 75 kW (100 hp) each. Four pumps in total operate to maintain the plant at 100 percent load, with two pumps as installed spares. Compressed gas (in this case, CO_2), is used in a discharge body to fluidize the material and complete the transfer into the transport pipeline. The material is conveyed in a pipe to the top of the bulk solids cooler, where the fluidizing gas (CO_2) is disengaged and the material is allowed to settle into the top of the receiving hopper. The CO_2 is collected by a vent system and recycled in the IGCC facility. A pictorial image of this type of screw pump is shown below.



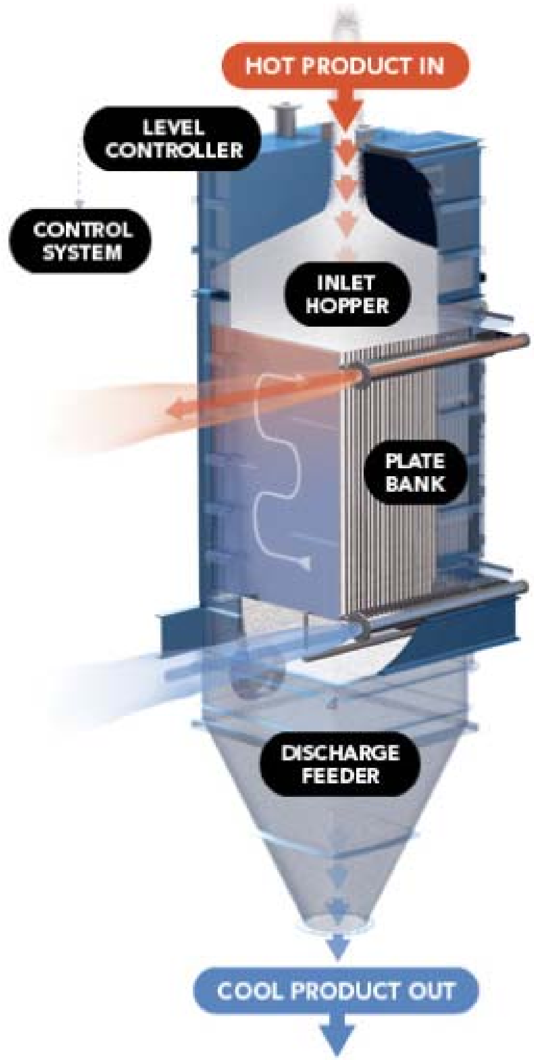
Reproduced by permission of FLSmidth A/S

Figure 7-6 FULLER-KINYON™ Screw Pump

Bulk Solids Coolers: These units operate by passing the fine granular coal down (by gravity) past a set of vertical plates containing cooling passages; the entire device is contained in a bin or silo. A total of four solids coolers are required for this 550 MWe IGCC plant with all four coolers in service at the same time. These units do not have moving parts, and have been extremely reliable in prior service; hence no spare is provided. Externally mounted rappers may be provided to mitigate potential sticking or bridging of the coal. The interior surfaces of the coolers will be polished stainless steel.

These units are commercially available from at least one manufacturer, who builds solids coolers and heaters for a wide range of materials, including minerals, fertilizers, grains and seeds, etc.

An external loop of ethylene glycol-based coolant is circulated through the plate passages. An illustration of this type of unit is presented below.



Reproduced by permission of Solex Thermal Science

Figure 7-7 Bulk Solids Cooler

Note: the following equipment is only required for the batch system.

Mixing Vessels: The mixing vessels are pressure vessels designed and fabricated in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII (Unfired Pressure Vessels), Division 2. They are code stamped, registered, and provided with overpressure protection. The vessels are provided with motor operated mixers that utilize two impellors submerged in the slurry mixture. The mixers promote good mixing of the coal and CO_2 into a homogeneous slurry ready for injection into the gasifiers. A general arrangement sketch of the mixing vessel is shown in Figure 6-6, with the top-mounted mixer incorporated.

***Note: the following equipment is only required for the continuous flow system*:**

Andritz Feed Bin: this is a surge bin designed to complement the metering screw and high pressure rotary valve

Metering Screw: This screw feeds the dry granular material to the inlet chamber of the rotary valve.

High Pressure Rotary Valve: This rotary device provides a continuous series of rotating pockets that transport dry granular solids across a pressure boundary from low pressure to high pressure with minimal back-leakage. The operation of the valve depends on venting the various moving compartments between each other as the valve rotates and solids alternately enter and exit the valve. The valve is rotated by a hydraulic drive system, with auxiliary motors for positioning and lubrication.

***Note: the following equipment is required for both batch and continuous flow systems*:**

Gasifier Feed Pumps: These are positive displacement piston type pumps selected for their ability to pump slurries and solids at high delivery pressures with high reliability and good wear characteristics. These pumps receive the slurry material from the bottom drain connection of the mixing vessels and discharge into the high pressure feed line to the gasifiers.

The pumps are rated at a capacity of 115 m^3/hr (4,060 ft^3/hr) and a delivery pressure of 6.00 MPa (870 psig) against a requirement for 90m^3/hr (3,180 ft^3/hr) and 5.79 MPa (840 psig). A total of two pumps per train, or four for the entire 550 MWe gasifier plant, are required to operate to maintain 100 percent load. Two additional pumps are provided as installed spares. Each pump requires a drive motor of 75 kW (100 hp) to power the hydraulic system that drives the pump actuators.

A specific vendor has been providing these types of pumps to several coal fired power plants in Europe (Sweden), where they pump a water/coal paste of about the same composition (25 percent water/75 percent coal) as the liquid CO_2/coal mixture described herein. Other vendors and types of pumps may be satisfactory for this service. For the purposes of this report, the specific vendor and pump model selected is illustrated below.

Figure 7-8 Putzmeister High Density Solids Pump

7.5.3 Coal and CO_2 Chilling, Mixing, and Feeding Subsystem-Minor Components

***Note: except for the pressure relief valves, the following components are required for both the batch and continuous flow systems*:**

Level Detectors for the day silos and mixing vessels are required. These are expected to be radar type units, which are able to detect a gas/liquid or gas/solid surface with good accuracy and reliability, and without moving parts or parts exposed to the medium under measurement.

Control Valves are required for the CO_2 vent of each mixing vessel. This is used during the fill phase of the cycle. As the chilled coal is introduced into the vessel, part of the CO_2 gas blanket must be released from the vessel to maintain the pressure within the vessel at nominally one (1.0) atmosphere. Control valves are also required for the CO_2 supply to each vessel, used when the tank is pressurized to its working pressure before pumping in the liquid CO_2.

Pressure Relief Valves are provided for each mixing vessel. These valves are spring loaded mechanical type valves, designed to meet ASME overpressure relief requirements for pressure vessels. In addition to these valves, the various fill and vent valves and the operation of the positive displacement gasifier feed pumps must be coordinated to avoid overpressure or the development of vacuum conditions in the mixing vessels. The flow of material into and out of these vessels will be controlled by the Gasifier Fuel Preparation system process controller. The need for pressure vessel vacuum relief valves in addition to the overpressure relief valves must be evaluated more definitively in an actual design.

Process Instrumentation (indicators and transmitters) for pressure, temperature, level, and flow will provide monitoring and control of system process parameters. The number, type, and location of these devices will be decided during detail design.

7.6 Refrigeration Package and Chiller Loop System

Note: This entire system is required for both the batch and continuous flow systems

7.6.1 Refrigeration Package and Chiller Loop Summary Description

This subsystem is a closed loop of circulating coolant (Dowtherm or equivalent). The system utilizes commercially available packaged refrigeration units to chill the coolant from -17.8°C to -26.1°C (0°F to -15°F) nominal values. The cold coolant is pumped around the loop by horizontal centrifugal circulating pumps (three are provided at 50 percent capacity each). The cold coolant is pumped to the bulk solids coolers described above, and two 50 percent capacity CO_2 condensers. The temperature rise across each of these units is nominally 8.3°C (15°F). An expansion/head tank is provided at the high point of the system to allow for volumetric changes in the coolant inventory between operating temperatures and nominal ambient temperatures (~21.1°C [70°F]).

7.6.2 Refrigeration Package and Chiller Loop Major Components

Commercial Refrigeration Packages: These are vapor compression type refrigeration units, supplied as packaged systems. Three packages are required, each at 50 percent capacity, comprised of two major skid mounted assemblies. The compressor driveline assembly skid contains a centrifugal compressor, a gearbox (speed increaser), and a drive motor rated at 5,220 kW (7,000 hp). The motors are expected to be designed for 3-phase 60 Hz AC electrical power delivered at 13.2 kV.

The skid contains auxiliaries such as a lube oil reservoir, lube oil cooler, control package, etc. The refrigeration cycle uses R-507 refrigerant, which is currently accepted as environmentally safe. An MSDS for this substance is provided in the Appendix to this report.

The heat exchanger skid for each refrigeration package contains four major horizontal cylindrical vessels: a condenser, which condenses the refrigerant vapor phase after it has accumulated the heat from the circulating coolant (this is the heat rejection to the environment from the refrigeration cycle); a subcooler, which further cools the refrigerant; an evaporator, which absorbs heat form the circulating coolant; and an accumulator, which acts as an expansion tank and holds added refrigerant inventory for the system.

Chiller Coolant Circulating Pumps: These are horizontal centrifugal single stage pumps. Typical specifications for these pumps will require a flow rate of 37.9 m^3/min (10,000.0 gpm) at 21.3 m (70 ft) total dynamic head (TDH). These pumps will be fabricated of cast carbon steel with stainless steel impellers, driven by electric motors rated at 187 kW (250 hp), 3-phase AC, 4,160 volts.

Expansion/Head Tank: This tank provides sufficient free volume to accommodate the expansion of the coolant inventory in the system (comprised of a commercially available ethylene glycol based fluid and water). This coolant will shrink in volume as the system is operated and cooled from ambient temperature (nominally 21°C (70°F)) to operating temperature (between -18 and -26°C (0 and -15°F). The tank is located at the high point of the system at the highest elevation in the building provided to house the components comprising the batch process liquid CO_2/coal slurry system.

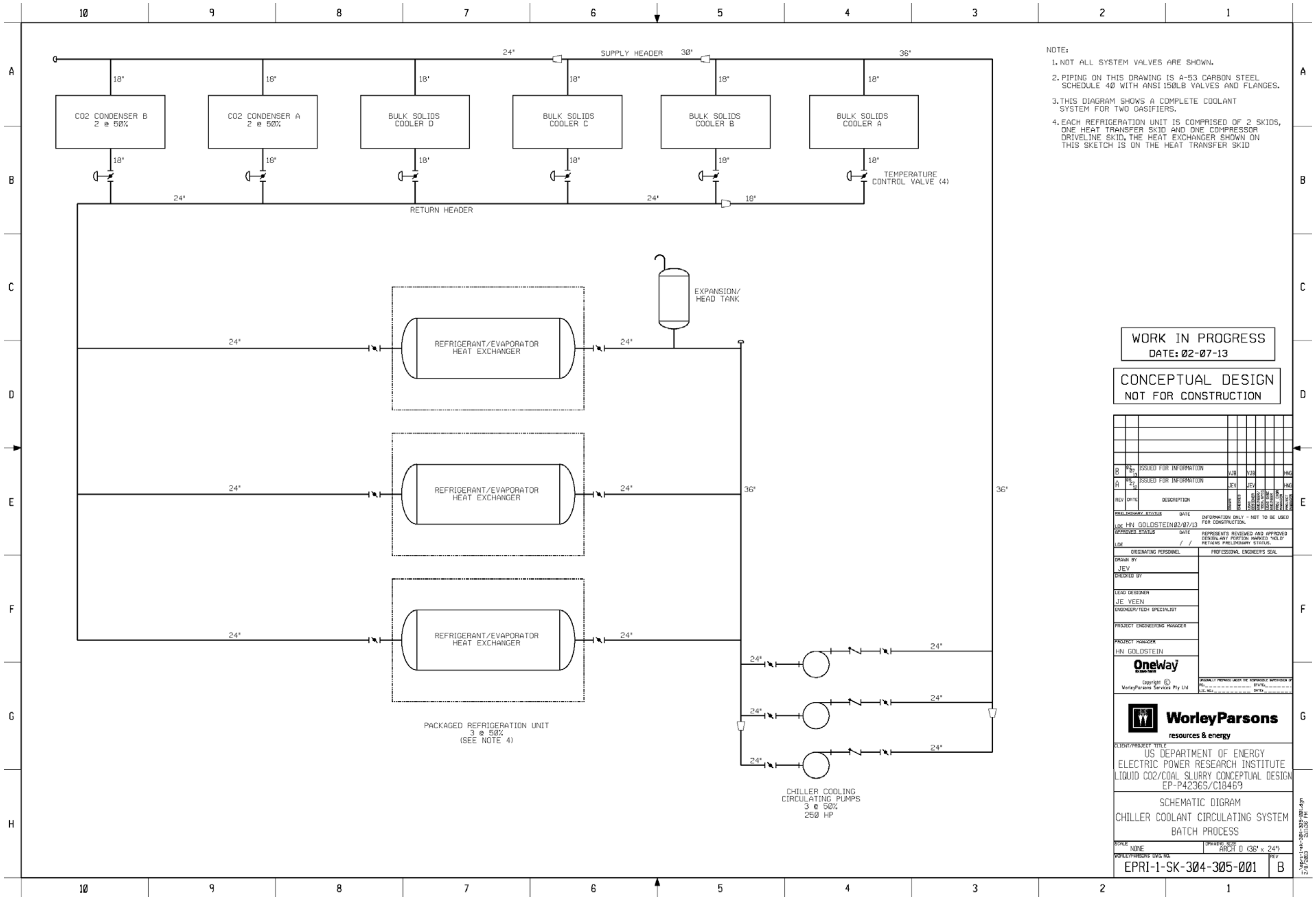


Figure 7-9 Chiller Coolant Circulation System Flow Diagram

7.7 CO_2 Preparation and Supply System

Note: This entire system is required for both the batch and continuous flow systems

7.7.1 CO_2 Preparation and Supply System Summary Description

This subsystem receives gaseous CO_2 from the CO_2 Capture and Compression block of the gasifier plant. The CO_2 is assumed to be available at nominal conditions of 3.10 MPa (450 psig) / 38°C (100°F). This follows the initial stages of compression and cleaning and drying in the tri-ethylene glycol unit that comprises part of the CO_2 capture and compression system. The CO_2 is expanded in a gas expander to recover some of the available energy as the pressure is let down to a nominal 1.90 MPa (275 psig). This adiabatic expansion also reduces the gas temperature to a nominal 6°C (43°F).

The gas expander generates 533 kWe driving an induction generator supplying 3-phase AC power to the facility 480 V electric bus. The expanded gas is routed to a pair of CO_2 condensers that desuperheat the gas, condense it, and subcool the liquid to a nominal -23.3°C (-10°F). The CO_2 liquid is pumped to the mixing vessels, described above, for preparation of the liquid CO_2/coal slurry.

7.7.2 CO_2 Preparation and Supply System Major Components

CO_2 Gas Expander: The gas expander is a centrifugal or axial flow turbine that extracts work from the CO_2 gas while reducing its temperature. The turbine is coupled to an induction generator producing a nominal 533 kWe which is fed to the liquid CO_2 coal slurry building 480 volt power bus. This opportunistically generated power reduces the net power consumption of the facility.

CO_2 Condenser: The CO_2 condenser is a shell and tube heat exchanger similar in design to a standard steam cycle power plant feedwater heater. The gaseous CO_2 is desuperheated, condensed, and subcooled for delivery to the slurry mixing vessels.

CO_2 Forwarding Pumps: These are conventional horizontal centrifugal pumps equipped for low temperature service (double mechanical seals and insulation), which pump the subcooled liquid CO_2 to the slurry mixing vessels. The pumps are rated at 2.5 m^3/min (650.0 gpm) at 18.3 m (60.0 ft) TDH, and are driven by 19 kW (25 hp) motors (3-phase, 60 Hz, 480 volt).

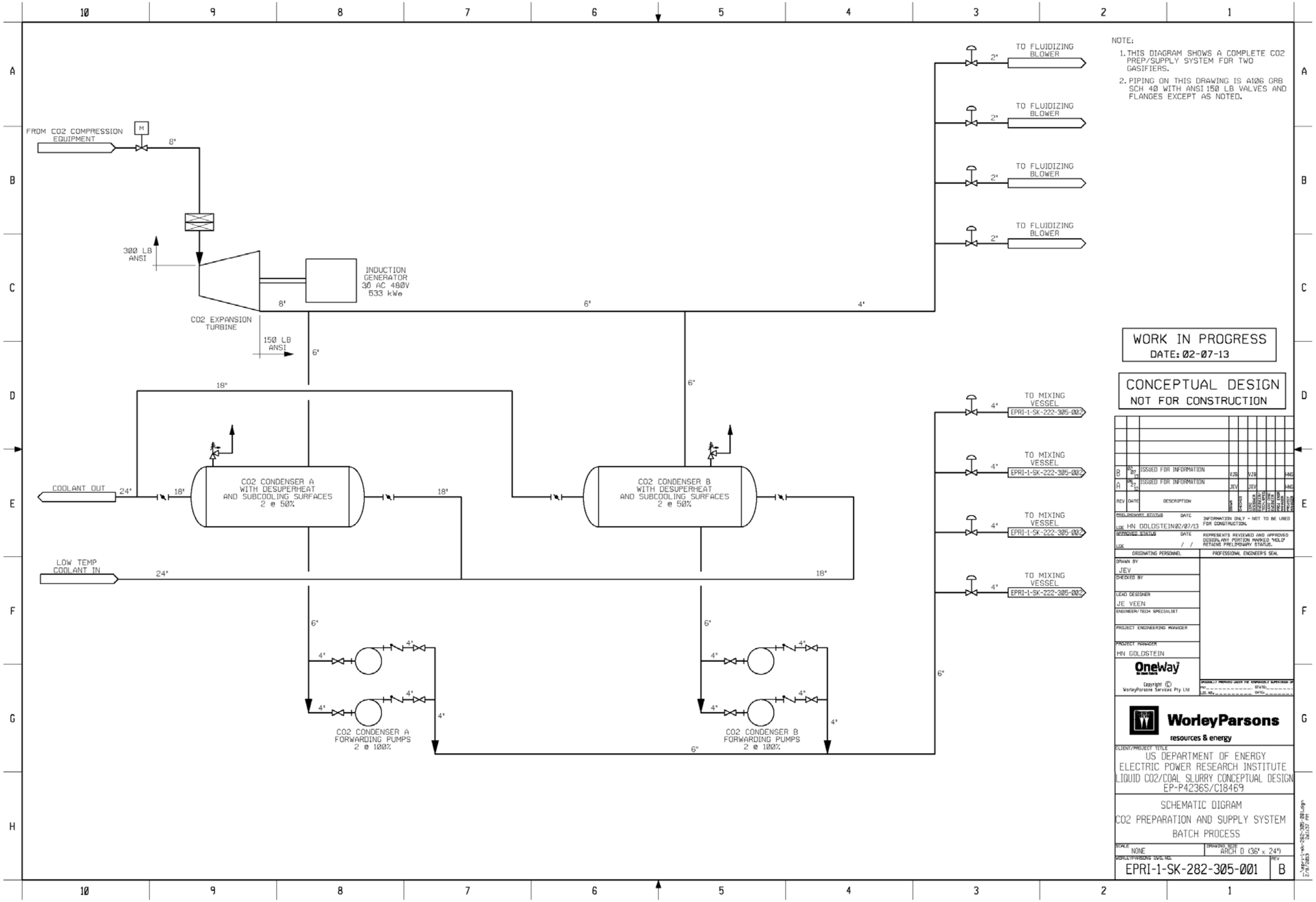


Figure 7-10 CO_2 Preparation and Supply System Flow Diagram

7.8 Electrical Power Distribution System

7.8.1 Electrical Power Distribution System Summary Description

Note: the entire electrical system is required for both batch and continuous flow systems, with minor changes to certain components.

This system ties in to the main IGCC plant switchyard to receive power from one of the main buses (assumed to operate at 345 kV). The voltage is stepped down to 13.2 kV using two 345/13.2 kV step-down transformers for distribution to the liquid CO_2/coal slurry building. The power is routed in cable bus on an overhead structure in cable tray.

At the liquid CO_2 slurry building, two power feeds are taken off the bus to a double ended set of 13.2 kV switchgear that controls the power to the refrigeration compressor driveline units. Two other power takeoffs feed two 13.2/4.16 kV stepdown transformers supplying power to two 4160V buses and associated switchgear that accommodate the 4160V loads in the building. The internal 4160V bus also feeds two 4160/480V transformers that provide power to two 480V motor control centers which feed these lower voltage loads.

The electrical generator that is driven by the CO_2 expansion turbine is connected to one of the 480V buses.

The electrical system is shown schematically on an electrical single line diagram, Figure 7-11.

7.8.1 Electrical Power Distribution System Major Components

The following list includes medium voltage components only; the complete conceptual design includes many other components, including low voltage items. These were documented in the material takeoff list developed to support the cost estimate.

Main Switchgear, Quantity 1: 15 kV, 63 kA, including the following:

- Main Circuit Breaker, Quantity 2: 4.16 kV, 2000 A,
- Main Tie Circuit Breaker, Quantity 2: 4.16 kV, 2000 A,
- Motor Feeder Circuit Breaker, Quantity 11: 4.16 kV, 1200A

High Voltage Transformers, Quantity 2: 345 kV/13.8 kV, 35 MVA, 3-phase, 60 Hz

Medium Voltage Transformers, Quantity 2: 13.8 kV/4.16 kV, 7.5 MVA, 3-phase, 60 Hz

Distribution Transformer, Quantity 2, 4.16 kV/480 V, 2 MVA

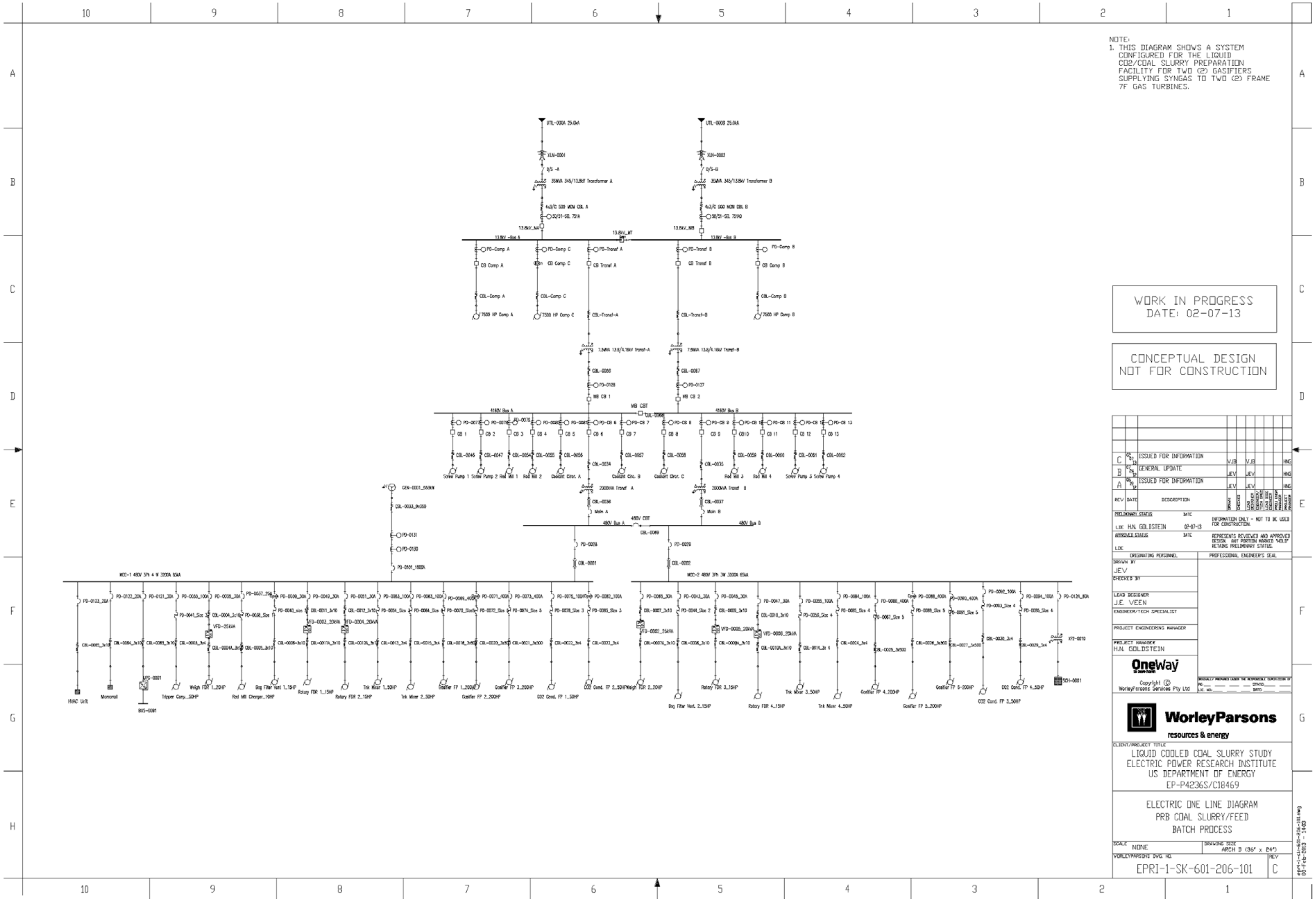


Figure 7-11 **Electrical One Line Diagram**

8. Reference Designs for Coal/Water Slurry and Dry Multiple Lock Hopper Preparation and Feed Systems

8.1 Coal/Water Slurry Preparation and Feed System

The same basic water/coal slurry design is used herein for each coal case that is evaluated, namely: Montana Rosebud Powder River Basin, and North Dakota Lignite. The different heating values of the fuels result in variations in size and capacity for the components comprising each system. Some minor changes are made to the scope of the system included in the Reference [1] report. First, the Reference [1] report does not include a building to house the various components that comprise the Prep and Feed system. The Cost Estimate included in this study for all cases evaluated includes a suitable building to house all of the components. Secondly, the coal day silo is included in Account 1 Coal Handling in the Reference report. For the Liquid CO_2 Slurry report, the silo is moved from Account 1 to Account 2, Coal Preparation and Feed. Finally, the coal day silo in the Reference [1] report is sized for approximately 10.5 hours of operation, whereas the silo incorporated for the Liquid CO_2 Coal Slurry report is sized for 24 hours of storage.

<u>System Description</u>

The scope of the Preparation and Feed System is defined as starting at the top of the fuel day silo and terminating at the discharge of the high pressure slurry gasifier feed pumps. This scope definition is consistent with that used for the design and cost estimating performed for the liquid CO_2/coal slurry cases described elsewhere in this report.

An adjustment is made to the Preparation and Feed system scope documented in the Baseline Report: that report included the fuel day silo in the Coal Handling System (Account 1) whereas in this report the silo is included in the Preparation and Feed System (Account 2). An additional adjustment is made for the capacity of the day silos. In the Baseline Report, for PRB coal, the capacity of the silos is given as a total of 3,265 tonne (3,600 ton) [3 silos at 1,088 tonne (1,200 ton) each].

For this report, the silo capacity for PRB coal is adjusted to provide a total capacity of 7,439 tonne (8,200 tons) [2 silos at 3,719 tonne (4,100 ton) each). This larger quantity represents a full 24 hour storage of fuel, whereas the capacity provided in the Baseline Report is approximately 11 hours. The larger capacity is used as more typical of design practice for large coal fired plants of any type (pulverized coal, circulating fluid bed, etc.).

For each fuel case, each silo discharges through a slide gate valve to a weigh feeder that meters the fuel to the inlet of a rod mill. The rod mills discharge to the inlet of a slurry batch tank equipped with mixers. As the rod mill product is discharged to the tank, filtered water is pumped into the tank and mixed with the coal. The slurry is mixed until it reaches the appropriate consistency and uniformity, after which it is pumped to a slurry storage tank, also equipped with mixers. The slurry is continuously mixed and discharged to the suction of the slurry recycle pumps, which continuously recirculate the slurry in a loop back to the tank inlet. A portion of the recycle flow is forwarded to the suction of the slurry product feed pumps for injection to the inlet feed nozzles of the gasifier.

The number of equipment items selected for this conceptual design and the corresponding equipment design parameters are presented in the table below for PRB coal. The table for ND Lignite follows.

Table 8-1 Water/Coal Slurry Preparation and Feed Equipment List - PRB Coal

Equipment No.	Description	Type	Design Condition	Qty	Spares
1	Day Silo	Field erected slip form concrete with stainless steel cone bottom.	4100 ton	2	0
2	Weigh Feeder	Gravimetric	170 ton/hr	2	0
3	Rod Mill	Rotary	170 ton/hr	4	2
4	Rod Mill Charger Skid	Traveling, rail mounted		1	0
5	Slurry Batch Tank	Field erected, CS with liner	40,000 gal	3@50%	
6	Mixer	Tank Mounted	50 hp	6	
7	Rod Mill Product Screw Pump	Horizontal Centrifugal Slurry Pump	1500 gpm/150 ft TDH	3	1
8	Slurry Storage Tank	Field Erected, CS with liner	625,000 gal	2	0
9	Mixer	Tank Mounted	100 hp	6	
10	Slurry Recycle Pump	Horizontal Centrifugal Slurry pump	1500 gpm/120 ft TDH	3	1
11	Slurry Product Feed Pump (Positive displacement pump)	Piston Type	1500 gpm/875 psig discharge pressure	8	2

Table 8-2 Water/Coal Slurry Preparation and Feed Equipment List - North Dakota Lignite

Equipment No.	Description	Type	Design Condition	Qty	Spares
1	Day Silo	Field erected slip form concrete with stainless steel cone bottom.	4530 ton	2	0
2	Weigh Feeder	Gravimetric	220 ton/hr	2	0
3	Rod Mill	Rotary	220 ton/hr	4	2
4	Rod Mill Charger Skid	Traveling, rail mounted		1	0
5	Slurry Batch Tank	Field erected, CS with liner	50,000 gal	2@50%	
6	Mixer	Tank Mounted	50 hp	6	
7	Rod Mill Product Screw Pump	Horizontal Centrifugal Slurry Pump	1500 gpm/150 ft TDH	3	1
8	Slurry Storage Tank	Field Erected, CS with liner	800,000 gal	2	0
9	Mixer	Tank Mounted	100 hp	6	
10	Slurry Recycle Pump	Horizontal Centrifugal Slurry pump	2000 gpm/120 ft TDH	3	1
11	Slurry Product Feed Pump (Positive displacement pump)	Piston Type	2000 gpm/875 psig discharge pressure	8	2

A flow diagram for the PRB coal water slurry is presented below.

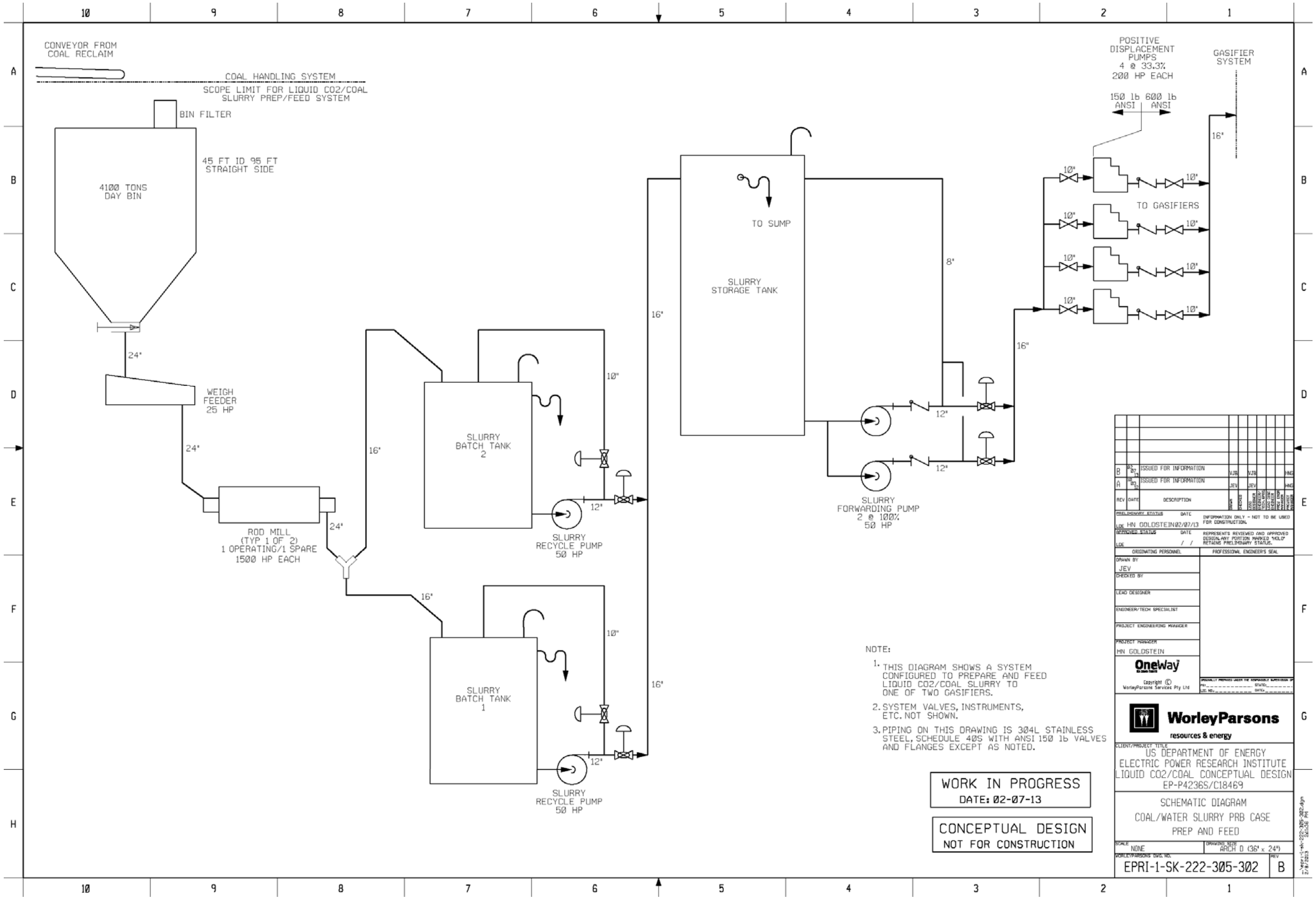


Figure 8-1 PRB Coal Water Slurry System Flow Diagram

8.2 Dry Multiple Lock Hopper Coal Prep and Feed System

This section describes a dry multiple lock hopper preparation and feed system for a gasifier other than an E-Gas™ unit, that requires a dry feed, and is provided as a point of reference only for comparing different types of preparation and feed systems. The dry feed system requires the addition of a grinding and drying system ahead of the lock hopper feed system. The combined grinding, drying, and feed system is described below. The size and capacity for this case maintains the same fuel heat input as in the Reference Cases S4B of the DOE Baseline study [1].

The scope for the fuel grinding, drying, and feed system begins with two day silos that together contain 24 hours of fuel for the entire plant (two gasifiers). Each day silo discharges to one train of grinding/drying equipment rated at 205 tons/hr. At this capacity, each train operates for a nominal 20 hours/day, leaving about 4 hours to deal with potential equipment outages. This time should nominally correspond to the mean time to repair any active component.

Each grinding/drying train comprises an impact mill type crusher, a velocity separator, a main mill fan, a cyclone separator an exhaust fan, a baghouse filter, and ancillary components. Rough sized coal (nominally ¾ inch x zero) is fed from the discharge of the coal silo through a rotary feeder to the inlet of each mill. The mill crushes the coal to a particle size compatible with the feed requirements of the gasifier, most likely in the range of 1 to 2 mm.

The crushed coal is dried as it circulates in the system and is exhausted from the mill through the velocity separator to a cyclone collector. The coal is separated from the air in the cyclone and discharged through a rotary valve to a surge bin located above the inlet to the lock hopper vessels. The circulating gas in the mill and cyclone circuit discharges some of the flow through a bag filter, and then to the plant stack or a separate monitored release point. This gas exiting the system removes moisture released by the coal as it is dried to a nominal 6 percent moisture.

The thermal energy required to dry the coal may be provided by using a portion of the clean syngas produced by the plant to fire in a fired heater that may be incorporated into the grinding/drying system. Alternatively, natural gas may be used if available. In both of these cases, the makeup gas to the mill system contains significantly less oxygen than pure air. This use of vitiated air from the fired heater significantly reduces the potential for ignition of the coal as it is heated and dried.

Each surge bin discharges through a slide gate valve to a gravimetric feeder, which meters the coal to the upper vessel of a lock hopper system (the storage injector). The storage injectors discharge into the primary injector vessels, which in turn discharge the dried ground coal into the gasifier. The combined volumes of the surge bins and the storage injectors are adequate to support a nominal 4 hours gasifier firing.

The lock hopper system requires a supply of pressurized gas to transport the coal into the gasifier. For this purpose, gaseous CO_2 taken from the capture system may be used.

Description of the detailed operation of the lock hopper system is beyond the scope of this report. However, lock hopper systems of this type have been used extensively in industry for many decades. A schematic drawing of the coal silo, coal drying system and lock hopper system is presented in Figure 8-2.

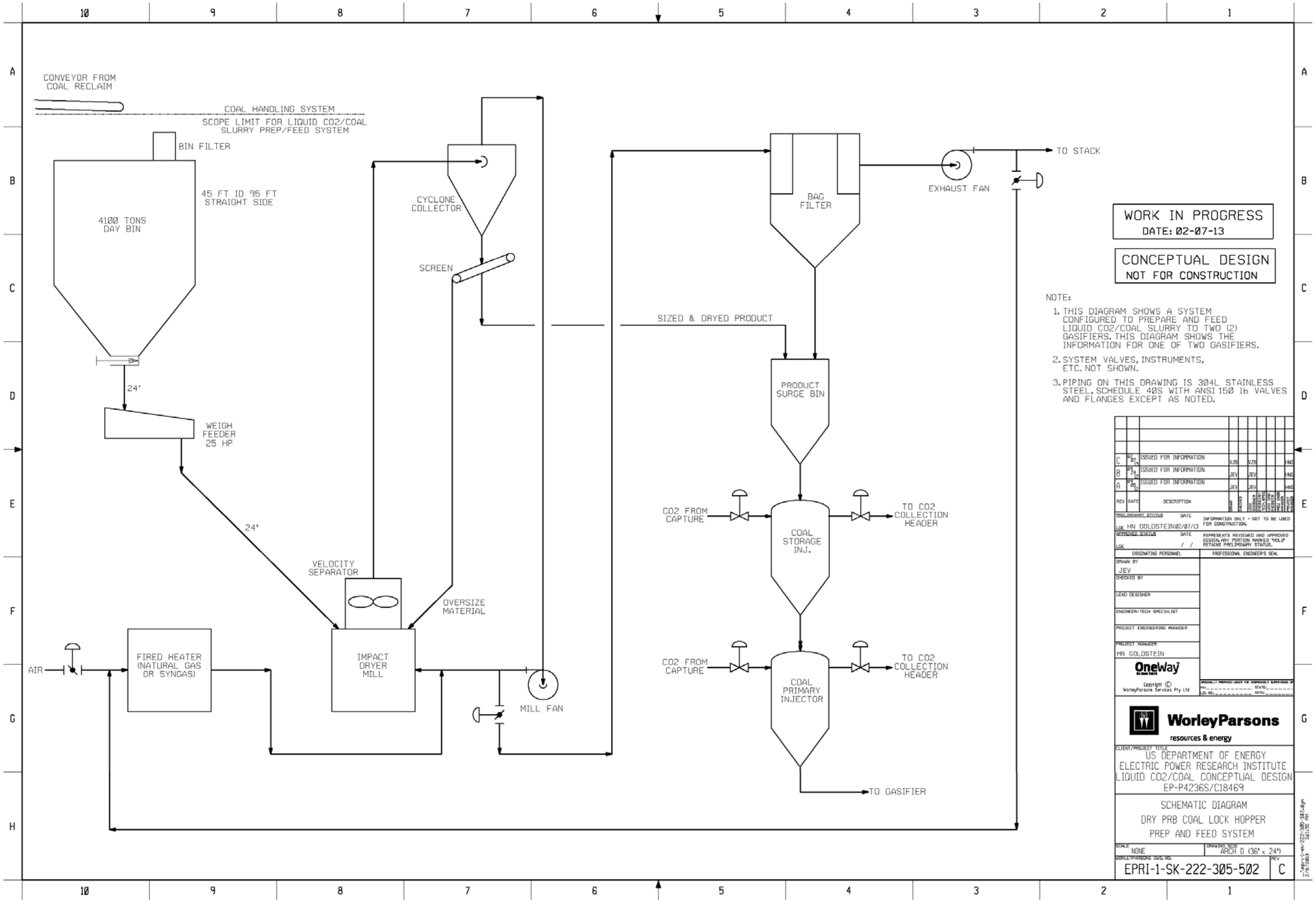


Figure 8-2 Coal Silo, Coal Drying, and Lock Hopper System Flow Diagram

9. Industry Search and Survey

This section provides the results of a preliminary survey of candidate industrial and manufacturing capability for CO_2/coal slurry system design and the equipment needed for its preparation. The survey shows that there is an adequate design and equipment base to provide such a system using commercially available equipment.

This survey focuses on designers and equipment available from suppliers within the United States, where there is an adequate base to choose from. In some areas where this preliminary survey only found limited suppliers in the U.S., international suppliers are also included.

The lists are neither definitive nor necessarily complete and the inclusion of an organization does not represent endorsement of potential suppliers, nor does the exclusion of any organization imply a lack of endorsement of their capability to produce such systems or equipment.

The preliminary survey identifies some of the potential suppliers who WorleyParsons expects are capable of supplying the design and equipment but makes no judgment regarding the quality or reputation of these designers or manufacturers. WorleyParsons included potential suppliers on the basis that those listed were representative and there were sufficient numbers of potential suppliers in that particular area to show there is a range of choice.

The left-hand column of Table 9-1 lists the equipment that is somewhat unique to the CO_2/Coal Slurry preparation/handling system. The right hand column lists equipment that is commonly used in other applications and where used in the liquid CO_2/coal slurry system does not encounter any unique design or environmental conditions.

Table 9-1 CO_2/Coal Slurry Preparation and Feed Designers and Manufacturers Included in This Survey

Equipment specific to CO_2-Coal Slurry preparation/handling included in this survey	Commonly available equipment in these systems which are not at issue
Bulk Solids Cooler CO_2 Condenser CO_2 Gas Expander Coal Grinding/Drying System Coal Transport Past Pressure Boundary Heat Transfer Skid Liquid CO_2/Coal Gasifier Slurry Feed Pump (Positive displacement pump) Mixer Mixing Vessel Refrigeration Driveline Rod Mill Screw Pump	Bag Filter CO_2 Slurry Batch Tank CO_2 Slurry Recycle Pump CO_2 Slurry Storage Tank Coal Conveyor Coal Day Silo Coal Flop Gate Coal Rotary Feeder Coal Weigh Feeder Expansion/Head Tank Liquid CO_2 Forwarding Pump Refrigerant Coolant Circulating Pump Vent Fan Rod Mill Rod Mill Charger

9.1 Approach to This Survey

This survey was prepared using information formed from the following:

- An Internet web search was made of designers and equipment, and this list vetted by phone calls and web inquiries.
- The in-house experience of WorleyParsons with manufacturers of this type of equipment

The designer and supplier data bases were synthesized from these sources.

9.2 Survey Data Bases

This system can be successfully designed by many firms experienced in coal facility and in CO_2 systems. A representative few of these potential designers for CO_2/coal slurry systems are listed in Table 9-2. A survey of a select group of the potential CO_2/coal slurry preparation/handling equipment suppliers is listed in Table 9-3. These data comprise the survey data base.

In addition, Table 9-4 lists some of the worldwide slurry pipeline designs. The designers of the slurry preparation and pumping stations for these systems, or some of the major equipment in the slurry preparation systems for these pipelines will provide additional sources of information for selecting the eventual suppliers for CO_2/coal slurry systems.

Table 9-2 Survey of Designers for CO_2/Coal Slurry Systems

	Item	Process Notes	Vendor/ Provider	website	Contact	Location	Project Remarks	Design Notes
1	Design / Construct / Operator		Air Products and Chemicals	http://www.airproducts.com/	(610) 481-4911 Kevin Fogash	Allentown, PA	Design/Construct/Operate. gasification, process engineering, liquid CO_2, CO_2 capture and compression	Extensive experience in CO_2, liquid CO_2, gas handling, preparation
2	Consultant		Arthur D. Little	http://www.adlittle.com/unitedstatesofamerica.html#boston	617-532-9550	Boston, MA	Management consultants, not designers	Holder of patent no. 4206610 “Method and apparatus for transporting coal as a coal/liquid carbon dioxide slurry”
3	Design / Construct		Bechtel	http://www.bechtel.com/pipelines.html	415-768-1234	San Francisco, CA	Design/Construct. IGCC, gasification, coal processing, pipelines, process engineering, CO_2 capture and compression	Extensive experience in coal projects. Designed Black Mesa coal-slurry pipeline, slurry preparation
4	Design / Construct		Fluor	http://www.fluor.com/business_segments/power/Pages/solid_fueled.aspx	(469) 398-7000	Irving, TX	Design/Construct. IGCC, gasification, coal processing, pipelines, process engineering, CO_2 capture and compression	Extensive experience in coal projects.

	Item	Process Notes	Vendor/ Provider	website	Contact	Location	Project Remarks	Design Notes
5	Design / Construct		KBR	http://www.kbr.com/	(312) 846-5796 James A. Van Laar	Chicago, Il	Design/Construct. IGCC,TRIG gasification, coal processing, pipelines, process engineering, CO_2 capture and compression	Extensive experience in coal projects. In Salah CO_2 injection project, dry coal fed to the pressurized TRIG gasifier through a system of lock hoppers
6	Design / Construction management		WorleyParsons	http://www.worleyparsons.com/CSG/Hydrocarbons/RefiningPetrochemicals/Pages/Petrochemicals.aspx	(713) 407-7243 James Powers (610) 855-2696 David Stauffer	Houston, TX Reading, PA	Design, construction management, IGCC, gasification, coal processing, pipelines, process engineering, CO_2 capture and compression	Extensive experience in coal projects. Prepared this study

Table 9-3 Survey of CO_2/Coal Slurry Preparation/Handling Equipment Suppliers

	Item	Process Notes	Vendor/ Provider	website	Contact	Location	Project Remarks	Design Notes
1	Bulk Solids Cooler	170 tph Cool from 80F to 0F	SOLEX Thermal Science	www.solexthermal.com	803-517-2773	Calgary, Canada	Quoted in the project. Experience w/ carbon black& coal fines	Gravity Flow. Indirect Type Plate HE
2	Bulk Solids Cooler	170 tph Cool from 80F to 0F	DIMPLE-t indirect heat exchange	www.dimple-t.com	(31)-543-531-883	Winterswijk, Netherlands	Experience w/ dried granular sludge, polymers, fertilizer, etc.	Gravity Flow. Indirect Type Plate HE
3	Bulk Solids Cooler	170 tph Cool from 80F to 0F	Coperion	www.coperion.com	201-327-6300	Ramsey, NJ HQ in Germany	Experience w/ carbon black, minerals, sand, etc.	Gravity Flow. Vertical shell & tube
4	Bulk Solids Cooler	170 tph Cool from 80F to 0F	Metso	www.metso.com	704-541-1453	Williamsport, PA	Experience with incinerator ash, coke, limestone.	Horizontal hollow screw.
5	CO_2 Condenser	670 gpm	Foster Wheeler			Clinton, NJ	Extensive experience in design of shell and tube condensers	Shell and tube condenser similar to steam cycle feedwater heater
6	CO_2 Condenser	670 gpm	SPX Heat Transfer	www.spxheattransfer.com	(610)-250-1000 Chris Klopp christopher.klopp@spxht.com	Bethlehem, PA	Interested in R&D project	Shell and tube condenser similar to steam cycle feedwater heater

	Item	Process Notes	Vendor/ Provider	website	Contact	Location	Project Remarks	Design Notes
7	CO_2 Condenser	670 gpm	Peerless Mfg. Co.	www.peerlessmfg.com	214-353-5597 Jon Segelhorst	Dallas, TX	Extensive experience with Coal Prep Equipment	Shell and tube condenser similar to steam cycle feedwater heater
8	CO_2 Gas Expander	475 to275 psig, 525 kWe, (88,000 pph) (100 F to 43 F)	AtlasCopco	www.atlascopco.com	860-477-0296 Bart Woodmansee	Connecticut	Experience with large industrial expanders.	
9	CO_2 Gas Expander	476 to 275 psig, 525 kWe, (88,000 pph) (100 F to 43 F)	Spilling	www.spilling.de		Hamburg, Germany		
10	Coal Grinding/Drying System	coal from silos is 1/2 x 0	Williams Patent Crusher & Pulverizer Co., Inc.	www.williamscrusher.com	314-621-3348 Harold J. Groves hjgroves@williamscrusher.com	St. Louis, MO	Extensive experience in coal drying and grinding systems	Dry Feed only
11	Coal Transport Past Pressure Boundary: High Pressure Rotary Valve	1 atm to 270 psig	Andritz Feed & Biofuel	http://dev.andritzsproutbauer.com/airlock-rotary-valve.asp	(800) 446-8629	Muncy, PA	Active in design of equipment for transport of granular solids	Selected for inclusion in report as example
12	Coal Transport Past Pressure Boundary: Lock-Hopper System	1 atm to 270 psig	Macawber Engineering Inc.	http://www.macawber.com/	(800) 433 2213	Maryville, TN		Dry Feed Only

	Item	Process Notes	Vendor/ Provider	website	Contact	Location	Project Remarks	Design Notes
13	Coal Transport Past Pressure Boundary: Feeder	1 atm to 270 psig	Pennsylvania Crusher Corporation	http://www.pcc-china.com/feeders/feeders_brochures.cfm	(610) 544-7200	Broomall, PA		Stamet pump tested by DOE
14	Liquid CO_2/ Coal Slurry Gasifier Feed Pump (Positive displacement pump)	90 m^3/hr, delivery pressure of 58 bar	Putzmeister Solid Pumps	www.pmsolid.com	(49) 7127-599-500	HQ in Germany	Extensive experience with coal and other slurry materials-selected as example for this report	Part. Size <15mm
15	Mixer	270 psig / -10^{o}F 112 tons of mixed coal and liquid CO_2 (3:1 mix by weight)	SPX Process Equipment, LIGHTNIN Operation	http://www.LIGHTNIN-MIXERS.COM	(888) 649-2378	Rochester, NY	Extensive experience in mixer design	
16	Mixing Vessel	270 psig / -10^{o}F 112 tons of mixed coal and liquid CO_2 (3:1 mix by weight) 500,000 primary stress cycles (1 atm to 17 atm cycles) 13 ft. diameter / 30 ft. high	NRG Manufacturing, Inc.	http://www.nrgm.com/custom-pressure-vessels.html	(888) 689-5830	Tomball TX	Many vessel fabrication shops exist with capability to supply these vessels	ASME Code stamped pressure vessel

	Item	Process Notes	Vendor/ Provider	website	Contact	Location	Project Remarks	Design Notes
17	Refrigeration Driveline and Heat Transfer Skid	Cool Dowtherm (or equivalent) circulating coolant from 0°F to -15°F 52 MMBtu/hr coal + CO_2 chilling duty	York Process Systems, Johnson Controls	http://www.johnsoncontrols.com/content/us/en/products/building_efficiency/industrial_refrigeration.html	610-640-0370 Paul Hinderhofer albert.p.hinderhofer@jci.com	Waynesboro, PA	This project requires very large commercial chillers for process applications	Optimization required for specification of process temperatures and pressures
18	Rod Mill	170 tons/hr, delivering pulverized coal 300 microns and finer	Metso Minerals	www.metso.com	412-298-7236 Chris Rettew chris.rettew@metso.com	Canonsburg, PA	Extensive experience with Coal Prep Equipment	
19	Rod Mill	170 tons/hr, delivering pulverized coal 300 microns and finer	FLSmidth	www.flsmidth.com	610-264-6900 (Tech) 800-871-7000 (Reg)	Bethlehem, PA Salt Lake City, UT	Extensive experience with Coal Prep Equipment	
20	Rod Mill Charger	Drum Hydraulic Ram, rails	Metso Minerals	www.metso.com	412-298-7236 Chris Rettew chris.rettew@metso.com	Canonsburg, PA	Extensive experience with Coal Prep Equipment	
21	Rod Mill Charger	Drum Hydraulic Ram, rails	FLSmidth	www.flsmidth.com	610-264-6900 (Tech) 800-871-7000 (Reg)	Bethlehem, PA Salt Lake City, UT	Extensive experience with Coal Prep Equipment	
22	Rod Mill Screw Pump	Pneumatic, 170 tph solids	FLSmidth	www.flsmidth.com	610-264-6900 (Tech) 800-871-7000 (Reg)	Bethlehem, PA Salt Lake City, UT	Extensive experience with Coal Prep Equipment	Fuller-Kinyon dry screw pumps

Table 9-4 Summary of Selected Worldwide Slurry Pipelines (Commercial, Planned, Retired, or Planned but Never Constructed)

Slurry material	System or Location	Length (miles)	Diameter (inches)	Throughput (million tons/year)	Operation
Coal	Consolidation	108	10	1.3	1957
	Black Mesa	273	18	4.8	1970
	Nevada Power Utah/Nev.	180	24	10.0	
	Energy Trans. Systems, Inc. Wyo./Ark.	1,036	38	25.0	1979
	Houston Nat. Gas Colo. to Tex.	750	22	9.0	
	Gulf Interstate N.W. Pipeline	800	30	16.0	
	ALTON	180	24	10.0	1981
	Belonovo-Novosibirsk, Siberia, Russia	158	---	3.4	1985
Limestone	Calaveras	17	7	1.5	1971
	Rugby	57	10	1.7	1964
	Trinidad	6	8	0.6	1959
	Colombia	17	---	0.4	1944
Copper Concentrate	Bougainvillea	---	6	1.0	1972
	West Irian	69	4	0.3	1972
	KBI Turkey	38	5	1.0	---
	Pinto Valley	11	4	0.4	1974
Magnetite Concentrate	Tasmania	53	---	2.3	1967
	Waipipi (land)	4	8	1.0	1971
	Waipipi (offshore)	1.8	12	1.0	1971
	Pena Colorada	30	8	1.8	1974
Magnetite and hematite	Sierra Grande	20	8	2.1	
	Brazil	250	20	12.0	
	Mexico	17	10	1.5	
	Africa	350	18	6.6	
	Brazil	240	20	12.0	
	India	36	20 to 22	10.0	
	Mexico	17	10	1.5	
	Australia	44	8	0.9	
Nickel refinery tailings	West Mining	4.3	4	0.1	1970
Gilsonite	Am. Gilsonite	72	6	0.4	1957
Phosphate	Australia	200	16 to 22	4.0 to 6.0	
Sulfur/hydrocarbon	Canada	800	12 to 16	---	
Tails	Japan	44	12	0.6	1968

Sources:

Woods, M.C., and Weinstein, R.E., Does Coal-Water Slurry Made Sense Given Today's Economics? NETL. Topical Report. EJ-2004-04. Rev. 05. December 2005

John M. Huneke, Testimony before the House Committee on Interior and Insular Affairs on Coal Slurry Pipeline Legislation, Washington, D. C., Sept. 12,1975. From " Coal Slurry Pipelines and Unit Train Systems." http://www.princeton.edu/~ota/disk3/1978/7817/781706.PDF

10. Capital Cost Estimates for Preparation and Feed System

Capital Cost Summary

The conceptual capital cost estimates presented herein are for a series of coal feed system alternatives to be incorporated into a nominal 550 MW net IGCC Plant using E-Gas™ gasifier technology with CO_2 capture. The conceptual design for this system is discussed elsewhere in this report. This design includes flow diagrams, general arrangement drawings, an electrical single line diagram, and other documentation. This estimate was developed from this information using high-level quantities for bulks, budgetary-level vendor quotes for certain equipment and internal WorleyParsons information.

The estimate is presented in 3Q2012 overnight costs and has an accuracy range of -15 percent / +30 percent.

Project Scope

The basic premise of the scope of work begins with Case S4B of the NETL report "Cost and Performance Baseline for Fossil Energy Plants Volume 3a: Low Rank Coal to Electricity: IGCC Cases" dated May 2011 (DOE/NETL-2010/1399).

Case S4B is a 2 x 2 x 1 IGCC plant using E-Gas™ gasification technology. Case S4B also includes CO_2 capture and compression.

The scope of the estimates presented herein is limited to the *fuel preparation and feed system* for a plant configuration similar to Case S4B. These estimates are typically presented in Account 2 of the EPRI TAG capital cost work breakdown structure. The following feed system conceptual designs were costed and presented in this section of the report.

1. Batch Type System, Liquid CO_2/Coal Slurry, PRB coal
2. Batch Type System, Liquid CO_2/Coal Slurry, North Dakota Lignite
3. Continuous Flow Type System, Liquid CO_2/Coal Slurry, PRB coal
4. Continuous Flow Type System, Liquid CO_2/Coal Slurry, North Dakota Lignite
5. Batch Type System, Water/Coal Slurry, PRB coal
6. Batch Type System, Water/Coal Slurry, North Dakota Lignite
7. Dry Lock Hopper Preparation and Feed Type System, PRB coal

For each Liquid CO_2/Coal Slurry case, the estimate scope includes:

- Coal day silos
- Coal sizing and forwarding equipment
- CO_2 expansion, forwarding & condensing systems
- Refrigeration & chilling system for CO_2 condensing
- Slurry mixing & forwarding systems
- Building to house the above systems

- Interconnections to connect the liquid CO_2 slurry systems to an IGCC plant similar to Case S4B

Note: The capital cost estimates for each of the liquid CO_2/coal slurry preparation and feed system cases (Account 2) noted above were developed using a bottoms up estimating approach, based on the conceptual design drawings presented in Appendix A of this report. The same is true for the dry lock hopper feed case. For the water slurry cases (Account 2) presented herein, the cost estimates were developed by escalating, and adjusting as appropriate, the Account 2 cost estimate data presented in the Bituminous Baseline and Low Rank Coal Baseline reports.

For each Water Slurry case, the following is included

- Coal day silos
- Coal sizing and forwarding equipment
- Slurry mixing & forwarding systems
- Building to house the above systems
- Interconnections to connect the water slurry systems to an IGCC plant similar to Case S4B

For the Dry Lockhopper System case, the following is included

- Coal day silos
- Coal drying, sizing and forwarding equipment
- Lockhopper system to inject dry coal into the gasifiers
- Building to house the above systems
- Interconnections to connect the system to an IGCC plant similar to Case S4B

Equipment & Material Pricing

Budgetary vendor pricing was received for the following equipment:

- Liquid CO_2 Feed Pumps
- Bulk Solids Cooler
- CO_2 Chilling System
- Rod Mills

The balance of equipment pricing is based on in-house cost information, including the dry lock hopper system. Bulk material pricing is based on in-house information.

Installation Labor

In keeping with the basis of the estimate prepared for Case S4B, installation costs are based on Midwest, Merit Shop. Labor is based on a 50-hour work week (5-10s). No additional incentives such as per-diems or bonuses are included.

The estimate is based on greenfield construction of the liquid CO_2 slurry systems being installed as part of the overall IGCC plant construction. The estimate does not represent a retrofit scenario.

Contracting Methodology

The estimate is based on an Engineering – Procurement – Construction Management (EPCM) approach. Additional premiums associated with an Engineer – Procure – Construct (EPC) contract are excluded.

Professional Services

Engineering & Design and Construction Management costs are estimated as a percentage of Bare Erected Costs (BEC). These costs consist of all home office engineering and procurement services as well as field construction management costs.

Escalation to Period of Performance

The estimate excludes escalation to period of performance. All costs are presented as overnight 3rd Quarter 2012 dollars.

Process Contingency

Process contingency is intended to compensate for uncertainty in cost estimates caused by performance uncertainties associated with the development status of a technology.

Process contingencies have been applied to the estimate as follows:

- Bulks Solids Cooling – 15 percent
- CO_2 Slurry and mixing – 15 percent
- Instrumentation and Controls – 15 percent

Project Contingency

Project Contingency addresses unforeseen elements of costs within the current defined project scope. It is expected that by the end of the project the entire contingency will be spent on either direct or indirect costs.

A 20 percent project contingency is included.

Exclusions

The following items are specifically excluded from the estimate:

- Premiums associated with an EPC Contracting approach.
- Premiums beyond 5-10's required to attract craft labor.
- Escalation to period of performance
- Import duties & tariffs
- Extraordinary noise mitigation or attenuation
- Modifications to IGCC balance of plant systems required to accommodate the liquid CO_2 slurry system. *This will be accounted for in the overall plant cost estimates, presented in Section 12 of this report.*

- All Owner's Costs
- Allowance for funds used during construction
- All taxes with the exception of payroll taxes

Typical Owner's Costs

Owner's costs are excluded from the estimate. Typical Owner's costs include, but are not limited to, the following:

- Permits & Licensing
- Land Acquisition / Rights of Way Costs
- Economic Development
- Project Development Costs
- Legal Fees
- Owner's Engineering / Project & Construction Management Staff
- Plant Operators during startup
- Electricity consumed during startup
- Fuel and Reagent consumed during startup
- Initial Fuel & Reagent Inventory
- Transmission Interconnections & Upgrades
- Operating Spare Parts
- Financing Costs

The following tables present the Capital Costs for each case as enumerated above.

Table 10-1 Capital Cost Summary – Batch System, Liquid CO_2/PRB Coal Slurry

ITEM	QTY	UNIT	MATERIAL	LABOR	TOTAL	COMMENTS
EQUIPMENT:						
Coal Day Bins (Furnish & Erect)	1	LS	$ 9,945,000	$ -	$ 9,945,000	
Coal Sizing & Forwarding Equipment	1	LS	$ 11,855,000	$ 953,000	$ 12,808,000	
Coal - Bulk Solids Coolers incl Rotary Feeder, Flop Gate & Venting	1	LS	$ 3,730,000	$ 405,000	$ 4,135,000	
CO2 Expansion / Forwarding / Condensing	1	LS	$ 1,600,000	$ 85,000	$ 1,685,000	
Refrigeration / Chilling Equipment	1	LS	$ 12,615,000	$ 998,000	$ 13,613,000	
Slurry Mixing & Forwarding Equipment	1	LS	$ 5,080,000	$ 640,000	$ 5,720,000	
Electrical Equipment	1	LS	$ 3,065,000	$ 211,000	$ 3,276,000	
Equipment Subtotal			$ 47,890,000	$ 3,292,000	$ 51,182,000	
BULK MATERIALS:						
Coal Slurry Building	1	LS	$ 23,363,000	$ 9,829,000	$ 33,192,000	
Balance of Bulks - Civil	1	LS	$ 10,000	$ 207,000	$ 217,000	
Balance of Bulks - Piping & Valves	1	LS	$ 5,373,000	$ 4,239,000	$ 9,612,000	
Balance of Bulks - Insulation	1	LS	$ 768,000	$ 2,668,000	$ 3,436,000	
Balance of Bulks - Electrical Bulks	1	LS	$ 559,000	$ 1,114,000	$ 1,673,000	
Balance of Bulks - Instrumentation	1	LS	$ 1,307,000	$ 501,000	$ 1,808,000	
Bulks Subtotal			$ 31,380,000	$ 18,558,000	$ 49,938,000	
Equipment & Bulks Subtotal			$ 79,270,000	$ 21,850,000	$ 101,120,000	
PROFESSIONAL SERVICES:						
Engineering, Construction Management, Home Office & Fee	1	LS			$ 10,112,000	
OTHER COSTS:						
Owner's Costs	1	LS			$ -	Excluded
Process Contingency	1	LS			$ 1,924,000	
Subtotal					**$ 113,156,000**	
Contingency - General	1	LS			$ 22,631,000	
TOTAL ESTIMATE (W/O TAXES) - EPCM BASIS					**$ 135,787,000**	

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Table 10-2 Capital Cost Summary – Batch System, Liquid CO_2/ND Lignite Slurry

ITEM	QTY	UNIT	MATERIAL	LABOR	TOTAL	COMMENTS
EQUIPMENT:						
Coal Day Bins (Furnish & Erect)	1	LS	$ 10,722,000	$ -	$ 10,722,000	
Coal Sizing & Forwarding Equipment	1	LS	$ 14,073,000	$ 1,108,000	$ 15,181,000	
Coal - Bulk Solids Coolers incl Rotary Feeder, Flop Gate & Venting	1	LS	$ 4,316,000	$ 461,000	$ 4,777,000	
CO2 Expansion / Forwarding / Condensing	1	LS	$ 1,822,000	$ 100,000	$ 1,922,000	
Refrigeration / Chilling Equipment	1	LS	$ 14,766,000	$ 1,095,000	$ 15,861,000	
Slurry Mixing & Forwarding Equipment	1	LS	$ 5,488,000	$ 668,000	$ 6,156,000	
Electrical Equipment	1	LS	$ 3,566,000	$ 237,000	$ 3,803,000	
Equipment Subtotal			$ 54,753,000	$ 3,669,000	$ 58,422,000	
BULK MATERIALS:						
Coal Slurry Building	1	LS	$ 24,364,000	$ 10,596,000	$ 34,960,000	
Balance of Bulks - Civil	1	LS	$ 10,000	$ 207,000	$ 217,000	
Balance of Bulks - Piping & Valves	1	LS	$ 5,773,000	$ 4,451,000	$ 10,224,000	
Balance of Bulks - Insulation	1	LS	$ 822,000	$ 3,163,000	$ 3,985,000	
Balance of Bulks - Electrical Bulks	1	LS	$ 559,000	$ 1,114,000	$ 1,673,000	
Balance of Bulks - Instrumentation	1	LS	$ 1,307,000	$ 501,000	$ 1,808,000	
Bulks Subtotal			$ 32,835,000	$ 20,032,000	$ 52,867,000	
Equipment & Bulks Subtotal			$ 87,588,000	$ 23,701,000	$ 111,289,000	
PROFESSIONAL SERVICES:						
Engineering, Construction Management, Home Office & Fee	1	LS			$ 11,129,000	
OTHER COSTS:						
Owner's Costs	1	LS			$ -	Excluded
Process Contingency	1	LS			$ 2,102,000	
Subtotal					**$ 124,520,000**	
Contingency - General	1	LS			$ 24,904,000	
TOTAL ESTIMATE (W/O TAXES) - EPCM BASIS					**$ 149,424,000**	

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Table 10-3 Capital Cost Summary – Continuous System, Liquid CO_2/PRB Coal Slurry

ITEM	QTY	UNIT	MATERIAL	LABOR	TOTAL	COMMENTS
EQUIPMENT:						
Coal Day Bins (Furnish & Erect)	1	LS	$ 9,945,000	$ -	$ 9,945,000	
Coal Sizing & Forwarding Equipment	1	LS	$ 11,855,000	$ 953,000	$ 12,808,000	
Coal - Bulk Solids Coolers incl Rotary Feeder, Flop Gate & Venting	1	LS	$ 3,730,000	$ 405,000	$ 4,135,000	
CO2 Expansion / Forwarding / Condensing	1	LS	$ 1,600,000	$ 85,000	$ 1,685,000	
Refrigeration / Chilling Equipment	1	LS	$ 12,615,000	$ 998,000	$ 13,613,000	
Slurry Mixing & Forwarding Equipment	1	LS	$ 6,815,000	$ 451,000	$ 7,266,000	
Electrical Equipment	1	LS	$ 3,219,000	$ 222,000	$ 3,441,000	
Equipment Subtotal			$ 49,779,000	$ 3,114,000	$ 52,893,000	
BULK MATERIALS:						
Coal Slurry Building	1	LS	$ 23,363,000	$ 9,829,000	$ 33,192,000	
Balance of Bulks - Civil	1	LS	$ 10,000	$ 207,000	$ 217,000	
Balance of Bulks - Piping & Valves	1	LS	$ 5,427,000	$ 4,281,000	$ 9,708,000	
Balance of Bulks - Insulation	1	LS	$ 775,000	$ 2,694,000	$ 3,469,000	
Balance of Bulks - Electrical Bulks	1	LS	$ 587,000	$ 1,169,000	$ 1,756,000	
Balance of Bulks - Instrumentation	1	LS	$ 1,326,000	$ 508,000	$ 1,834,000	
Bulks Subtotal			$ 31,488,000	$ 18,688,000	$ 50,176,000	
Equipment & Bulks Subtotal			$ 81,267,000	$ 21,802,000	$ 103,069,000	
PROFESSIONAL SERVICES:						
Engineering, Construction Management, Home Office & Fee	1	LS			$ 10,307,000	
OTHER COSTS:						
Owner's Costs	1	LS			$ -	Excluded
Process Contingency	1	LS			$ 2,184,000	
Subtotal					**$ 115,560,000**	
Contingency - General	1	LS			$ 23,112,000	
TOTAL ESTIMATE (W/O TAXES) - EPCM BASIS					**$ 138,672,000**	

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Table 10-4 Capital Cost Summary – Continuous System, Liquid CO_2/ND Lignite Slurry

ITEM	QTY	UNIT	MATERIAL	LABOR	TOTAL	COMMENTS
EQUIPMENT:						
Coal Day Bins (Furnish & Erect)	1	LS	$ 10,722,000	$ -	$ 10,722,000	
Coal Sizing & Forwarding Equipment	1	LS	$ 14,073,000	$ 1,108,000	$ 15,181,000	
Coal - Bulk Solids Coolers incl Rotary Feeder, Flop Gate & Venting	1	LS	$ 4,316,000	$ 461,000	$ 4,777,000	
CO2 Expansion / Forwarding / Condensing	1	LS	$ 1,822,000	$ 100,000	$ 1,922,000	
Refrigeration / Chilling Equipment	1	LS	$ 14,766,000	$ 1,095,000	$ 15,861,000	
Slurry Mixing & Forwarding Equipment	1	LS	$ 7,923,000	$ 492,000	$ 8,415,000	
Electrical Equipment	1	LS	$ 3,744,000	$ 249,000	$ 3,993,000	
Equipment Subtotal			$ 57,366,000	$ 3,505,000	$ 60,871,000	
BULK MATERIALS:						
Coal Slurry Building	1	LS	$ 24,364,000	$ 10,596,000	$ 34,960,000	
Balance of Bulks - Civil	1	LS	$ 10,000	$ 207,000	$ 217,000	
Balance of Bulks - Piping & Valves	1	LS	$ 5,831,000	$ 4,496,000	$ 10,327,000	
Balance of Bulks - Insulation	1	LS	$ 831,000	$ 3,194,000	$ 4,025,000	
Balance of Bulks - Electrical Bulks	1	LS	$ 587,000	$ 1,169,000	$ 1,756,000	
Balance of Bulks - Instrumentation	1	LS	$ 1,326,000	$ 508,000	$ 1,834,000	
Bulks Subtotal			$ 32,949,000	$ 20,170,000	$ 53,119,000	
Equipment & Bulks Subtotal			$ 90,315,000	$ 23,675,000	$ 113,990,000	
PROFESSIONAL SERVICES:						
Engineering, Construction Management, Home Office & Fee	1	LS			$ 11,399,000	
OTHER COSTS:						
Owner's Costs	1	LS			$ -	Excluded
Process Contingency	1	LS			$ 2,479,000	
Subtotal					**$ 127,868,000**	
Contingency - General	1	LS			$ 25,574,000	
TOTAL ESTIMATE (W/O TAXES) - EPCM BASIS					**$ 153,442,000**	

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Table 10-5 Capital Cost Summary – Batch System, Water/PRB Coal Slurry

Client: EPRI | Report Date: 2013-Feb-25
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 3 - PRB - water slurry feed
Plant Size: 565.6 MW,net | Estimate Type: Conceptual | Cost Base (Jun) 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED											
2.1	Coal Storage & Feed	$10,410	$0	$0	$0	$0	**$10,410**	$866	$0	$0	**$11,275**	$20
2.2	Prepared Coal Storage & Feed	$2,584	$615	$410	$0	$0	**$3,608**	$303	$0	$782	**$4,693**	$8
2.3	Slurry Prep & Feed (incl. crushing)	$27,119	$0	$12,194	$0	$0	**$39,313**	$3,430	$0	$8,549	**$51,291**	$91
2.4	Misc.Coal Prep & Feed	$1,421	$1,028	$3,135	$0	$0	**$5,584**	$501	$0	$1,217	**$7,301**	$13
	SUBTOTAL 2	**$41,534**	**$1,642**	**$15,738**	**$0**	**$0**	**$58,914**	**$5,099**	**$0**	**$10,548**	**$74,561**	**$132**
3	FEEDWATER & MISC. BOP SYSTEMS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4	GASIFIER & ACCESSORIES	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5B	CO2 COMPRESSION	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	COMBUSTION TURBINE/ACCESSORIES	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	HRSG, DUCTING & STACK	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	STEAM TURBINE GENERATOR	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	COOLING WATER SYSTEM	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	ACCESSORY ELECTRIC PLANT											
11.2	Station Service Equipment	$160	$0	$15	$0	$0	$176	$16	$0	$19	$211	$0
11.3	Switchgear & Motor Control	$296	$0	$57	$0	$0	$353	$33	$0	$58	$444	$1
11.4	Conduit & Cable Tray	$0	$153	$478	$0	$0	$631	$58	$0	$172	$862	$2
11.5	Wire & Cable	$0	$293	$182	$0	$0	$475	$32	$0	$127	$634	$1
11.8	Main Power Transformers	$893	$0	$4	$0	$0	$896	$69	$0	$145	$1,110	$2
11.9	Electrical Foundations	$0	$4	$11	$0	$0	$15	$1	$0	$5	$21	$0
	SUBTOTAL 11	**$1,349**	**$450**	**$747**	**$0**	**$0**	**$2,546**	**$211**	**$0**	**$526**	**$3,283**	**$6**
12	INSTRUMENTATION & CONTROL											
12.6	Control Boards,Panels & Racks	$47	$0	$32	$0	$0	$79	$7	$0	$17	$104	$0
12.8	Instrument Wiring & Tubing	$0	$106	$205	$0	$0	$311	$25	$0	$84	$421	$1
12.9	Other I & C Equipment	$183	$0	$93	$0	$0	$276	$26	$0	$45	$347	$1
	SUBTOTAL 12	**$230**	**$106**	**$330**	**$0**	**$0**	**$666**	**$59**	**$0**	**$147**	**$872**	**$2**
13	IMPROVEMENTS TO SITE											
13.3	Site Facilities	$98	$0	$112	$0	$0	$210	$21	$0	$69	$299	$1
	SUBTOTAL 13	**$98**	**$0**	**$112**	**$0**	**$0**	**$210**	**$21**	**$0**	**$69**	**$299**	**$1**
14	BUILDINGS & STRUCTURES											
14.10	Coal Prep Building	$0	$19,796	$8,328	$0	$0	$28,124	$2,419	$0	$6,109	$36,652	$65
	SUBTOTAL 14	**$0**	**$19,796**	**$8,328**	**$0**	**$0**	**$28,124**	**$2,419**	**$0**	**$6,109**	**$36,652**	**$65**
	TOTAL COST	**$43,210**	**$21,995**	**$25,255**	**$0**	**$0**	**$90,460**	**$7,808**	**$0**	**$17,398**	**$115,667**	**$205**

Table 10-6 Capital Cost Summary – Batch System, Water/ND Lignite Slurry

Client: EPRI **Report Date:** 2013-Feb-25
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 5 - Lignite - water slurry feed
Plant Size: 574.5 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED											
2.1	Coal Storage & Feed	$11,174	$0	$0	$0	$0	**$11,174**	$929	$0	$0	**$12,103**	$21
2.2	Prepared Coal Storage & Feed	$3,118	$741	$494	$0	$0	**$4,353**	$365	$0	$944	**$5,662**	$10
2.3	Slurry Prep & Feed (incl. crushing)	$32,717	$0	$14,711	$0	$0	**$47,428**	$4,138	$0	$10,313	**$61,880**	$108
2.4	Misc.Coal Prep & Feed	$1,714	$1,240	$3,782	$0	$0	**$6,736**	$604	$0	$1,468	**$8,808**	$15
	SUBTOTAL 2	**$48,723**	**$1,981**	**$18,987**	**$0**	**$0**	**$69,691**	**$6,036**	**$0**	**$12,725**	**$88,453**	**$154**
3	FEEDWATER & MISC. BOP SYSTEMS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4	GASIFIER & ACCESSORIES	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5B	CO2 COMPRESSION	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	COMBUSTION TURBINE/ACCESSORIES	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	HRSG, DUCTING & STACK	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	STEAM TURBINE GENERATOR	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	COOLING WATER SYSTEM	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	ACCESSORY ELECTRIC PLANT											
11.2	Station Service Equipment	$181	$0	$17	$0	$0	$199	$19	$0	$22	$239	$0
11.3	Switchgear & Motor Control	$335	$0	$64	$0	$0	$399	$37	$0	$65	$502	$1
11.4	Conduit & Cable Tray	$0	$173	$540	$0	$0	$714	$66	$0	$195	$975	$2
11.5	Wire & Cable	$0	$331	$206	$0	$0	$537	$37	$0	$143	$717	$1
11.8	Main Power Transformers	$1,092	$0	$5	$0	$0	$1,096	$85	$0	$177	$1,358	$2
11.9	Electrical Foundations	$0	$5	$13	$0	$0	$18	$2	$0	$6	$25	$0
	SUBTOTAL 11	**$1,608**	**$509**	**$845**	**$0**	**$0**	**$2,962**	**$245**	**$0**	**$608**	**$3,815**	**$7**
12	INSTRUMENTATION & CONTROL											
12.6	Control Boards,Panels & Racks	$51	$0	$34	$0	$0	$86	$8	$0	$19	$112	$0
12.8	Instrument Wiring & Tubing	$0	$115	$223	$0	$0	$338	$27	$0	$91	$456	$1
12.9	Other I & C Equipment	$198	$0	$101	$0	$0	$299	$28	$0	$49	$377	$1
	SUBTOTAL 12	**$249**	**$115**	**$358**	**$0**	**$0**	**$723**	**$64**	**$0**	**$159**	**$945**	**$2**
13	IMPROVEMENTS TO SITE											
13.3	Site Facilities	$110	$0	$126	$0	$0	$235	$23	$0	$78	$336	$1
	SUBTOTAL 13	**$110**	**$0**	**$126**	**$0**	**$0**	**$235**	**$23**	**$0**	**$78**	**$336**	**$1**
14	BUILDINGS & STRUCTURES											
14.10	Coal Prep Building	$0	$20,961	$9,116	$0	$0	$30,078	$2,590	$0	$6,534	$39,201	$68
	SUBTOTAL 14	**$0**	**$20,961**	**$9,116**	**$0**	**$0**	**$30,078**	**$2,590**	**$0**	**$6,534**	**$39,201**	**$68**
	TOTAL COST	**$50,690**	**$23,567**	**$29,432**	**$0**	**$0**	**$103,689**	**$8,958**	**$0**	**$20,104**	**$132,751**	**$231**

Table 10-7 Capital Cost Summary – Dry Lock Hopper, PRB Coal

ITEM	QTY	UNIT	MATERIAL	LABOR	TOTAL	COMMENTS
EQUIPMENT:						
Coal Day Bins (Furnish & Erect)	1	LS	$ 9,945,000	$ -	$ 9,945,000	
Coal Sizing & Forwarding Equipment	1	LS	$ 14,666,000	$ 3,600,000	$ 18,266,000	
Coal - Bulk Solids Coolers incl Rotary Feeder, Flop Gate & Venting	1	LS	$ -	$ -	$ -	
CO2 Expansion / Forwarding / Condensing	1	LS	$ -	$ -	$ -	
Refrigeration / Chilling Equipment	1	LS	$ -	$ -	$ -	
Slurry Mixing & Forwarding Equipment	1	LS	$ -	$ -	$ -	
Electrical Equipment	1	LS	$ 1,928,000	$ 171,000	$ 2,099,000	
Equipment Subtotal			$ 26,539,000	$ 3,771,000	$ 30,310,000	
BULK MATERIALS:						
Coal Slurry Building	1	LS	$ 24,059,000	$ 10,993,000	$ 35,052,000	
Balance of Bulks - Civil	1	LS	$ 10,000	$ 207,000	$ 217,000	
Balance of Bulks - Piping & Valves	1	LS	$ 2,242,000	$ 1,938,000	$ 4,180,000	
Balance of Bulks - Insulation	1	LS	$ 67,000	$ 160,000	$ 227,000	
Balance of Bulks - Electrical Bulks	1	LS	$ 301,000	$ 576,000	$ 877,000	
Balance of Bulks - Instrumentation	1	LS	$ 891,000	$ 330,000	$ 1,221,000	
Bulks Subtotal			$ 27,570,000	$ 14,204,000	$ 41,774,000	
Equipment & Bulks Subtotal			$ 54,109,000	$ 17,975,000	$ 72,084,000	
PROFESSIONAL SERVICES:						
Engineering, Construction Management, Home Office & Fee	1	LS			$ 7,208,000	
OTHER COSTS:						
Owner's Costs	1	LS			$ -	Excluded
Process Contingency	1	LS			$ -	
Subtotal					**$ 79,292,000**	
Contingency - General	1	LS			$ 15,858,000	
TOTAL ESTIMATE (W/O TAXES) - EPCM BASIS					**$ 95,150,000**	

11. O&M Cost Estimates for Prep and Feed

The production costs or O&M expenses pertain to those charges associated with operating and maintaining the gasifier plant over its expected life. These costs include:

- Operating labor
- Maintenance – material and labor
- Administrative and support labor
- Consumables
- Waste disposal

There are two components of O&M costs: fixed O&M, which is independent of power generation, and variable O&M, which is proportional to power generation.

Operating Labor

Operating labor cost was determined based on of the number of operators required for each specific case. The average base labor rate used to determine annual cost is $15/hr. The associated labor burden is estimated at 25 percent of the base labor rate.

Maintenance Material and Labor

Maintenance cost was evaluated on the basis of relationships of maintenance cost to initial capital cost. This represents a weighted analysis in which the individual cost relationships were considered for each major plant component or section.

Administrative and Support Labor

Labor administration and overhead charges are assessed at rate of 25 percent of the burdened operation and maintenance labor.

Consumables

The cost of consumables will be determined on the basis of individual rates of consumption, the unit cost of each specific consumable commodity, and the plant annual operating hours. Quantities for major consumables such as fuel and sorbent were taken from technology-specific heat and mass balance diagrams developed for each plant application. Other consumables were evaluated on the basis of the quantity required using reference data. The quantities for initial fills and daily consumables were calculated on an 80 percent operating capacity basis. The annual cost for the daily consumables was then adjusted to incorporate the annual plant operating basis, or capacity factor. Initial fills of the consumables, fuels and chemicals, are different from the initial chemical loadings, which are included with the equipment pricing in the capital cost.

Waste Disposal

Waste quantities and disposal costs were determined and evaluated similarly to the consumables. In this study, spent mercury catalyst and slag are considered with the disposal costs.

Table 11-1 O&M Cost Summary – Batch System, Liquid CO_2/PRB Coal Slurry

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Batch Feed - Liquid CO2 Slurry - PRB					Heat Rate-net (Btu/kWh):	
					Coal #/hr	687.0
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	1.5		1.5			
Foreman	0.0		0.0			
Lab Tech's, etc.	0.0		0.0			
TOTAL-O.J.'s	2.5		2.5			
					Annual Cost	Annual Unit Cost
					$	#/hr-net
Annual Operating Labor Cost					$1,167,270	$1.699
Maintenance Labor Cost					$659,526	$0.960
Administrative & Support Labor					$456,699	$0.665
Property Taxes and Insurance					$2,715,740	$3.953
TOTAL FIXED OPERATING COSTS					**$4,999,235**	**$7.277**
VARIABLE OPERATING COSTS						
						#/-net
Maintenance Material Cost					**$989,289**	**$0.00021**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0	0	1.53	$0	**$0**	**$0.00000**
Chemicals						
MU & WT Chem. (lb)	0	0	0.24	$0	$0	$0.00000
Carbon (Mercury Removal) (lb)	0	0	1.48	$0	$0	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	0	0.00	704.61	$0	$0	$0.00000
Selexol Solution (gal)	0	0	33.58	$0	$0	$0.00000
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.00	185.42	$0	$0	$0.00000
Subtotal Chemicals				**$0**	**$0**	**$0.00000**
Other						
Aux Power (MW)	0	331	60.00	$0	$5,795,896	$0.00120
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$5,795,896**	$0.00120
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	0	0.59	$0	$0	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	0	22.92	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products & Emissions						
Sulfur (tons)	0	0	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$6,785,185**	**$0.00141**
Fuel (ton)	0	0	15.22	**$0**	**$0**	**$0.00000**

Table 11-2 O&M Cost Summary – Batch System, Liquid CO_2/ND Lignite Slurry

INITIAL & ANNUAL O&M EXPENSES						
Batch Feed - Liquid CO2 Slurry - ND Lignite					Cost Base (Jun):	2012
					Heat Rate-net (Btu/kWh):	
					Coal #/hr	918.7
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	1.5		1.5			
Foreman	0.0		0.0			
Lab Tech's, etc.	0.0		0.0			
TOTAL-O.J.'s	2.5		2.5			
					Annual Cost	Annual Unit Cost
					$	#/hr-net
Annual Operating Labor Cost					$1,167,270	$1.271
Maintenance Labor Cost					$735,845	$0.801
Administrative & Support Labor					$475,779	$0.518
Property Taxes and Insurance					$2,988,480	$3.253
TOTAL FIXED OPERATING COSTS					**$5,367,374**	**$5.843**
VARIABLE OPERATING COSTS						
						#/-net
Maintenance Material Cost					**$1,103,767**	**$0.00017**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0	0	1.53	$0	**$0**	**$0.00000**
Chemicals						
MU & WT Chem. (lb)	0	0	0.24	$0	$0	$0.00000
Carbon (Mercury Removal) (lb)	0	0	1.48	$0	$0	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	0	0.00	704.61	$0	$0	$0.00000
Selexol Solution (gal)	0	0	33.58	$0	$0	$0.00000
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.00	185.42	$0	$0	$0.00000
Subtotal Chemicals				**$0**	**$0**	**$0.00000**
Other						
Aux Power (MW)	0	424	60.00	$0	$7,432,825	$0.00115
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$7,432,825**	$0.00115
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	0	0.59	$0	$0	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	0	22.92	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products & Emissions						
Sulfur (tons)	0	0	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$8,536,592**	**$0.00133**
Fuel (ton)	0	0	15.22	**$0**	**$0**	**$0.00000**

Table 11-3 O&M Cost Summary – Continuous System, Liquid CO_2/PRB Coal Slurry

INITIAL & ANNUAL O&M EXPENSES		
Continuous Feed - Liquid CO2 Slurry - PRB	Cost Base (Jun):	2012
	Heat Rate-net (Btu/kWh):	
	Coal #/hr	687.0
	Capacity Factor (%):	80

OPERATING & MAINTENANCE LABOR			
Operating Labor			
Operating Labor Rate(base):	41.00	$/hour	
Operating Labor Burden:	30.00	% of base	
Labor O-H Charge Rate:	25.00	% of labor	
			Total
Skilled Operator	1.0		1.0
Operator	1.5		1.5
Foreman	0.0		0.0
Lab Tech's, etc.	0.0		0.0
TOTAL-O.J.'s	2.5		2.5

	Annual Cost $	Annual Unit Cost #/hr-net
Annual Operating Labor Cost	$1,167,270	$1.699
Maintenance Labor Cost	$674,582	$0.982
Administrative & Support Labor	$460,463	$0.670
Property Taxes and Insurance	$2,773,440	$4.037
TOTAL FIXED OPERATING COSTS	**$5,075,756**	**$7.389**

VARIABLE OPERATING COSTS

Consumables	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost	Annual Cost	#/-net
Maintenance Material Cost					**$1,011,874**	**$0.00021**
Water (/1000 gallons)	0	0	1.53	$0	**$0**	**$0.00000**
Chemicals						
MU & WT Chem. (lb)	0	0	0.24	$0	$0	$0.00000
Carbon (Mercury Removal) (lb)	0	0	1.48	$0	$0	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	0	0.00	704.61	$0	$0	$0.00000
Selexol Solution (gal)	0	0	33.58	$0	$0	$0.00000
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.00	185.42	$0	$0	$0.00000
Subtotal Chemicals				**$0**	**$0**	**$0.00000**
Other						
Aux Power (MW)	0	331	60.00	$0	$5,795,896	$0.00120
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$5,795,896**	$0.00120
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	0	0.59	$0	$0	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	0	22.92	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products & Emissions						
Sulfur (tons)	0	0	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$6,807,770**	**$0.00141**
Fuel (ton)	0	0	15.22	**$0**	**$0**	**$0.00000**

Table 11-4 O&M Cost Summary – Continuous System, Liquid CO_2/ND Lignite Slurry

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Continuous Feed - Liquid CO2 Slurry - ND Lignite					Heat Rate-net (Btu/kWh):	
					Coal #/hr	918.7
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	1.5		1.5			
Foreman	0.0		0.0			
Lab Tech's, etc.	0.0		0.0			
TOTAL-O.J.'s	2.5		2.5			
					Annual Cost $	Annual Unit Cost #/hr-net
Annual Operating Labor Cost					$1,167,270	$1.271
Maintenance Labor Cost					$757,098	$0.824
Administrative & Support Labor					$481,092	$0.524
Property Taxes and Insurance					$3,068,840	$3.341
TOTAL FIXED OPERATING COSTS					**$5,474,300**	**$5.959**
VARIABLE OPERATING COSTS						
						#/-net
Maintenance Material Cost					**$1,135,647**	**$0.00018**
Consumables	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost		
Water (/1000 gallons)	0	0	1.53	$0	**$0**	**$0.00000**
Chemicals						
MU & WT Chem. (lb)	0	0	0.24	$0	$0	$0.00000
Carbon (Mercury Removal) (lb)	0	0	1.48	$0	$0	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	0	0.00	704.61	$0	$0	$0.00000
Selexol Solution (gal)	0	0	33.58	$0	$0	$0.00000
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.00	185.42	$0	$0	$0.00000
Subtotal Chemicals				**$0**	**$0**	**$0.00000**
Other						
Aux Power (MW)	0	424	60.00	$0	$7,432,825	$0.00115
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$7,432,825**	$0.00115
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	0	0.59	$0	$0	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	0	22.92	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products & Emissions						
Sulfur (tons)	0	0	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$8,568,472**	**$0.00133**
Fuel (ton)	0	0	15.22	**$0**	**$0**	**$0.00000**

Table 11-5 O&M Cost Summary – Batch System, Water/PRB Coal Slurry

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Case 3 - PRB - water slurry feed					Heat Rate-net (Btu/kWh):	
					Coal #/hr:	733
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	1.5		1.5			
Foreman	0.0		0.0			
Lab Tech's, etc.	0.0		0.0			
TOTAL-O.J.'s	2.5		2.5			
					Annual Cost	Annual Unit Cost
					$	#/hr-net
Annual Operating Labor Cost					$1,167,270	$1.592
Maintenance Labor Cost					$580,480	$0.792
Administrative & Support Labor					$436,937	$0.596
Property Taxes and Insurance					$2,313,336	$3.155
TOTAL FIXED OPERATING COSTS					**$4,498,023**	**$6.134**
VARIABLE OPERATING COSTS						
						#/hr-net
Maintenance Material Cost					**$870,719**	**$0.00017**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0	0	1.53	**$0**	**$0**	**$0.00000**
Chemicals						
MU & WT Chem. (lb)	0	0	0.24	$0	$0	$0.00000
Carbon (Mercury Removal) (lb)	0	0	1.48	$0	$0	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	0	0.00	704.61	$0	$0	$0.00000
Selexol Solution (gal)	0	0	33.58	$0	$0	$0.00000
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.00	185.42	$0	$0	$0.00000
Subtotal Chemicals				**$0**	**$0**	**$0.00000**
Other						
Aux Power	0	73	60.00	$0	$1,285,407	$0.00025
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$1,285,407**	$0.00025
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	0	0.59	$0	$0	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	0	22.92	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products & Emissions						
Sulfur (tons)	0	64	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$2,156,127**	**$0.00042**
Fuel (ton)	0	0	20.05	**$0**	**$0**	**$0.00000**

Table 11-6 O&M Cost Summary – Batch System, Water/ND Lignite Slurry

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Case 5 - Lignite - water slurry feed					Heat Rate-net (Btu/kWh):	
					Coal #/hr	974
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	1.5		1.5			
Foreman	0.0		0.0			
Lab Tech's, etc.	0.0		0.0			
TOTAL-O.J.'s	2.5		2.5			
					Annual Cost	Annual Unit Cost
					$	#/hr-net
Annual Operating Labor Cost					$1,167,270	$1.198
Maintenance Labor Cost					$675,681	$0.693
Administrative & Support Labor					$460,738	$0.473
Property Taxes and Insurance					$2,655,017	$2.725
TOTAL FIXED OPERATING COSTS					**$4,958,706**	**$5.089**
VARIABLE OPERATING COSTS						
						#/hr-net
Maintenance Material Cost					**$1,013,522**	**$0.00015**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0	0	1.53	**$0**	**$0**	**$0.00000**
Chemicals						
MU & WT Chem. (lb)	0	0	0.24	$0	$0	$0.00000
Carbon (Mercury Removal) (lb)	0	0	1.48	$0	$0	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	0	0.00	704.61	$0	$0	$0.00000
Selexol Solution (gal)	0	0	33.58	$0	$0	$0.00000
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.00	185.42	$0	$0	$0.00000
Subtotal Chemicals				**$0**	**$0**	**$0.00000**
Other						
Aux Power	0	94	60.00	$0	$1,639,452	$0.00024
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$1,639,452**	$0.00024
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	0	0.59	$0	$0	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	0	22.92	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products & Emissions						
Sulfur (tons)	0	74	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$2,652,973**	**$0.00039**
Fuel (ton)	0	0	19.91	**$0**	**$0**	**$0.00000**

Table 11-7 O&M Cost Summary – Dry Lock Hopper, PRB Coal

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Dry Feed - PRB					Heat Rate-net (Btu/kWh):	
					Coal #/hr	687.0
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	1.5		1.5			
Foreman	0.0		0.0			
Lab Tech's, etc.	0.0		0.0			
TOTAL-O.J.'s	2.5		2.5			
					Annual Cost	Annual Unit Cost
					$	#/hr-net
Annual Operating Labor Cost					$1,167,270	$1.699
Maintenance Labor Cost					$425,533	$0.619
Administrative & Support Labor					$398,201	$0.580
Property Taxes and Insurance					$1,903,000	$2.770
TOTAL FIXED OPERATING COSTS					**$3,894,004**	**$5.669**
VARIABLE OPERATING COSTS						
						#/-net
Maintenance Material Cost					**$638,300**	**$0.00013**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0	0	1.53	$0	**$0**	**$0.00000**
Chemicals						
MU & WT Chem. (lb)	0	0	0.24	$0	$0	$0.00000
Carbon (Mercury Removal) (lb)	0	0	1.48	$0	$0	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	0	0.00	704.61	$0	$0	$0.00000
Selexol Solution (gal)	0	0	33.58	$0	$0	$0.00000
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.00	185.42	$0	$0	$0.00000
Subtotal Chemicals				**$0**	**$0**	**$0.00000**
Other						
Aux Power (MW)	0	113	60.00	$0	$1,986,348	$0.00041
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$1,986,348**	$0.00041
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	0	0.59	$0	$0	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	0	22.92	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products & Emissions						
Sulfur (tons)	0	0	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$2,624,647**	**$0.00055**
Fuel (ton)	0	0	15.22	**$0**	**$0**	**$0.00000**

12. Capital Cost Estimates for Complete IGCC Plant

The conceptual capital cost estimates presented herein are for a nominal 550 MWnet IGCC Plant using E-Gas™ gasification technology and CO_2 Capture. The conceptual design for this type of plant is documented in the Reference [1] Baseline report.

The capital cost estimates for the entire plant were developed by using a WorleyParsons proprietary cost model for this type of plant, with process parameter inputs provided by EPRI. Philips 66 contributed to this effort by providing adjustment factors to EPRI for the effects of changing from coal/water slurry feed to liquid CO_2/coal slurry feed for each of the fuels evaluated (Power River Basin coal and North Dakota lignite). The capital costs for Account 2 Coal prep and Feed System for the liquid CO_2/coal slurry cases are based on the batch feed type system; the differences between the batch and continuous flow type systems is negligible in the context of total plant costs.

The estimates for the coal/water slurry cases were benchmarked to the costs provided in the Reference [1] baseline report, with adjustments for escalation and scope as appropriate. The estimates for the liquid CO_2/coal slurry cases were developed by the model.

The estimate is presented in 3Q2012 overnight costs and has an accuracy range of -15 percent / +30 percent.

The following presents a description on how previously developed information was integrated with newly developed information to develop the estimates presented in this report.

12.1 Methodology for Liquid CO_2/Coal Slurry Cost Evaluation

The methodology used to evaluate an IGCC plant with carbon capture utilizing a liquid CO_2/coal feed is described below. The evaluation methodology is actually comprised of two separate parts: one for the heat/mass balance development of the complete IGCC plant and the second is for the capital cost evaluation of the same IGCC plant. The heat and mass balance information is used to scale various equipment and systems from a baseline case that was developed over many years of design and engineering for IGCC plants. Refer to Section 14 for a discussion of the history of the performance modeling.

<u>Cost Modeling</u>

The cost modeling for the Baseline study was performed by WorleyParsons using performance and design data provided by RDS and Booz Allen, as described above. WorleyParsons had developed a capital cost and an O&M cost model for different types of fossil fired power plants over the course of many years of engineering and design. This model is updated and calibrated periodically to reflect industry trends and current pricing. The models are configured to evaluate costs in conformance with the EPRI TAG.

As per the EPRI TAG, the cost model features a work breakdown structure comprised of 14 Accounts, each containing multiple subaccounts. These accounts are adjusted to suit each specific case being evaluated, with respect to technical data such as process conditions, time of construction (escalation), site location (labor pricing, productivity), and other factors that may apply.

Starting with the appropriate case from the Baseline study, adjustments were made to reflect the EPRI technical input. For the ND lignite case, as no case was provided in the Baseline study, the PRB case from that study was adjusted and scaled to arrive at a cost for the purposes of this study.

The costs presented in the Baseline reports used as references herein were adjusted to reflect escalation, etc. to arrive at the data date, site, etc. for the cases presented herein. An exception to this methodology involves Account 2 Fuel Preparation and Feed. For the liquid CO_2 study cases, no prior case existed to serve as a basis for adjustment. The system presented in this report comprising the liquid CO_2/coal slurry Prep and Feed System is essentially a first of a kind.

Thus, the capital cost estimate for these cases (Account 2 for the liquid CO_2 cases) was prepared based on development of conceptual design information for this account. Requests were made to selected vendors for novel equipment and for particularly expensive items. Material take-off information was developed for structural, mechanical, and electrical quantities based on the development of schematic system diagrams (Flow Diagrams and Electrical One-Line Diagram) and on the preparation of multi-view general arrangement drawings of the Fuel Prep and Feed building and its contents.

The O&M costs were developed for Account 2 as a stand-alone facility and also for the entire IGCC plant. Input data to the cost model for these O&M estimates relies on relatively standard cost factors and WorleyParsons estimates of quantity and types of labor required for operation and maintenance of the IGCC facility.

Finally, the capital and O&M cost data are input to the approved DOE COE estimation model to arrive at values for first year COE and levelized COE. The DOE model and methodology is described in the "QGESS: Cost Estimation Methodology for NETL Assessments of Power Plant Performance" [3].

Project Scope

The basic premise of the scope of work begins with Case S4B of the NETL low rank coal baseline report [1].

Case S4B is a 2 x 2 x 1 IGCC plant using E-Gas™ gasification technology. Case S4B also includes CO_2 capture and compression.

The scope of the estimates presented herein is the same as that presented in the Reference 1 baseline report. The following cases have been evaluated:

- Water/Coal Slurry, PRB coal
- Liquid CO_2/Coal Slurry, PRB coal
- Water/Coal Slurry, North Dakota Lignite
- Liquid CO_2/Coal Slurry, North Dakota Lignite

12.2 Estimate Details

The following tables present the Capital Costs for each case as enumerated above.

Table 12-1 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 90% Capture

Client: EPRI **Report Date:** 2013-May-21
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 1 - PRB - water slurry feed, 90% Capture
Plant Size: 537.1 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING	$19,669	$3,784	$15,813	$0	$0	**$39,265**	$3,502	$0	$8,554	**$51,321**	$96
2	COAL & SORBENT PREP & FEED	$40,011	$6,509	$19,329	$0	$0	**$65,849**	$5,760	$0	$12,067	**$83,676**	$156
3	FEEDWATER & MISC. BOP SYSTEMS	$11,304	$9,966	$10,214	$0	$0	**$31,483**	$2,862	$0	$7,679	**$42,024**	$78
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$167,318	$0	$91,807	$0	$0	**$259,125**	$22,881	$36,282	$48,685	**$366,973**	$683
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.3	ASU/Oxidant Compression	$241,285	$0	w/equip.	$0	$0	**$241,285**	$22,567	$0	$26,385	**$290,236**	$540
4.4-4.9	Other Gasification Equipment	$25,338	$14,740	$18,163	$0	$0	**$58,242**	$5,459	$0	$13,846	**$77,546**	$144
	SUBTOTAL 4	**$433,941**	**$14,740**	**$109,970**	**$0**	**$0**	**$558,651**	**$50,906**	**$36,282**	**$88,916**	**$734,756**	**$1,368**
5A	GAS CLEANUP & PIPING	$95,787	$4,388	$79,570	$0	$0	**$179,745**	$16,834	$27,632	$45,073	**$269,283**	$501
5B	CO2 COMPRESSION	$41,154	$0	$19,040	$0	$0	**$60,194**	$5,605	$0	$13,160	**$78,960**	$147
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	**$120,642**	$11,086	$12,064	$14,379	**$158,171**	$295
6.2-6.9	Combustion Turbine Other	$0	$935	$1,111	$0	$0	**$2,046**	$192	$0	$671	**$2,909**	$5
	SUBTOTAL 6	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$300**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$28,500	$0	$5,563	$0	$0	**$34,063**	$3,147	$0	$3,721	**$40,932**	$76
7.2-7.9	Ductwork and Stack	$2,705	$1,868	$2,526	$0	$0	**$7,099**	$644	$0	$1,254	**$8,996**	$17
	SUBTOTAL 7	**$31,205**	**$1,868**	**$8,089**	**$0**	**$0**	**$41,162**	**$3,791**	**$0**	**$4,975**	**$49,928**	**$93**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$37,500	$0	$6,213	$0	$0	**$43,713**	$3,865	$0	$4,758	**$52,335**	$97
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$19,635	$1,160	$11,120	$0	$0	**$31,915**	$2,567	$0	$7,849	**$42,332**	$79
	SUBTOTAL 8	**$57,135**	**$1,160**	**$17,332**	**$0**	**$0**	**$75,628**	**$6,432**	**$0**	**$12,607**	**$94,667**	**$176**
9	COOLING WATER SYSTEM	$5,777	$8,968	$7,211	$0	$0	**$21,956**	$1,958	$0	$5,078	**$28,992**	$54
10	ASH/SPENT SORBENT HANDLING SYS	$26,687	$2,017	$13,230	$0	$0	**$41,934**	$3,900	$0	$5,001	**$50,835**	$95
11	ACCESSORY ELECTRIC PLANT	$39,125	$16,942	$31,392	$0	$0	**$87,459**	$7,389	$0	$18,149	**$112,996**	$210
12	INSTRUMENTATION & CONTROL	$13,480	$2,759	$9,130	$0	$0	**$25,369**	$2,277	$1,268	$4,861	**$33,776**	$63
13	IMPROVEMENTS TO SITE	$4,017	$2,368	$10,757	$0	$0	**$17,142**	$1,694	$0	$5,651	**$24,486**	$46
14	BUILDINGS & STRUCTURES	$0	$27,945	$17,956	$0	$0	**$45,901**	$4,012	$0	$9,285	**$59,198**	$110
	TOTAL COST	**$933,158**	**$104,348**	**$376,921**	**$0**	**$0**	**$1,414,427**	**$128,200**	**$77,247**	**$256,105**	**$1,875,979**	**$3,493**

Table 12-1 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 90% Capture continued

Client: EPRI — Report Date: 2013-May-21
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 1 - PRB - water slurry feed, 90% Capture
Plant Size: 537.1 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING											
1.1	Coal Receive & Unload	$5,678	$0	$2,805	$0	$0	$8,484	$742	$0	$1,845	$11,071	$21
1.2	Coal Stackout & Reclaim	$7,337	$0	$1,798	$0	$0	$9,136	$783	$0	$1,984	$11,903	$22
1.3	Coal Conveyors & Yd Crush	$4,869	$0	$639	$0	$0	$5,508	$466	$0	$1,195	$7,169	$13
1.4	Other Coal Handling	$1,785	$0	$412	$0	$0	$2,197	$188	$0	$477	$2,862	$5
1.5	Sorbent Receive & Unload	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.6	Sorbent Stackout & Reclaim	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.7	Sorbent Conveyors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.8	Other Sorbent Handling	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.9	Coal & Sorbent Hnd.Foundations	$0	$3,784	$10,158	$0	$0	$13,942	$1,322	$0	$3,053	$18,316	$34
	SUBTOTAL 1.	**$19,669**	**$3,784**	**$15,813**	**$0**	**$0**	**$39,265**	**$3,502**	**$0**	**$8,554**	**$51,321**	**$96**
2	COAL & SORBENT PREP & FEED											
2.1	Coal Storage & Feed	$10,410	$0	$0	$0	$0	$10,410	$866	$0	$0	$11,275	$21
2.2	Prepared Coal Storage & Feed	$2,458	$585	$390	$0	$0	$3,432	$288	$0	$744	$4,463	$8
2.3	Slurry Prep & Feed (incl. crushing)	$25,792	$0	$11,597	$0	$0	$37,389	$3,262	$0	$8,130	$48,782	$91
2.4	Misc.Coal Prep & Feed	$1,352	$977	$2,981	$0	$0	$5,310	$476	$0	$1,157	$6,944	$13
2.5	Sorbent Prep Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.6	Sorbent Storage & Feed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.7	Sorbent Injection System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.8	Booster Air Supply System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.9	Coal & Sorbent Feed Foundation	$0	$4,947	$4,361	$0	$0	$9,308	$869	$0	$2,035	$12,212	$23
	SUBTOTAL 2.	**$40,011**	**$6,509**	**$19,329**	**$0**	**$0**	**$65,849**	**$5,760**	**$0**	**$12,067**	**$83,676**	**$156**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$4,027	$6,992	$3,691	$0	$0	$14,710	$1,326	$0	$3,207	$19,243	$36
3.2	Water Makeup & Pretreating	$531	$55	$293	$0	$0	$879	$81	$0	$288	$1,248	$2
3.3	Other Feedwater Subsystems	$2,284	$753	$677	$0	$0	$3,715	$319	$0	$807	$4,840	$9
3.4	Service Water Systems	$309	$619	$2,147	$0	$0	$3,075	$290	$0	$1,009	$4,374	$8
3.5	Other Boiler Plant Systems	$1,667	$625	$1,548	$0	$0	$3,840	$348	$0	$838	$5,026	$9
3.6	FO Supply Sys & Nat Gas	$391	$738	$688	$0	$0	$1,817	$170	$0	$397	$2,384	$4
3.7	Waste Treatment Equipment	$721	$0	$448	$0	$0	$1,169	$112	$0	$384	$1,665	$3
3.8	Misc. Power Plant Equipment	$1,373	$185	$721	$0	$0	$2,279	$217	$0	$749	$3,245	$6
	SUBTOTAL 3.	**$11,304**	**$9,966**	**$10,214**	**$0**	**$0**	**$31,483**	**$2,862**	**$0**	**$7,679**	**$42,024**	**$78**

Table 12-1 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 90% Capture continued

Client: EPRI **Report Date:** 2013-May-21
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 1 - PRB - water slurry feed, 90% Capture
Plant Size: 537.1 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$167,318	$0	$91,807	$0	$0	$259,125	$22,881	$36,282	$48,685	$366,973	$683
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$241,285	$0	w/equip.	$0	$0	$241,285	$22,567	$0	$26,385	$290,236	$540
4.4	LT Heat Recovery & FG Saturation	$25,338	$0	$9,583	$0	$0	$34,922	$3,293	$0	$7,643	$45,858	$85
4.5	Misc. Gasification Equipment	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.6	Other Gasification Equipment	$0	$2,187	$890	$0	$0	$3,077	$286	$0	$673	$4,036	$8
4.8	Major Component Rigging	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.9	Gasification Foundations	$0	$12,553	$7,690	$0	$0	$20,243	$1,879	$0	$5,530	$27,652	$51
	SUBTOTAL 4.	**$433,941**	**$14,740**	**$109,970**	**$0**	**$0**	**$558,651**	**$50,906**	**$36,282**	**$88,916**	**$734,756**	**$1,368**
5A	GAS CLEANUP & PIPING											
5A.1	Double Stage Selexol	$74,338	$0	$63,079	$0	$0	$137,417	$12,889	$27,483	$35,558	$213,348	$397
5A.2	Elemental Sulfur Plant	$6,941	$1,360	$8,956	$0	$0	$17,256	$1,628	$0	$3,777	$22,661	$42
5A.3	Mercury Removal	$1,685	$0	$1,283	$0	$0	$2,968	$278	$148	$679	$4,073	$8
5A.4	Shift Reactors	$10,555	$0	$4,249	$0	$0	$14,804	$1,377	$0	$3,236	$19,417	$36
5A.5	Particulate Removal	w/4.1	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
5A.6	Blowback Gas Systems	$2,266	$381	$215	$0	$0	$2,863	$263	$0	$625	$3,751	$7
5A.7	Fuel Gas Piping	$0	$1,399	$926	$0	$0	$2,326	$202	$0	$506	$3,033	$6
5A.9	HGCU Foundations	$0	$1,247	$863	$0	$0	$2,111	$196	$0	$692	$2,999	$6
	SUBTOTAL 5A.	**$95,787**	**$4,388**	**$79,570**	**$0**	**$0**	**$179,745**	**$16,834**	**$27,632**	**$45,073**	**$269,283**	**$501**
5B	CO2 COMPRESSION											
5B.1	CO2 Removal System	w/ 5A.1	$0	w/ 5A.1	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$41,154	$0	$19,040	$0	$0	$60,194	$5,605	$0	$13,160	$78,960	$147
	SUBTOTAL 5B.	**$41,154**	**$0**	**$19,040**	**$0**	**$0**	**$60,194**	**$5,605**	**$0**	**$13,160**	**$78,960**	**$147**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	$120,642	$11,086	$12,064	$14,379	$158,171	$295
6.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$935	$1,111	$0	$0	$2,046	$192	$0	$671	$2,909	$5
	SUBTOTAL 6.	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$300**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$28,500	$0	$5,563	$0	$0	$34,063	$3,147	$0	$3,721	$40,932	$76
7.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$0	$1,363	$989	$0	$0	$2,352	$202	$0	$511	$3,065	$6
7.4	Stack	$2,705	$0	$1,016	$0	$0	$3,721	$346	$0	$407	$4,474	$8
7.9	HRSG,Duct & Stack Foundations	$0	$505	$520	$0	$0	$1,025	$96	$0	$336	$1,458	$3
	SUBTOTAL 7.	**$31,205**	**$1,868**	**$8,089**	**$0**	**$0**	**$41,162**	**$3,791**	**$0**	**$4,975**	**$49,928**	**$93**

Table 12-1 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 90% Capture continued

Client: EPRI | **Report Date:** 2013-May-21

Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 1 - PRB - water slurry feed, 90% Capture

Plant Size: 537.1 MW,net | **Estimate Type:** Conceptual | **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$37,500	$0	$6,213	$0	$0	$43,713	$3,865	$0	$4,758	$52,335	$97
8.2	Turbine Plant Auxiliaries	$251	$0	$576	$0	$0	$827	$79	$0	$91	$996	$2
8.3	Condenser & Auxiliaries	$3,120	$0	$1,846	$0	$0	$4,966	$464	$0	$543	$5,972	$11
8.4	Steam Piping	$16,264	$0	$6,592	$0	$0	$22,856	$1,717	$0	$6,143	$30,716	$57
8.9	TG Foundations	$0	$1,160	$2,106	$0	$0	$3,267	$308	$0	$1,072	$4,647	$9
	SUBTOTAL 8.	**$57,135**	**$1,160**	**$17,332**	**$0**	**$0**	**$75,628**	**$6,432**	**$0**	**$12,607**	**$94,667**	**$176**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,130	$0	$950	$0	$0	$4,080	$378	$0	$669	$5,127	$10
9.2	Circulating Water Pumps	$1,486	$0	$96	$0	$0	$1,583	$137	$0	$258	$1,977	$4
9.3	Circ.Water System Auxiliaries	$139	$0	$20	$0	$0	$159	$15	$0	$26	$200	$0
9.4	Circ.Water Piping	$0	$6,145	$1,506	$0	$0	$7,651	$641	$0	$1,658	$9,950	$19
9.5	Make-up Water System	$318	$0	$441	$0	$0	$758	$70	$0	$166	$994	$2
9.6	Component Cooling Water Sys	$704	$842	$583	$0	$0	$2,130	$190	$0	$464	$2,783	$5
9.9	Circ.Water System Foundations	$0	$1,981	$3,615	$0	$0	$5,595	$528	$0	$1,837	$7,960	$15
	SUBTOTAL 9.	**$5,777**	**$8,968**	**$7,211**	**$0**	**$0**	**$21,956**	**$1,958**	**$0**	**$5,078**	**$28,992**	**$54**
10	ASH/SPENT SORBENT HANDLING SYS											
10.1	Slag Dewatering & Cooling	$23,266	$0	$11,474	$0	$0	$34,739	$3,237	$0	$3,798	$41,774	$78
10.2	Gasifier Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.3	Cleanup Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.4	High Temperature Ash Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.5	Other Ash Recovery Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.6	Ash Storage Silos	$770	$0	$838	$0	$0	$1,607	$151	$0	$264	$2,022	$4
10.7	Ash Transport & Feed Equipment	$1,057	$0	$249	$0	$0	$1,307	$116	$0	$213	$1,636	$3
10.8	Misc. Ash Handling Equipment	$1,594	$1,954	$584	$0	$0	$4,132	$381	$0	$677	$5,190	$10
10.9	Ash/Spent Sorbent Foundation	$0	$63	$86	$0	$0	$149	$14	$0	$49	$212	$0
	SUBTOTAL 10.	**$26,687**	**$2,017**	**$13,230**	**$0**	**$0**	**$41,934**	**$3,900**	**$0**	**$5,001**	**$50,835**	**$95**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$1,170	$0	$1,173	$0	$0	$2,343	$219	$0	$256	$2,818	$5
11.2	Station Service Equipment	$5,737	$0	$543	$0	$0	$6,280	$588	$0	$687	$7,555	$14
11.3	Switchgear & Motor Control	$10,589	$0	$2,028	$0	$0	$12,616	$1,185	$0	$2,070	$15,872	$30
11.4	Conduit & Cable Tray	$0	$5,480	$17,085	$0	$0	$22,565	$2,088	$0	$6,163	$30,817	$57
11.5	Wire & Cable	$0	$10,473	$6,502	$0	$0	$16,974	$1,155	$0	$4,532	$22,662	$42
11.6	Protective Equipment	$0	$805	$3,081	$0	$0	$3,886	$372	$0	$639	$4,897	$9
11.7	Standby Equipment	$278	$0	$285	$0	$0	$563	$53	$0	$92	$709	$1
11.8	Main Power Transformers	$21,352	$0	$181	$0	$0	$21,532	$1,662	$0	$3,479	$26,673	$50
11.9	Electrical Foundations	$0	$184	$514	$0	$0	$698	$66	$0	$229	$993	$2
	SUBTOTAL 11.	**$39,125**	**$16,942**	**$31,392**	**$0**	**$0**	**$87,459**	**$7,389**	**$0**	**$18,149**	**$112,996**	**$210**

Table 12-1 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 90% Capture continued

Client: EPRI **Report Date:** 2013-May-21

Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 1 - PRB - water slurry feed, 90% Capture

Plant Size: 537.1 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,331	$0	$934	$0	$0	$2,265	$214	$113	$389	$2,981	$6
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$306	$0	$206	$0	$0	$512	$48	$26	$117	$703	$1
12.7	Computer & Accessories	$7,099	$0	$239	$0	$0	$7,338	$686	$367	$839	$9,229	$17
12.8	Instrument Wiring & Tubing	$0	$2,759	$5,329	$0	$0	$8,088	$653	$404	$2,286	$11,431	$21
12.9	Other I & C Equipment	$4,745	$0	$2,422	$0	$0	$7,167	$676	$358	$1,230	$9,432	$18
	SUBTOTAL 12.	**$13,480**	**$2,759**	**$9,130**	**$0**	**$0**	**$25,369**	**$2,277**	**$1,268**	**$4,861**	**$33,776**	**$63**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$126	$2,924	$0	$0	$3,050	$295	$0	$1,003	$4,348	$8
13.2	Site Improvements	$0	$2,242	$3,233	$0	$0	$5,475	$542	$0	$1,805	$7,822	$15
13.3	Site Facilities	$4,017	$0	$4,600	$0	$0	$8,617	$857	$0	$2,842	$12,316	$23
	SUBTOTAL 13.	**$4,017**	**$2,368**	**$10,757**	**$0**	**$0**	**$17,142**	**$1,694**	**$0**	**$5,651**	**$24,486**	**$46**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$319	$186	$0	$0	$505	$44	$0	$110	$659	$1
14.2	Steam Turbine Building	$0	$2,947	$4,336	$0	$0	$7,283	$658	$0	$1,191	$9,133	$17
14.3	Administration Building	$0	$1,120	$839	$0	$0	$1,960	$172	$0	$320	$2,452	$5
14.4	Circulation Water Pumphouse	$0	$200	$110	$0	$0	$310	$27	$0	$51	$387	$1
14.5	Water Treatment Buildings	$0	$425	$428	$0	$0	$853	$76	$0	$139	$1,068	$2
14.6	Machine Shop	$0	$546	$386	$0	$0	$932	$82	$0	$152	$1,166	$2
14.7	Warehouse	$0	$882	$588	$0	$0	$1,470	$129	$0	$240	$1,838	$3
14.8	Other Buildings & Structures	$0	$528	$425	$0	$0	$953	$84	$0	$207	$1,244	$2
14.9	Waste Treating Building & Str.	$0	$1,181	$2,330	$0	$0	$3,511	$321	$0	$766	$4,598	$9
14.10	Coal Prep Building	$0	$19,796	$8,328	$0	$0	$28,124	$2,419	$0	$6,109	$36,652	$68
	SUBTOTAL 14.	**$0**	**$27,945**	**$17,956**	**$0**	**$0**	**$45,901**	**$4,012**	**$0**	**$9,285**	**$59,198**	**$110**
	TOTAL COST	**$933,158**	**$104,348**	**$376,921**	**$0**	**$0**	**$1,414,427**	**$128,200**	**$77,247**	**$256,105**	**$1,875,979**	**$3,493**

Table 12-2 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 90% Capture

Client: EPRI **Report Date:** 2013-May-21
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 2 - PRB - LCO2 slurry feed, 90% Capture
Plant Size: 504.2 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
1	COAL & SORBENT HANDLING	$19,523	$3,758	$15,698	$0	$0	$38,978	$3,477	$0	$8,491	$50,946	$101
2	COAL & SORBENT PREP & FEED	$46,167	$11,998	$17,302	$0	$0	$75,466	$6,588	$2,769	$14,810	$99,633	$198
3	FEEDWATER & MISC. BOP SYSTEMS	$12,051	$10,225	$11,291	$0	$0	$33,567	$3,055	$0	$8,273	$44,895	$89
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$160,798	$0	$87,872	$0	$0	$248,670	$21,960	$34,714	$46,743	$352,088	$698
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$236,974	$0	w/equip.	$0	$0	$236,974	$22,164	$0	$25,914	$285,051	$565
4.4-4.9	Other Gasification Equipment	$28,035	$14,457	$19,054	$0	$0	$61,545	$5,771	$0	$14,563	$81,879	$162
	SUBTOTAL 4	$425,807	$14,457	$106,926	$0	$0	$547,189	$49,894	$34,714	$87,220	$719,018	$1,426
5A	GAS CLEANUP & PIPING	$96,774	$3,463	$83,112	$0	$0	$183,349	$17,186	$30,546	$46,373	$277,454	$550
5B	CO2 COMPRESSION	$42,050	$0	$18,049	$0	$0	$60,099	$5,592	$0	$13,138	$78,829	$156
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	$120,642	$11,086	$12,064	$14,379	$158,171	$314
6.2-6.9	Combustion Turbine Other	$0	$935	$1,111	$0	$0	$2,046	$192	$0	$671	$2,909	$6
	SUBTOTAL 6	$113,864	$935	$7,888	$0	$0	$122,688	$11,278	$12,064	$15,051	$161,081	$320
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$29,770	$0	$5,811	$0	$0	$35,581	$3,288	$0	$3,887	$42,756	$85
7.2-7.9	Ductwork and Stack	$2,623	$1,811	$2,450	$0	$0	$6,884	$624	$0	$1,216	$8,724	$17
	SUBTOTAL 7	$32,393	$1,811	$8,261	$0	$0	$42,465	$3,912	$0	$5,103	$51,480	$102
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$35,040	$0	$5,806	$0	$0	$40,846	$3,611	$0	$4,446	$48,903	$97
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$19,396	$1,091	$10,810	$0	$0	$31,297	$2,512	$0	$7,718	$41,527	$82
	SUBTOTAL 8	$54,436	$1,091	$16,616	$0	$0	$72,143	$6,123	$0	$12,163	$90,430	$179
9	COOLING WATER SYSTEM	$5,621	$8,639	$7,049	$0	$0	$21,309	$1,901	$0	$4,928	$28,138	$56
10	ASH/SPENT SORBENT HANDLING SYS	$26,504	$2,005	$13,139	$0	$0	$41,647	$3,873	$0	$4,967	$50,487	$100
11	ACCESSORY ELECTRIC PLANT	$39,940	$17,210	$31,762	$0	$0	$88,912	$7,507	$0	$18,455	$114,875	$228
12	INSTRUMENTATION & CONTROL	$13,229	$2,707	$8,960	$0	$0	$24,896	$2,235	$1,245	$4,771	$33,146	$66
13	IMPROVEMENTS TO SITE	$3,956	$2,332	$10,594	$0	$0	$16,882	$1,668	$0	$5,565	$24,115	$48
14	BUILDINGS & STRUCTURES	$0	$31,428	$19,302	$0	$0	$50,730	$4,426	$0	$10,344	$65,500	$130
	TOTAL COST	$932,316	$112,060	$375,946	$0	$0	$1,420,322	$128,715	$81,338	$259,652	$1,890,027	$3,749

Table 12-2 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 90% Capture continued

	Client:	EPRI								Report Date:	2013-May-21		
	Project:	LCO2/Coal Slurry Economics											
		TOTAL PLANT COST SUMMARY											
	Case:	Case 2 - PRB - LCO2 slurry feed, 90% Capture											
	Plant Size:	504.2 MW,net		Estimate Type:	Conceptual			Cost Base (Jun)	2012	($x1000)			
Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST		
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW	
1	COAL & SORBENT HANDLING												
1.1	Coal Receive & Unload	$5,640	$0	$2,786	$0	$0	$8,426	$737	$0	$1,833	$10,996	$22	
1.2	Coal Stackout & Reclaim	$7,288	$0	$1,786	$0	$0	$9,074	$778	$0	$1,970	$11,822	$23	
1.3	Coal Conveyors & Yd Crush	$4,823	$0	$627	$0	$0	$5,449	$461	$0	$1,182	$7,093	$14	
1.4	Other Coal Handling	$1,773	$0	$409	$0	$0	$2,182	$187	$0	$474	$2,842	$6	
1.5	Sorbent Receive & Unload	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
1.6	Sorbent Stackout & Reclaim	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
1.7	Sorbent Conveyors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
1.8	Other Sorbent Handling	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
1.9	Coal & Sorbent Hnd.Foundations	$0	$3,758	$10,089	$0	$0	$13,847	$1,313	$0	$3,032	$18,192	$36	
	SUBTOTAL 1.	**$19,523**	**$3,758**	**$15,698**	**$0**	**$0**	**$38,978**	**$3,477**	**$0**	**$8,491**	**$50,946**	**$101**	
2	COAL & SORBENT PREP & FEED												
2.1	Coal Storage & Feed	$9,945	$0	$0	$0	$0	$9,945	$827	$0	$0	$10,772	$21	
2.2	Coal Prep & Feed	$1,365	$0	$203	$0	$0	$1,568	$133	$0	$340	$2,041	$4	
2.3	Coal Slurry Prep & Feed	$33,515	$6,116	$9,810	$0	$0	$49,441	$4,293	$2,769	$11,300	$67,803	$134	
2.4	Misc.Coal Prep & Feed	$1,342	$970	$2,960	$0	$0	$5,272	$473	$0	$1,149	$6,894	$14	
2.5	Sorbent Prep Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2.6	Sorbent Storage & Feed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2.7	Sorbent Injection System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2.8	Booster Air Supply System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2.9	Coal & Sorbent Feed Foundation	$0	$4,911	$4,329	$0	$0	$9,240	$863	$0	$2,021	$12,123	$24	
	SUBTOTAL 2.	**$46,167**	**$11,998**	**$17,302**	**$0**	**$0**	**$75,466**	**$6,588**	**$2,769**	**$14,810**	**$99,633**	**$198**	
3	FEEDWATER & MISC. BOP SYSTEMS												
3.1	Feedwater System	$3,998	$6,942	$3,665	$0	$0	$14,605	$1,316	$0	$3,184	$19,105	$38	
3.2	Water Makeup & Pretreating	$667	$69	$368	$0	$0	$1,104	$101	$0	$362	$1,567	$3	
3.3	Other Feedwater Subsystems	$2,268	$747	$673	$0	$0	$3,688	$317	$0	$801	$4,805	$10	
3.4	Service Water Systems	$389	$777	$2,696	$0	$0	$3,861	$364	$0	$1,268	$5,493	$11	
3.5	Other Boiler Plant Systems	$2,094	$784	$1,944	$0	$0	$4,822	$437	$0	$1,052	$6,311	$13	
3.6	FO Supply Sys & Nat Gas	$383	$724	$675	$0	$0	$1,783	$167	$0	$390	$2,339	$5	
3.7	Waste Treatment Equipment	$906	$0	$562	$0	$0	$1,468	$140	$0	$482	$2,090	$4	
3.8	Misc. Power Plant Equipment	$1,348	$181	$708	$0	$0	$2,236	$213	$0	$735	$3,184	$6	
	SUBTOTAL 3.	**$12,051**	**$10,225**	**$11,291**	**$0**	**$0**	**$33,567**	**$3,055**	**$0**	**$8,273**	**$44,895**	**$89**	

Table 12-2 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 90% Capture continued

Client: EPRI **Report Date:** 2013-May-21
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 2 - PRB - LCO2 slurry feed, 90% Capture
Plant Size: 504.2 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$160,798	$0	$87,872	$0	$0	$248,670	$21,960	$34,714	$46,743	$352,088	$698
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$236,974	$0	w/equip.	$0	$0	$236,974	$22,164	$0	$25,914	$285,051	$565
4.4	LT Heat Recovery & FG Saturation	$28,035	$0	$10,603	$0	$0	$38,637	$3,644	$0	$8,456	$50,737	$101
4.5	Misc. Gasification Equipment	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.6	Other Gasification Equipment	$0	$1,973	$803	$0	$0	$2,776	$258	$0	$607	$3,641	$7
4.8	Major Component Rigging	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.9	Gasification Foundations	$0	$12,484	$7,648	$0	$0	$20,132	$1,869	$0	$5,500	$27,501	$55
	SUBTOTAL 4.	**$425,807**	**$14,457**	**$106,926**	**$0**	**$0**	**$547,189**	**$49,894**	**$34,714**	**$87,220**	**$719,018**	**$1,426**
5A	GAS CLEANUP & PIPING											
5A.1	Double Stage Selexol	$82,198	$0	$69,748	$0	$0	$151,946	$14,252	$30,389	$39,317	$235,905	$468
5A.2	Elemental Sulfur Plant	$6,964	$1,364	$8,985	$0	$0	$17,314	$1,633	$0	$3,789	$22,736	$45
5A.3	Mercury Removal	$1,783	$0	$1,357	$0	$0	$3,139	$294	$157	$718	$4,309	$9
5A.4	Shift Reactors	$4,064	$0	$1,636	$0	$0	$5,700	$530	$0	$1,246	$7,476	$15
5A.5	Particulate Removal	w/4.1	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
5A.6	Blowback Gas Systems	$1,766	$297	$167	$0	$0	$2,230	$205	$0	$487	$2,923	$6
5A.7	Fuel Gas Piping	$0	$953	$630	$0	$0	$1,583	$138	$0	$344	$2,065	$4
5A.9	HGCU Foundations	$0	$849	$588	$0	$0	$1,437	$134	$0	$471	$2,042	$4
	SUBTOTAL 5A.	**$96,774**	**$3,463**	**$83,112**	**$0**	**$0**	**$183,349**	**$17,186**	**$30,546**	**$46,373**	**$277,454**	**$550**
5B	CO2 COMPRESSION											
5B.1	CO2 Removal System	w/ 5A.1	$0	w/ 5A.1	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$42,050	$0	$18,049	$0	$0	$60,099	$5,592	$0	$13,138	$78,829	$156
	SUBTOTAL 5B.	**$42,050**	**$0**	**$18,049**	**$0**	**$0**	**$60,099**	**$5,592**	**$0**	**$13,138**	**$78,829**	**$156**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	$120,642	$11,086	$12,064	$14,379	$158,171	$314
6.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$935	$1,111	$0	$0	$2,046	$192	$0	$671	$2,909	$6
	SUBTOTAL 6.	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$320**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$29,770	$0	$5,811	$0	$0	$35,581	$3,288	$0	$3,887	$42,756	$85
7.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$0	$1,322	$959	$0	$0	$2,281	$196	$0	$495	$2,972	$6
7.4	Stack	$2,623	$0	$985	$0	$0	$3,609	$335	$0	$394	$4,338	$9
7.9	HRSG,Duct & Stack Foundations	$0	$490	$505	$0	$0	$994	$93	$0	$326	$1,413	$3
	SUBTOTAL 7.	**$32,393**	**$1,811**	**$8,261**	**$0**	**$0**	**$42,465**	**$3,912**	**$0**	**$5,103**	**$51,480**	**$102**

Table 12-2 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 90% Capture continued

	Client:	EPRI								Report Date:	2013-May-21		
	Project:	LCO2/Coal Slurry Economics											
		TOTAL PLANT COST SUMMARY											
	Case:	Case 2 - PRB - LCO2 slurry feed, 90% Capture											
	Plant Size:	504.2 MW,net		Estimate Type:	Conceptual			Cost Base (Jun)		2012	($x1000)		
Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST		
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW	
8	STEAM TURBINE GENERATOR												
8.1	Steam TG & Accessories	$35,040	$0	$5,806	$0	$0	$40,846	$3,611	$0	$4,446	$48,903	$97	
8.2	Turbine Plant Auxiliaries	$236	$0	$541	$0	$0	$778	$74	$0	$85	$936	$2	
8.3	Condenser & Auxiliaries	$2,990	$0	$1,735	$0	$0	$4,725	$441	$0	$517	$5,683	$11	
8.4	Steam Piping	$16,170	$0	$6,554	$0	$0	$22,724	$1,707	$0	$6,108	$30,539	$61	
8.9	TG Foundations	$0	$1,091	$1,980	$0	$0	$3,071	$290	$0	$1,008	$4,369	$9	
	SUBTOTAL 8.	**$54,436**	**$1,091**	**$16,616**	**$0**	**$0**	**$72,143**	**$6,123**	**$0**	**$12,163**	**$90,430**	**$179**	
9	COOLING WATER SYSTEM												
9.1	Cooling Towers	$3,000	$0	$910	$0	$0	$3,910	$363	$0	$641	$4,913	$10	
9.2	Circulating Water Pumps	$1,423	$0	$91	$0	$0	$1,514	$131	$0	$247	$1,891	$4	
9.3	Circ.Water System Auxiliaries	$134	$0	$19	$0	$0	$153	$14	$0	$25	$192	$0	
9.4	Circ.Water Piping	$0	$5,920	$1,450	$0	$0	$7,370	$618	$0	$1,598	$9,586	$19	
9.5	Make-up Water System	$385	$0	$534	$0	$0	$919	$85	$0	$201	$1,205	$2	
9.6	Component Cooling Water Sys	$678	$811	$562	$0	$0	$2,052	$183	$0	$447	$2,682	$5	
9.9	Circ.Water System Foundations	$0	$1,908	$3,483	$0	$0	$5,391	$509	$0	$1,770	$7,669	$15	
	SUBTOTAL 9.	**$5,621**	**$8,639**	**$7,049**	**$0**	**$0**	**$21,309**	**$1,901**	**$0**	**$4,928**	**$28,138**	**$56**	
10	ASH/SPENT SORBENT HANDLING SYS												
10.1	Slag Dewatering & Cooling	$23,103	$0	$11,393	$0	$0	$34,496	$3,215	$0	$3,771	$41,482	$82	
10.2	Gasifier Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0	
10.3	Cleanup Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0	
10.4	High Temperature Ash Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
10.5	Other Ash Recovery Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
10.6	Ash Storage Silos	$765	$0	$833	$0	$0	$1,598	$150	$0	$262	$2,010	$4	
10.7	Ash Transport & Feed Equipment	$1,051	$0	$248	$0	$0	$1,299	$115	$0	$212	$1,626	$3	
10.8	Misc. Ash Handling Equipment	$1,585	$1,942	$580	$0	$0	$4,107	$379	$0	$673	$5,159	$10	
10.9	Ash/Spent Sorbent Foundation	$0	$63	$85	$0	$0	$148	$14	$0	$49	$210	$0	
	SUBTOTAL 10.	**$26,504**	**$2,005**	**$13,139**	**$0**	**$0**	**$41,647**	**$3,873**	**$0**	**$4,967**	**$50,487**	**$100**	
11	ACCESSORY ELECTRIC PLANT												
11.1	Generator Equipment	$1,148	$0	$1,152	$0	$0	$2,299	$214	$0	$251	$2,765	$5	
11.2	Station Service Equipment	$5,841	$0	$553	$0	$0	$6,394	$598	$0	$699	$7,692	$15	
11.3	Switchgear & Motor Control	$10,780	$0	$2,064	$0	$0	$12,844	$1,207	$0	$2,108	$16,159	$32	
11.4	Conduit & Cable Tray	$0	$5,579	$17,394	$0	$0	$22,973	$2,126	$0	$6,275	$31,374	$62	
11.5	Wire & Cable	$0	$10,662	$6,619	$0	$0	$17,281	$1,176	$0	$4,614	$23,072	$46	
11.6	Protective Equipment	$0	$789	$3,020	$0	$0	$3,809	$365	$0	$626	$4,799	$10	
11.7	Standby Equipment	$274	$0	$281	$0	$0	$555	$53	$0	$91	$698	$1	
11.8	Main Power Transformers	$21,898	$0	$177	$0	$0	$22,074	$1,704	$0	$3,567	$27,345	$54	
11.9	Electrical Foundations	$0	$180	$503	$0	$0	$683	$64	$0	$224	$971	$2	
	SUBTOTAL 11.	**$39,940**	**$17,210**	**$31,762**	**$0**	**$0**	**$88,912**	**$7,507**	**$0**	**$18,455**	**$114,875**	**$228**	

Table 12-2 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 90% Capture continued

Client: EPRI — Report Date: 2013-May-21
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 2 - PRB - LCO2 slurry feed, 90% Capture
Plant Size: 504.2 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,306	$0	$917	$0	$0	$2,223	$210	$111	$382	$2,925	$6
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$300	$0	$202	$0	$0	$502	$48	$25	$115	$690	$1
12.7	Computer & Accessories	$6,966	$0	$234	$0	$0	$7,201	$673	$360	$823	$9,057	$18
12.8	Instrument Wiring & Tubing	$0	$2,707	$5,229	$0	$0	$7,937	$641	$397	$2,244	$11,218	$22
12.9	Other I & C Equipment	$4,657	$0	$2,377	$0	$0	$7,034	$664	$352	$1,207	$9,256	$18
	SUBTOTAL 12.	**$13,229**	**$2,707**	**$8,960**	**$0**	**$0**	**$24,896**	**$2,235**	**$1,245**	**$4,771**	**$33,146**	**$66**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$124	$2,879	$0	$0	$3,003	$290	$0	$988	$4,282	$8
13.2	Site Improvements	$0	$2,208	$3,184	$0	$0	$5,392	$534	$0	$1,778	$7,703	$15
13.3	Site Facilities	$3,956	$0	$4,531	$0	$0	$8,487	$844	$0	$2,799	$12,130	$24
	SUBTOTAL 13.	**$3,956**	**$2,332**	**$10,594**	**$0**	**$0**	**$16,882**	**$1,668**	**$0**	**$5,565**	**$24,115**	**$48**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$319	$186	$0	$0	$505	$44	$0	$110	$659	$1
14.2	Steam Turbine Building	$0	$2,801	$4,121	$0	$0	$6,922	$626	$0	$1,132	$8,681	$17
14.3	Administration Building	$0	$1,109	$830	$0	$0	$1,939	$171	$0	$316	$2,426	$5
14.4	Circulation Water Pumphouse	$0	$198	$108	$0	$0	$307	$27	$0	$50	$383	$1
14.5	Water Treatment Buildings	$0	$534	$538	$0	$0	$1,071	$95	$0	$175	$1,342	$3
14.6	Machine Shop	$0	$540	$382	$0	$0	$922	$81	$0	$150	$1,154	$2
14.7	Warehouse	$0	$873	$582	$0	$0	$1,454	$127	$0	$237	$1,819	$4
14.8	Other Buildings & Structures	$0	$523	$420	$0	$0	$943	$83	$0	$205	$1,231	$2
14.9	Waste Treating Building & Str.	$0	$1,168	$2,305	$0	$0	$3,474	$318	$0	$758	$4,549	$9
14.10	Coal Prep Building	$0	$23,363	$9,829	$0	$0	$33,192	$2,855	$0	$7,209	$43,256	$86
	SUBTOTAL 14.	**$0**	**$31,428**	**$19,302**	**$0**	**$0**	**$50,730**	**$4,426**	**$0**	**$10,344**	**$65,500**	**$130**
	TOTAL COST	**$932,316**	**$112,060**	**$375,946**	**$0**	**$0**	**$1,420,322**	**$128,715**	**$81,338**	**$259,652**	**$1,890,027**	**$3,749**

Table 12-3 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 90% Capture

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 3 - Lignite - water slurry feed, 90% Capture
Plant Size: 576.6 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING	$24,933	$4,736	$19,837	$0	$0	**$49,506**	$4,414	$0	$10,784	**$64,704**	$112
2	COAL & SORBENT PREP & FEED	$48,763	$8,265	$24,545	$0	$0	**$81,574**	$7,145	$0	$15,323	**$104,042**	$180
3	FEEDWATER & MISC. BOP SYSTEMS	$13,061	$11,188	$12,149	$0	$0	**$36,398**	$3,311	$0	$8,948	**$48,657**	$84
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$213,038	$0	$119,139	$0	$0	**$332,177**	$29,310	$47,313	$62,235	**$471,035**	$817
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.3	ASU/Oxidant Compression	$288,619	$0	w/equip.	$0	$0	**$288,619**	$26,994	$0	$31,561	**$347,174**	$602
4.4-4.9	Other Gasification Equipment	$27,545	$17,815	$20,762	$0	$0	**$66,122**	$6,195	$0	$15,789	**$88,106**	$153
	SUBTOTAL 4	**$529,203**	**$17,815**	**$139,900**	**$0**	**$0**	**$686,918**	**$62,499**	**$47,313**	**$109,585**	**$906,315**	**$1,572**
5A	GAS CLEANUP & PIPING	$103,290	$4,663	$86,540	$0	$0	**$194,494**	$18,219	$30,140	$48,802	**$291,654**	$506
5B	CO2 COMPRESSION	$44,043	$0	$20,508	$0	$0	**$64,551**	$6,012	$0	$14,113	**$84,676**	$147
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	**$120,642**	$11,086	$12,064	$14,379	**$158,171**	$274
6.2-6.9	Combustion Turbine Other	$0	$935	$1,111	$0	$0	**$2,046**	$192	$0	$671	**$2,909**	$5
	SUBTOTAL 6	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$279**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$29,310	$0	$5,721	$0	$0	**$35,031**	$3,237	$0	$3,827	**$42,095**	$73
7.2-7.9	Ductwork and Stack	$2,728	$1,884	$2,547	$0	$0	**$7,159**	$649	$0	$1,265	**$9,073**	$16
	SUBTOTAL 7	**$32,038**	**$1,884**	**$8,268**	**$0**	**$0**	**$42,190**	**$3,886**	**$0**	**$5,091**	**$51,167**	**$89**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$46,210	$0	$7,657	$0	$0	**$53,867**	$4,763	$0	$5,863	**$64,492**	$112
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$22,242	$1,404	$12,855	$0	$0	**$36,501**	$2,947	$0	$8,934	**$48,382**	$84
	SUBTOTAL 8	**$68,452**	**$1,404**	**$20,511**	**$0**	**$0**	**$90,368**	**$7,709**	**$0**	**$14,797**	**$112,875**	**$196**
9	COOLING WATER SYSTEM	$6,932	$10,486	$8,526	$0	$0	**$25,944**	$2,314	$0	$5,986	**$34,244**	$59
10	ASH/SPENT SORBENT HANDLING SYS	$37,307	$2,711	$18,490	$0	$0	**$58,507**	$5,442	$0	$6,956	**$70,905**	$123
11	ACCESSORY ELECTRIC PLANT	$41,706	$18,468	$34,011	$0	$0	**$94,185**	$7,960	$0	$19,617	**$121,761**	$211
12	INSTRUMENTATION & CONTROL	$13,895	$2,844	$9,411	$0	$0	**$26,150**	$2,347	$1,307	$5,011	**$34,816**	$60
13	IMPROVEMENTS TO SITE	$4,221	$2,488	$11,302	$0	$0	**$18,011**	$1,779	$0	$5,937	**$25,728**	$45
14	BUILDINGS & STRUCTURES	$0	$29,903	$19,780	$0	$0	**$49,683**	$4,348	$0	$10,018	**$64,049**	$111
	TOTAL COST	**$1,081,709**	**$117,790**	**$441,669**	**$0**	**$0**	**$1,641,169**	**$148,663**	**$90,824**	**$296,018**	**$2,176,673**	**$3,775**

Table 12-3 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 90% Capture continued

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 3 - Lignite - water slurry feed, 90% Capture
Plant Size: 576.6 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
1	COAL & SORBENT HANDLING											
1.1	Coal Receive & Unload	$7,107	$0	$3,511	$0	$0	$10,618	$929	$0	$2,309	$13,857	$24
1.2	Coal Stackout & Reclaim	$9,184	$0	$2,251	$0	$0	$11,435	$981	$0	$2,483	$14,898	$26
1.3	Coal Conveyors & Yd Crush	$6,409	$0	$845	$0	$0	$7,255	$614	$0	$1,574	$9,443	$16
1.4	Other Coal Handling	$2,234	$0	$515	$0	$0	$2,749	$235	$0	$597	$3,582	$6
1.5	Sorbent Receive & Unload	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.6	Sorbent Stackout & Reclaim	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.7	Sorbent Conveyors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.8	Other Sorbent Handling	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.9	Coal & Sorbent Hnd.Foundations	$0	$4,736	$12,714	$0	$0	$17,450	$1,654	$0	$3,821	$22,925	$40
	SUBTOTAL 1.	**$24,933**	**$4,736**	**$19,837**	**$0**	**$0**	**$49,506**	**$4,414**	**$0**	**$10,784**	**$64,704**	**$112**
2	COAL & SORBENT PREP & FEED											
2.1	Coal Storage & Feed	$11,174	$0	$0	$0	$0	$11,174	$929	$0	$0	$12,103	$21
2.2	Prepared Coal Storage & Feed	$3,121	$742	$495	$0	$0	$4,358	$365	$0	$945	$5,668	$10
2.3	Slurry Prep & Feed (incl. crushing)	$32,752	$0	$14,727	$0	$0	$47,480	$4,143	$0	$10,324	$61,947	$107
2.4	Misc.Coal Prep & Feed	$1,716	$1,241	$3,786	$0	$0	$6,743	$605	$0	$1,470	$8,818	$15
2.5	Sorbent Prep Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.6	Sorbent Storage & Feed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.7	Sorbent Injection System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.8	Booster Air Supply System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.9	Coal & Sorbent Feed Foundation	$0	$6,282	$5,537	$0	$0	$11,819	$1,103	$0	$2,585	$15,507	$27
	SUBTOTAL 2.	**$48,763**	**$8,265**	**$24,545**	**$0**	**$0**	**$81,574**	**$7,145**	**$0**	**$15,323**	**$104,042**	**$180**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$4,415	$7,667	$4,048	$0	$0	$16,130	$1,454	$0	$3,517	$21,101	$37
3.2	Water Makeup & Pretreating	$701	$72	$388	$0	$0	$1,161	$107	$0	$380	$1,648	$3
3.3	Other Feedwater Subsystems	$2,505	$825	$743	$0	$0	$4,073	$350	$0	$885	$5,307	$9
3.4	Service Water Systems	$409	$817	$2,836	$0	$0	$4,062	$383	$0	$1,333	$5,778	$10
3.5	Other Boiler Plant Systems	$2,202	$825	$2,045	$0	$0	$5,073	$460	$0	$1,106	$6,639	$12
3.6	FO Supply Sys & Nat Gas	$415	$785	$732	$0	$0	$1,932	$180	$0	$422	$2,535	$4
3.7	Waste Treatment Equipment	$953	$0	$591	$0	$0	$1,544	$147	$0	$507	$2,199	$4
3.8	Misc. Power Plant Equipment	$1,460	$196	$767	$0	$0	$2,424	$230	$0	$796	$3,450	$6
	SUBTOTAL 3.	**$13,061**	**$11,188**	**$12,149**	**$0**	**$0**	**$36,398**	**$3,311**	**$0**	**$8,948**	**$48,657**	**$84**

Table 12-3 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 90% Capture continued

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 3 - Lignite - water slurry feed, 90% Capture
Plant Size: 576.6 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$213,038	$0	$119,139	$0	$0	$332,177	$29,310	$47,313	$62,235	$471,035	$817
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$288,619	$0	w/equip.	$0	$0	$288,619	$26,994	$0	$31,561	$347,174	$602
4.4	LT Heat Recovery & FG Saturation	$27,545	$0	$10,418	$0	$0	$37,963	$3,580	$0	$8,309	$49,852	$86
4.5	Misc. Gasification Equipment	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.6	Other Gasification Equipment	$0	$2,772	$1,128	$0	$0	$3,900	$363	$0	$852	$5,115	$9
4.8	Major Component Rigging	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.9	Gasification Foundations	$0	$15,043	$9,216	$0	$0	$24,259	$2,252	$0	$6,628	$33,139	$57
	SUBTOTAL 4.	**$529,203**	**$17,815**	**$139,900**	**$0**	**$0**	**$686,918**	**$62,499**	**$47,313**	**$109,585**	**$906,315**	**$1,572**
5A	GAS CLEANUP & PIPING											
5A.1	Double Stage Selexol	$81,105	$0	$68,822	$0	$0	$149,927	$14,063	$29,985	$38,795	$232,770	$404
5A.2	Elemental Sulfur Plant	$8,057	$1,578	$10,395	$0	$0	$20,031	$1,890	$0	$4,384	$26,305	$46
5A.3	Mercury Removal	$1,753	$0	$1,334	$0	$0	$3,086	$289	$154	$706	$4,236	$7
5A.4	Shift Reactors	$9,819	$0	$3,952	$0	$0	$13,771	$1,281	$0	$3,010	$18,062	$31
5A.5	Particulate Removal	w/4.1	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
5A.6	Blowback Gas Systems	$2,556	$430	$242	$0	$0	$3,228	$297	$0	$705	$4,230	$7
5A.7	Fuel Gas Piping	$0	$1,404	$929	$0	$0	$2,333	$203	$0	$507	$3,042	$5
5A.9	HGCU Foundations	$0	$1,251	$866	$0	$0	$2,117	$197	$0	$694	$3,008	$5
	SUBTOTAL 5A.	**$103,290**	**$4,663**	**$86,540**	**$0**	**$0**	**$194,494**	**$18,219**	**$30,140**	**$48,802**	**$291,654**	**$506**
5B	CO2 COMPRESSION											
5B.1	CO2 Removal System	w/ 5A.1	$0	w/ 5A.1	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$44,043	$0	$20,508	$0	$0	$64,551	$6,012	$0	$14,113	$84,676	$147
	SUBTOTAL 5B.	**$44,043**	**$0**	**$20,508**	**$0**	**$0**	**$64,551**	**$6,012**	**$0**	**$14,113**	**$84,676**	**$147**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	$120,642	$11,086	$12,064	$14,379	$158,171	$274
6.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$935	$1,111	$0	$0	$2,046	$192	$0	$671	$2,909	$5
	SUBTOTAL 6.	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$279**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$29,310	$0	$5,721	$0	$0	$35,031	$3,237	$0	$3,827	$42,095	$73
7.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$0	$1,375	$998	$0	$0	$2,372	$204	$0	$515	$3,091	$5
7.4	Stack	$2,728	$0	$1,025	$0	$0	$3,753	$349	$0	$410	$4,512	$8
7.9	HRSG,Duct & Stack Foundations	$0	$509	$525	$0	$0	$1,034	$97	$0	$339	$1,470	$3
	SUBTOTAL 7.	**$32,038**	**$1,884**	**$8,268**	**$0**	**$0**	**$42,190**	**$3,886**	**$0**	**$5,091**	**$51,167**	**$89**

Table 12-3 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 90% Capture continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 3 - Lignite - water slurry feed, 90% Capture
Plant Size: 576.6 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$46,210	$0	$7,657	$0	$0	$53,867	$4,763	$0	$5,863	$64,492	$112
8.2	Turbine Plant Auxiliaries	$304	$0	$697	$0	$0	$1,001	$95	$0	$110	$1,205	$2
8.3	Condenser & Auxiliaries	$3,740	$0	$2,234	$0	$0	$5,974	$558	$0	$653	$7,185	$12
8.4	Steam Piping	$18,198	$0	$7,376	$0	$0	$25,574	$1,921	$0	$6,874	$34,369	$60
8.9	TG Foundations	$0	$1,404	$2,549	$0	$0	$3,953	$373	$0	$1,298	$5,624	$10
	SUBTOTAL 8.	**$68,452**	**$1,404**	**$20,511**	**$0**	**$0**	**$90,368**	**$7,709**	**$0**	**$14,797**	**$112,875**	**$196**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,760	$0	$1,150	$0	$0	$4,910	$455	$0	$805	$6,170	$11
9.2	Circulating Water Pumps	$1,784	$0	$125	$0	$0	$1,909	$165	$0	$311	$2,385	$4
9.3	Circ.Water System Auxiliaries	$163	$0	$23	$0	$0	$186	$17	$0	$30	$234	$0
9.4	Circ.Water Piping	$0	$7,186	$1,760	$0	$0	$8,946	$750	$0	$1,939	$11,635	$20
9.5	Make-up Water System	$402	$0	$558	$0	$0	$959	$88	$0	$210	$1,257	$2
9.6	Component Cooling Water Sys	$823	$985	$682	$0	$0	$2,490	$222	$0	$542	$3,255	$6
9.9	Circ.Water System Foundations	$0	$2,316	$4,227	$0	$0	$6,543	$617	$0	$2,148	$9,308	$16
	SUBTOTAL 9.	**$6,932**	**$10,486**	**$8,526**	**$0**	**$0**	**$25,944**	**$2,314**	**$0**	**$5,986**	**$34,244**	**$59**
10	ASH/SPENT SORBENT HANDLING SYS											
10.1	Slag Dewatering & Cooling	$32,709	$0	$16,131	$0	$0	$48,840	$4,551	$0	$5,339	$58,730	$102
10.2	Gasifier Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.3	Cleanup Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.4	High Temperature Ash Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.5	Other Ash Recovery Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.6	Ash Storage Silos	$1,034	$0	$1,126	$0	$0	$2,160	$203	$0	$354	$2,717	$5
10.7	Ash Transport & Feed Equipment	$1,421	$0	$335	$0	$0	$1,756	$156	$0	$287	$2,198	$4
10.8	Misc. Ash Handling Equipment	$2,142	$2,626	$784	$0	$0	$5,552	$512	$0	$910	$6,974	$12
10.9	Ash/Spent Sorbent Foundation	$0	$85	$115	$0	$0	$200	$19	$0	$66	$285	$0
	SUBTOTAL 10.	**$37,307**	**$2,711**	**$18,490**	**$0**	**$0**	**$58,507**	**$5,442**	**$0**	**$6,956**	**$70,905**	**$123**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$1,243	$0	$1,247	$0	$0	$2,490	$232	$0	$272	$2,995	$5
11.2	Station Service Equipment	$6,281	$0	$595	$0	$0	$6,876	$643	$0	$752	$8,271	$14
11.3	Switchgear & Motor Control	$11,592	$0	$2,220	$0	$0	$13,812	$1,298	$0	$2,266	$17,376	$30
11.4	Conduit & Cable Tray	$0	$5,999	$18,704	$0	$0	$24,703	$2,286	$0	$6,747	$33,737	$59
11.5	Wire & Cable	$0	$11,465	$7,118	$0	$0	$18,583	$1,265	$0	$4,962	$24,810	$43
11.6	Protective Equipment	$0	$805	$3,081	$0	$0	$3,886	$372	$0	$639	$4,897	$8
11.7	Standby Equipment	$292	$0	$300	$0	$0	$592	$56	$0	$97	$745	$1
11.8	Main Power Transformers	$22,298	$0	$194	$0	$0	$22,492	$1,736	$0	$3,634	$27,862	$48
11.9	Electrical Foundations	$0	$198	$553	$0	$0	$751	$71	$0	$247	$1,068	$2
	SUBTOTAL 11.	**$41,706**	**$18,468**	**$34,011**	**$0**	**$0**	**$94,185**	**$7,960**	**$0**	**$19,617**	**$121,761**	**$211**

Table 12-3 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 90% Capture continued

Client: EPRI — Report Date: 2013-Jul-18

Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 3 - Lignite - water slurry feed, 90% Capture

Plant Size: 576.6 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,372	$0	$963	$0	$0	$2,334	$221	$117	$401	$3,073	$5
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$315	$0	$212	$0	$0	$528	$50	$26	$121	$725	$1
12.7	Computer & Accessories	$7,317	$0	$246	$0	$0	$7,563	$707	$378	$865	$9,513	$16
12.8	Instrument Wiring & Tubing	$0	$2,844	$5,493	$0	$0	$8,337	$673	$417	$2,357	$11,783	$20
12.9	Other I & C Equipment	$4,891	$0	$2,497	$0	$0	$7,388	$697	$369	$1,268	$9,722	$17
	SUBTOTAL 12.	**$13,895**	**$2,844**	**$9,411**	**$0**	**$0**	**$26,150**	**$2,347**	**$1,307**	**$5,011**	**$34,816**	**$60**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$132	$3,072	$0	$0	$3,204	$310	$0	$1,054	$4,568	$8
13.2	Site Improvements	$0	$2,355	$3,397	$0	$0	$5,752	$570	$0	$1,897	$8,219	$14
13.3	Site Facilities	$4,221	$0	$4,834	$0	$0	$9,054	$900	$0	$2,986	$12,941	$22
	SUBTOTAL 13.	**$4,221**	**$2,488**	**$11,302**	**$0**	**$0**	**$18,011**	**$1,779**	**$0**	**$5,937**	**$25,728**	**$45**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$319	$186	$0	$0	$505	$44	$0	$110	$659	$1
14.2	Steam Turbine Building	$0	$3,448	$5,071	$0	$0	$8,519	$770	$0	$1,393	$10,683	$19
14.3	Administration Building	$0	$1,160	$869	$0	$0	$2,028	$178	$0	$331	$2,538	$4
14.4	Circulation Water Pumphouse	$0	$207	$113	$0	$0	$321	$28	$0	$52	$401	$1
14.5	Water Treatment Buildings	$0	$561	$565	$0	$0	$1,127	$100	$0	$184	$1,411	$2
14.6	Machine Shop	$0	$565	$399	$0	$0	$965	$85	$0	$157	$1,207	$2
14.7	Warehouse	$0	$913	$608	$0	$0	$1,521	$133	$0	$248	$1,902	$3
14.8	Other Buildings & Structures	$0	$547	$440	$0	$0	$986	$87	$0	$215	$1,288	$2
14.9	Waste Treating Building & Str.	$0	$1,222	$2,411	$0	$0	$3,634	$332	$0	$793	$4,759	$8
14.10	Coal Prep Building	$0	$20,961	$9,116	$0	$0	$30,078	$2,590	$0	$6,534	$39,201	$68
	SUBTOTAL 14.	**$0**	**$29,903**	**$19,780**	**$0**	**$0**	**$49,683**	**$4,348**	**$0**	**$10,018**	**$64,049**	**$111**
	TOTAL COST	**$1,081,709**	**$117,790**	**$441,669**	**$0**	**$0**	**$1,641,169**	**$148,663**	**$90,824**	**$296,018**	**$2,176,673**	**$3,775**

Table 12-4 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 90% Capture

Client: EPRI **Report Date:** 2013-Jul-18

Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 4 - Lignite - LCO2 slurry feed, 90% Capture

Plant Size: 517.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor		Sales Tax	Bare Erected Cost $	Eng'g CM H.O.& Fee	Contingencies		TOTAL PLANT COST	
				Direct	Indirect				Process	Project	$	$/kW
1	COAL & SORBENT HANDLING	$23,837	$4,544	$18,977	$0	$0	**$47,358**	$4,223	$0	$10,316	**$61,896**	$120
2	COAL & SORBENT PREP & FEED	$52,830	$13,771	$19,993	$0	$0	**$86,594**	$7,560	$3,155	$17,139	**$114,448**	$221
3	FEEDWATER & MISC. BOP SYSTEMS	$12,814	$10,900	$12,004	$0	$0	**$35,718**	$3,250	$0	$8,797	**$47,765**	$92
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$185,769	$0	$102,657	$0	$0	**$288,426**	$25,460	$40,677	$54,126	**$408,688**	$790
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.3	ASU/Oxidant Compression	$262,514	$0	w/equip.	$0	$0	**$262,514**	$24,552	$0	$28,707	**$315,773**	$611
4.4-4.9	Other Gasification Equipment	$37,294	$16,901	$23,975	$0	$0	**$78,171**	$7,333	$0	$18,383	**$103,887**	$201
	SUBTOTAL 4	**$485,577**	**$16,901**	**$126,632**	**$0**	**$0**	**$629,111**	**$57,345**	**$40,677**	**$101,216**	**$828,348**	**$1,602**
5A	GAS CLEANUP & PIPING	$109,672	$3,807	$91,955	$0	$0	**$205,434**	$19,251	$33,096	$51,719	**$309,501**	$599
5B	CO2 COMPRESSION	$33,080	$0	$19,994	$0	$0	**$53,073**	$4,957	$0	$11,606	**$69,637**	$135
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	**$120,642**	$11,086	$12,064	$14,379	**$158,171**	$306
6.2-6.9	Combustion Turbine Other	$0	$935	$1,111	$0	$0	**$2,046**	$192	$0	$671	**$2,909**	$6
	SUBTOTAL 6	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$312**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$26,250	$0	$5,123	$0	$0	**$31,373**	$2,899	$0	$3,427	**$37,699**	$73
7.2-7.9	Ductwork and Stack	$2,904	$2,005	$2,712	$0	$0	**$7,621**	$691	$0	$1,346	**$9,659**	$19
	SUBTOTAL 7	**$29,154**	**$2,005**	**$7,835**	**$0**	**$0**	**$38,994**	**$3,590**	**$0**	**$4,773**	**$47,358**	**$92**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$40,080	$0	$6,641	$0	$0	**$46,721**	$4,131	$0	$5,085	**$55,937**	$108
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$20,583	$1,233	$11,716	$0	$0	**$33,533**	$2,699	$0	$8,244	**$44,475**	$86
	SUBTOTAL 8	**$60,663**	**$1,233**	**$18,358**	**$0**	**$0**	**$80,254**	**$6,830**	**$0**	**$13,329**	**$100,413**	**$194**
9	COOLING WATER SYSTEM	$6,614	$10,033	$8,173	$0	$0	**$24,820**	$2,214	$0	$5,729	**$32,763**	$63
10	ASH/SPENT SORBENT HANDLING SYS	$35,754	$2,611	$17,721	$0	$0	**$56,087**	$5,216	$0	$6,670	**$67,973**	$131
11	ACCESSORY ELECTRIC PLANT	$43,544	$18,366	$33,798	$0	$0	**$95,708**	$8,072	$0	$19,835	**$123,615**	$239
12	INSTRUMENTATION & CONTROL	$13,509	$2,765	$9,150	$0	$0	**$25,424**	$2,282	$1,271	$4,872	**$33,849**	$65
13	IMPROVEMENTS TO SITE	$4,071	$2,400	$10,902	$0	$0	**$17,373**	$1,716	$0	$5,727	**$24,816**	$48
14	BUILDINGS & STRUCTURES	$0	$32,849	$20,634	$0	$0	**$53,483**	$4,671	$0	$10,895	**$69,049**	$134
	TOTAL COST	**$1,024,984**	**$123,121**	**$424,014**	**$0**	**$0**	**$1,572,119**	**$142,456**	**$90,263**	**$287,674**	**$2,092,512**	**$4,047**

Table 12-4 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 90% Capture continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 4 - Lignite - LCO2 slurry feed, 90% Capture
Plant Size: 517.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING											
1.1	Coal Receive & Unload	$6,819	$0	$3,369	$0	$0	$10,188	$892	$0	$2,216	$13,295	$26
1.2	Coal Stackout & Reclaim	$8,811	$0	$2,160	$0	$0	$10,971	$941	$0	$2,382	$14,294	$28
1.3	Coal Conveyors & Yd Crush	$6,063	$0	$755	$0	$0	$6,818	$577	$0	$1,479	$8,874	$17
1.4	Other Coal Handling	$2,143	$0	$494	$0	$0	$2,638	$226	$0	$573	$3,436	$7
1.5	Sorbent Receive & Unload	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.6	Sorbent Stackout & Reclaim	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.7	Sorbent Conveyors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.8	Other Sorbent Handling	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.9	Coal & Sorbent Hnd.Foundations	$0	$4,544	$12,199	$0	$0	$16,743	$1,587	$0	$3,666	$21,996	$43
	SUBTOTAL 1.	**$23,837**	**$4,544**	**$18,977**	**$0**	**$0**	**$47,358**	**$4,223**	**$0**	**$10,316**	**$61,896**	**$120**
2	COAL & SORBENT PREP & FEED											
2.1	Coal Storage & Feed	$10,722	$0	$0	$0	$0	$10,722	$892	$0	$0	$11,614	$22
2.2	Coal Prep & Feed	$1,550	$0	$226	$0	$0	$1,776	$151	$0	$385	$2,312	$4
2.3	Coal Slurry Prep & Feed	$38,916	$6,572	$10,845	$0	$0	$56,333	$4,883	$3,155	$12,874	$77,245	$149
2.4	Misc.Coal Prep & Feed	$1,642	$1,188	$3,623	$0	$0	$6,453	$579	$0	$1,406	$8,438	$16
2.5	Sorbent Prep Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.6	Sorbent Storage & Feed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.7	Sorbent Injection System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.8	Booster Air Supply System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.9	Coal & Sorbent Feed Foundation	$0	$6,011	$5,299	$0	$0	$11,310	$1,056	$0	$2,473	$14,839	$29
	SUBTOTAL 2.	**$52,830**	**$13,771**	**$19,993**	**$0**	**$0**	**$86,594**	**$7,560**	**$3,155**	**$17,139**	**$114,448**	**$221**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$4,277	$7,427	$3,921	$0	$0	$15,624	$1,408	$0	$3,406	$20,439	$40
3.2	Water Makeup & Pretreating	$710	$73	$392	$0	$0	$1,175	$108	$0	$385	$1,668	$3
3.3	Other Feedwater Subsystems	$2,426	$800	$720	$0	$0	$3,945	$339	$0	$857	$5,141	$10
3.4	Service Water Systems	$414	$827	$2,870	$0	$0	$4,111	$388	$0	$1,350	$5,849	$11
3.5	Other Boiler Plant Systems	$2,229	$835	$2,070	$0	$0	$5,134	$466	$0	$1,120	$6,720	$13
3.6	FO Supply Sys & Nat Gas	$397	$750	$700	$0	$0	$1,847	$173	$0	$404	$2,424	$5
3.7	Waste Treatment Equipment	$964	$0	$598	$0	$0	$1,563	$149	$0	$514	$2,226	$4
3.8	Misc. Power Plant Equipment	$1,396	$188	$733	$0	$0	$2,318	$220	$0	$761	$3,299	$6
	SUBTOTAL 3.	**$12,814**	**$10,900**	**$12,004**	**$0**	**$0**	**$35,718**	**$3,250**	**$0**	**$8,797**	**$47,765**	**$92**

Table 12-4 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 90% Capture continued

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 4 - Lignite - LCO2 slurry feed, 90% Capture
Plant Size: 517.0 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$185,769	$0	$102,657	$0	$0	$288,426	$25,460	$40,677	$54,126	$408,688	$790
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$262,514	$0	w/equip.	$0	$0	$262,514	$24,552	$0	$28,707	$315,773	$611
4.4	LT Heat Recovery & FG Saturation	$37,294	$0	$14,105	$0	$0	$51,399	$4,847	$0	$11,249	$67,495	$131
4.5	Misc. Gasification Equipment	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.6	Other Gasification Equipment	$0	$2,352	$957	$0	$0	$3,309	$308	$0	$723	$4,340	$8
4.8	Major Component Rigging	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.9	Gasification Foundations	$0	$14,550	$8,913	$0	$0	$23,463	$2,178	$0	$6,410	$32,052	$62
	SUBTOTAL 4.	**$485,577**	**$16,901**	**$126,632**	**$0**	**$0**	**$629,111**	**$57,345**	**$40,677**	**$101,216**	**$828,348**	**$1,602**
5A	GAS CLEANUP & PIPING											
5A.1	Double Stage Selexol	$89,080	$0	$75,589	$0	$0	$164,670	$15,445	$32,934	$42,610	$255,659	$494
5A.2	Elemental Sulfur Plant	$7,785	$1,525	$10,044	$0	$0	$19,354	$1,826	$0	$4,236	$25,416	$49
5A.3	Mercury Removal	$1,840	$0	$1,400	$0	$0	$3,240	$304	$162	$741	$4,447	$9
5A.4	Shift Reactors	$8,509	$0	$3,425	$0	$0	$11,934	$1,110	$0	$2,609	$15,652	$30
5A.5	Particulate Removal	w/4.1	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
5A.6	Blowback Gas Systems	$2,458	$414	$233	$0	$0	$3,105	$286	$0	$678	$4,068	$8
5A.7	Fuel Gas Piping	$0	$988	$654	$0	$0	$1,642	$143	$0	$357	$2,141	$4
5A.9	HGCU Foundations	$0	$880	$609	$0	$0	$1,490	$139	$0	$489	$2,117	$4
	SUBTOTAL 5A.	**$109,672**	**$3,807**	**$91,955**	**$0**	**$0**	**$205,434**	**$19,251**	**$33,096**	**$51,719**	**$309,501**	**$599**
5B	CO2 COMPRESSION											
5B.1	CO2 Removal System	w/ 5A.1	$0	w/ 5A.1	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$43,830	$0	$19,994	$0	$0	$63,823	$5,942	$0	$13,953	$83,719	$162
	SUBTOTAL 5B.	**$43,830**	**$0**	**$19,994**	**$0**	**$0**	**$63,823**	**$5,942**	**$0**	**$13,953**	**$83,719**	**$162**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	$120,642	$11,086	$12,064	$14,379	$158,171	$306
6.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$935	$1,111	$0	$0	$2,046	$192	$0	$671	$2,909	$6
	SUBTOTAL 6.	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$312**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$26,250	$0	$5,123	$0	$0	$31,373	$2,899	$0	$3,427	$37,699	$73
7.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$0	$1,463	$1,062	$0	$0	$2,525	$217	$0	$548	$3,291	$6
7.4	Stack	$2,904	$0	$1,091	$0	$0	$3,995	$371	$0	$437	$4,803	$9
7.9	HRSG,Duct & Stack Foundations	$0	$542	$559	$0	$0	$1,101	$103	$0	$361	$1,565	$3
	SUBTOTAL 7.	**$29,154**	**$2,005**	**$7,835**	**$0**	**$0**	**$38,994**	**$3,590**	**$0**	**$4,773**	**$47,358**	**$92**

Table 12-4 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 90% Capture continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 4 - Lignite - LCO2 slurry feed, 90% Capture
Plant Size: 517.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$40,080	$0	$6,641	$0	$0	$46,721	$4,131	$0	$5,085	$55,937	$108
8.2	Turbine Plant Auxiliaries	$267	$0	$612	$0	$0	$879	$83	$0	$96	$1,059	$2
8.3	Condenser & Auxiliaries	$3,280	$0	$1,962	$0	$0	$5,242	$490	$0	$573	$6,304	$12
8.4	Steam Piping	$17,036	$0	$6,905	$0	$0	$23,940	$1,798	$0	$6,435	$32,174	$62
8.9	TG Foundations	$0	$1,233	$2,238	$0	$0	$3,472	$328	$0	$1,140	$4,939	$10
	SUBTOTAL 8.	**$60,663**	**$1,233**	**$18,358**	**$0**	**$0**	**$80,254**	**$6,830**	**$0**	**$13,329**	**$100,413**	**$194**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,570	$0	$1,090	$0	$0	$4,660	$432	$0	$764	$5,856	$11
9.2	Circulating Water Pumps	$1,694	$0	$116	$0	$0	$1,811	$156	$0	$295	$2,262	$4
9.3	Circ.Water System Auxiliaries	$156	$0	$22	$0	$0	$178	$16	$0	$29	$223	$0
9.4	Circ.Water Piping	$0	$6,875	$1,684	$0	$0	$8,559	$717	$0	$1,855	$11,132	$22
9.5	Make-up Water System	$406	$0	$563	$0	$0	$969	$89	$0	$212	$1,270	$2
9.6	Component Cooling Water Sys	$788	$942	$653	$0	$0	$2,383	$212	$0	$519	$3,114	$6
9.9	Circ.Water System Foundations	$0	$2,216	$4,044	$0	$0	$6,260	$591	$0	$2,055	$8,906	$17
	SUBTOTAL 9.	**$6,614**	**$10,033**	**$8,173**	**$0**	**$0**	**$24,820**	**$2,214**	**$0**	**$5,729**	**$32,763**	**$63**
10	ASH/SPENT SORBENT HANDLING SYS											
10.1	Slag Dewatering & Cooling	$31,326	$0	$15,449	$0	$0	$46,774	$4,359	$0	$5,113	$56,247	$109
10.2	Gasifier Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.3	Cleanup Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.4	High Temperature Ash Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.5	Other Ash Recovery Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.6	Ash Storage Silos	$996	$0	$1,084	$0	$0	$2,080	$196	$0	$341	$2,618	$5
10.7	Ash Transport & Feed Equipment	$1,369	$0	$322	$0	$0	$1,691	$150	$0	$276	$2,117	$4
10.8	Misc. Ash Handling Equipment	$2,064	$2,529	$755	$0	$0	$5,348	$494	$0	$876	$6,718	$13
10.9	Ash/Spent Sorbent Foundation	$0	$82	$111	$0	$0	$193	$18	$0	$63	$274	$1
	SUBTOTAL 10.	**$35,754**	**$2,611**	**$17,721**	**$0**	**$0**	**$56,087**	**$5,216**	**$0**	**$6,670**	**$67,973**	**$131**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$1,189	$0	$1,193	$0	$0	$2,382	$222	$0	$260	$2,865	$6
11.2	Station Service Equipment	$6,241	$0	$591	$0	$0	$6,833	$639	$0	$747	$8,219	$16
11.3	Switchgear & Motor Control	$11,520	$0	$2,206	$0	$0	$13,726	$1,289	$0	$2,252	$17,267	$33
11.4	Conduit & Cable Tray	$0	$5,962	$18,587	$0	$0	$24,549	$2,272	$0	$6,705	$33,526	$65
11.5	Wire & Cable	$0	$11,394	$7,073	$0	$0	$18,467	$1,257	$0	$4,931	$24,655	$48
11.6	Protective Equipment	$0	$823	$3,150	$0	$0	$3,973	$380	$0	$653	$5,007	$10
11.7	Standby Equipment	$282	$0	$289	$0	$0	$571	$54	$0	$94	$719	$1
11.8	Main Power Transformers	$24,312	$0	$184	$0	$0	$24,496	$1,890	$0	$3,958	$30,344	$59
11.9	Electrical Foundations	$0	$187	$525	$0	$0	$712	$67	$0	$234	$1,013	$2
	SUBTOTAL 11.	**$43,544**	**$18,366**	**$33,798**	**$0**	**$0**	**$95,708**	**$8,072**	**$0**	**$19,835**	**$123,615**	**$239**

Table 12-4 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 90% Capture continued

	Client:	EPRI								Report Date:	2013-Jul-18		
	Project:	LCO2/Coal Slurry Economics											
		TOTAL PLANT COST SUMMARY											
	Case:	Case 4 - Lignite - LCO2 slurry feed, 90% Capture											
	Plant Size:	517.0 MW,net		Estimate Type:	Conceptual				Cost Base (Jun)	2012	($x1000)		
Acct		**Equipment**	**Material**	**Labor**		**Sales**	**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**		
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Tax**	**Cost $**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**	
12	INSTRUMENTATION & CONTROL												
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0	
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0	
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0	
12.4	Other Major Component Control	$1,334	$0	$936	$0	$0	$2,270	$215	$113	$390	$2,987	$6	
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0	
12.6	Control Boards,Panels & Racks	$307	$0	$207	$0	$0	$513	$49	$26	$117	$705	$1	
12.7	Computer & Accessories	$7,114	$0	$239	$0	$0	$7,353	$687	$368	$841	$9,249	$18	
12.8	Instrument Wiring & Tubing	$0	$2,765	$5,340	$0	$0	$8,105	$654	$405	$2,291	$11,456	$22	
12.9	Other I & C Equipment	$4,755	$0	$2,427	$0	$0	$7,183	$678	$359	$1,233	$9,452	$18	
	SUBTOTAL 12.	**$13,509**	**$2,765**	**$9,150**	**$0**	**$0**	**$25,424**	**$2,282**	**$1,271**	**$4,872**	**$33,849**	**$65**	
13	IMPROVEMENTS TO SITE												
13.1	Site Preparation	$0	$128	$2,963	$0	$0	$3,091	$299	$0	$1,017	$4,406	$9	
13.2	Site Improvements	$0	$2,272	$3,277	$0	$0	$5,549	$550	$0	$1,829	$7,928	$15	
13.3	Site Facilities	$4,071	$0	$4,662	$0	$0	$8,734	$868	$0	$2,881	$12,483	$24	
	SUBTOTAL 13.	**$4,071**	**$2,400**	**$10,902**	**$0**	**$0**	**$17,373**	**$1,716**	**$0**	**$5,727**	**$24,816**	**$48**	
14	BUILDINGS & STRUCTURES												
14.1	Combustion Turbine Area	$0	$319	$186	$0	$0	$505	$44	$0	$110	$659	$1	
14.2	Steam Turbine Building	$0	$3,099	$4,558	$0	$0	$7,657	$692	$0	$1,252	$9,601	$19	
14.3	Administration Building	$0	$1,131	$847	$0	$0	$1,978	$174	$0	$323	$2,475	$5	
14.4	Circulation Water Pumphouse	$0	$202	$111	$0	$0	$313	$27	$0	$51	$391	$1	
14.5	Water Treatment Buildings	$0	$568	$572	$0	$0	$1,141	$102	$0	$186	$1,428	$3	
14.6	Machine Shop	$0	$551	$390	$0	$0	$941	$83	$0	$154	$1,177	$2	
14.7	Warehouse	$0	$890	$593	$0	$0	$1,483	$130	$0	$242	$1,855	$4	
14.8	Other Buildings & Structures	$0	$533	$429	$0	$0	$962	$85	$0	$209	$1,256	$2	
14.9	Waste Treating Building & Str.	$0	$1,192	$2,352	$0	$0	$3,544	$324	$0	$774	$4,641	$9	
14.10	Coal Prep Building	$0	$24,364	$10,596	$0	$0	$34,960	$3,011	$0	$7,594	$45,565	$88	
	SUBTOTAL 14.	**$0**	**$32,849**	**$20,634**	**$0**	**$0**	**$53,483**	**$4,671**	**$0**	**$10,895**	**$69,049**	**$134**	
	TOTAL COST	**$1,035,734**	**$123,121**	**$424,014**	**$0**	**$0**	**$1,582,869**	**$143,441**	**$90,263**	**$290,021**	**$2,106,594**	**$4,074**	

Table 12-5 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 5 - PRB - water slurry feed - 1,000 #/MH-hr CO2
Plant Size: 607.2 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING	$19,046	$3,675	$15,324	$0	$0	**$38,044**	$3,393	$0	$8,287	**$49,725**	$82
2	COAL & SORBENT PREP & FEED	$39,103	$6,309	$18,736	$0	$0	**$64,148**	$5,610	$0	$11,697	**$81,455**	$134
3	FEEDWATER & MISC. BOP SYSTEMS	$11,802	$10,248	$10,809	$0	$0	**$32,859**	$2,988	$0	$8,048	**$43,896**	$72
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$163,214	$0	$89,364	$0	$0	**$252,578**	$22,305	$35,300	$47,469	**$357,651**	$589
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.3	ASU/Oxidant Compression	$235,383	$0	w/equip.	$0	$0	**$235,383**	$22,015	$0	$25,740	**$283,137**	$466
4.4-4.9	Other Gasification Equipment	$25,879	$14,364	$18,155	$0	$0	**$58,398**	$5,474	$0	$13,855	**$77,726**	$128
	SUBTOTAL 4	**$424,476**	**$14,364**	**$107,518**	**$0**	**$0**	**$546,358**	**$49,793**	**$35,300**	**$87,063**	**$718,515**	**$1,183**
5A	GAS CLEANUP & PIPING	$71,489	$4,299	$63,647	$0	$0	**$139,436**	$13,065	$22,756	$35,279	**$210,536**	$347
5B	CO2 COMPRESSION	$18,545	$0	$8,967	$0	$0	**$27,512**	$2,563	$0	$6,015	**$36,091**	$59
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	**$120,642**	$11,086	$12,064	$14,379	**$158,171**	$260
6.2-6.9	Combustion Turbine Other	$0	$935	$1,111	$0	$0	**$2,046**	$192	$0	$671	**$2,909**	$5
	SUBTOTAL 6	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$265**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$29,480	$0	$5,754	$0	$0	**$35,234**	$3,256	$0	$3,849	**$42,339**	$70
7.2-7.9	Ductwork and Stack	$2,633	$1,818	$2,458	$0	$0	**$6,909**	$627	$0	$1,220	**$8,756**	$14
	SUBTOTAL 7	**$32,113**	**$1,818**	**$8,213**	**$0**	**$0**	**$42,143**	**$3,882**	**$0**	**$5,069**	**$51,095**	**$84**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$40,940	$0	$6,783	$0	$0	**$47,723**	$4,219	$0	$5,194	**$57,136**	$94
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$19,598	$1,257	$11,364	$0	$0	**$32,219**	$2,604	$0	$7,868	**$42,691**	$70
	SUBTOTAL 8	**$60,538**	**$1,257**	**$18,146**	**$0**	**$0**	**$79,941**	**$6,824**	**$0**	**$13,062**	**$99,827**	**$164**
9	COOLING WATER SYSTEM	$6,282	$9,642	$7,785	$0	$0	**$23,708**	$2,114	$0	$5,477	**$31,299**	$52
10	ASH/SPENT SORBENT HANDLING SYS	$25,906	$1,965	$12,843	$0	$0	**$40,714**	$3,786	$0	$4,857	**$49,357**	$81
11	ACCESSORY ELECTRIC PLANT	$37,726	$15,547	$29,150	$0	$0	**$82,423**	$6,957	$0	$16,983	**$106,363**	$175
12	INSTRUMENTATION & CONTROL	$14,023	$2,870	$9,498	$0	$0	**$26,391**	$2,369	$1,320	$5,057	**$35,137**	$58
13	IMPROVEMENTS TO SITE	$4,095	$2,414	$10,966	$0	$0	**$17,475**	$1,727	$0	$5,761	**$24,962**	$41
14	BUILDINGS & STRUCTURES	$0	$28,253	$18,362	$0	$0	**$46,615**	$4,077	$0	$9,405	**$60,096**	$99
	TOTAL COST	**$879,007**	**$103,597**	**$347,851**	**$0**	**$0**	**$1,330,456**	**$120,427**	**$71,440**	**$237,112**	**$1,759,435**	**$2,898**

Table 12-5 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 5 - PRB - water slurry feed - 1,000 #/MH-hr CO2
Plant Size: 607.2 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
1	COAL & SORBENT HANDLING											
1.1	Coal Receive & Unload	$5,514	$0	$2,725	$0	$0	$8,239	$721	$0	$1,792	$10,752	$18
1.2	Coal Stackout & Reclaim	$7,126	$0	$1,747	$0	$0	$8,872	$761	$0	$1,927	$11,560	$19
1.3	Coal Conveyors & Yd Crush	$4,672	$0	$588	$0	$0	$5,260	$445	$0	$1,141	$6,846	$11
1.4	Other Coal Handling	$1,733	$0	$400	$0	$0	$2,133	$183	$0	$463	$2,779	$5
1.5	Sorbent Receive & Unload	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.6	Sorbent Stackout & Reclaim	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.7	Sorbent Conveyors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.8	Other Sorbent Handling	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.9	Coal & Sorbent Hnd.Foundations	$0	$3,675	$9,865	$0	$0	$13,540	$1,284	$0	$2,965	$17,788	$29
	SUBTOTAL 1.	**$19,046**	**$3,675**	**$15,324**	**$0**	**$0**	**$38,044**	**$3,393**	**$0**	**$8,287**	**$49,725**	**$82**
2	COAL & SORBENT PREP & FEED											
2.1	Coal Storage & Feed	$10,410	$0	$0	$0	$0	$10,410	$866	$0	$0	$11,275	$19
2.2	Prepared Coal Storage & Feed	$2,382	$567	$378	$0	$0	$3,327	$279	$0	$721	$4,327	$7
2.3	Slurry Prep & Feed (incl. crushing)	$25,001	$0	$11,242	$0	$0	$36,242	$3,162	$0	$7,881	$47,285	$78
2.4	Misc.Coal Prep & Feed	$1,310	$947	$2,890	$0	$0	$5,147	$462	$0	$1,122	$6,731	$11
2.5	Sorbent Prep Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.6	Sorbent Storage & Feed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.7	Sorbent Injection System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.8	Booster Air Supply System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.9	Coal & Sorbent Feed Foundation	$0	$4,795	$4,227	$0	$0	$9,022	$842	$0	$1,973	$11,837	$19
	SUBTOTAL 2.	**$39,103**	**$6,309**	**$18,736**	**$0**	**$0**	**$64,148**	**$5,610**	**$0**	**$11,697**	**$81,455**	**$134**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$4,086	$7,096	$3,746	$0	$0	$14,929	$1,346	$0	$3,255	$19,529	$32
3.2	Water Makeup & Pretreating	$590	$61	$326	$0	$0	$977	$90	$0	$320	$1,387	$2
3.3	Other Feedwater Subsystems	$2,318	$764	$688	$0	$0	$3,770	$324	$0	$819	$4,912	$8
3.4	Service Water Systems	$344	$688	$2,387	$0	$0	$3,419	$323	$0	$1,122	$4,864	$8
3.5	Other Boiler Plant Systems	$1,854	$695	$1,721	$0	$0	$4,270	$387	$0	$931	$5,588	$9
3.6	FO Supply Sys & Nat Gas	$400	$756	$705	$0	$0	$1,861	$174	$0	$407	$2,442	$4
3.7	Waste Treatment Equipment	$802	$0	$498	$0	$0	$1,300	$124	$0	$427	$1,851	$3
3.8	Misc. Power Plant Equipment	$1,407	$189	$739	$0	$0	$2,334	$222	$0	$767	$3,323	$5
	SUBTOTAL 3.	**$11,802**	**$10,248**	**$10,809**	**$0**	**$0**	**$32,859**	**$2,988**	**$0**	**$8,048**	**$43,896**	**$72**

Table 12-5 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 5 - PRB - water slurry feed - 1,000 #/MH-hr CO2
Plant Size: 607.2 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$163,214	$0	$89,364	$0	$0	$252,578	$22,305	$35,300	$47,469	$357,651	$589
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$235,383	$0	w/equip.	$0	$0	$235,383	$22,015	$0	$25,740	$283,137	$466
4.4	LT Heat Recovery & FG Saturation	$25,879	$0	$9,788	$0	$0	$35,666	$3,363	$0	$7,806	$46,836	$77
4.5	Misc. Gasification Equipment	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.6	Other Gasification Equipment	$0	$2,104	$856	$0	$0	$2,961	$275	$0	$647	$3,883	$6
4.8	Major Component Rigging	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.9	Gasification Foundations	$0	$12,260	$7,511	$0	$0	$19,771	$1,835	$0	$5,402	$27,008	$44
	SUBTOTAL 4.	**$424,476**	**$14,364**	**$107,518**	**$0**	**$0**	**$546,358**	**$49,793**	**$35,300**	**$87,063**	**$718,515**	**$1,183**
5A	GAS CLEANUP & PIPING											
5A.1	Double Stage Selexol	$61,230	$0	$51,957	$0	$0	$113,187	$10,617	$22,637	$29,288	$175,729	$289
5A.2	Elemental Sulfur Plant	$6,734	$1,319	$8,689	$0	$0	$16,743	$1,579	$0	$3,664	$21,987	$36
5A.3	Mercury Removal	$1,351	$0	$1,028	$0	$0	$2,379	$223	$119	$544	$3,264	$5
5A.4	Shift Reactors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.5	Particulate Removal	w/4.1	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
5A.6	Blowback Gas Systems	$2,174	$366	$206	$0	$0	$2,746	$253	$0	$600	$3,598	$6
5A.7	Fuel Gas Piping	$0	$1,382	$915	$0	$0	$2,297	$200	$0	$499	$2,996	$5
5A.9	HGCU Foundations	$0	$1,232	$853	$0	$0	$2,085	$194	$0	$684	$2,962	$5
	SUBTOTAL 5A.	**$71,489**	**$4,299**	**$63,647**	**$0**	**$0**	**$139,436**	**$13,065**	**$22,756**	**$35,279**	**$210,536**	**$347**
5B	CO2 COMPRESSION											
5B.1	CO2 Removal System	w/ 5A.1	$0	w/ 5A.1	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$18,545	$0	$8,967	$0	$0	$27,512	$2,563	$0	$6,015	$36,091	$59
	SUBTOTAL 5B.	**$18,545**	**$0**	**$8,967**	**$0**	**$0**	**$27,512**	**$2,563**	**$0**	**$6,015**	**$36,091**	**$59**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	$120,642	$11,086	$12,064	$14,379	$158,171	$260
6.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$935	$1,111	$0	$0	$2,046	$192	$0	$671	$2,909	$5
	SUBTOTAL 6.	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$265**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$29,480	$0	$5,754	$0	$0	$35,234	$3,256	$0	$3,849	$42,339	$70
7.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$0	$1,327	$963	$0	$0	$2,289	$197	$0	$497	$2,983	$5
7.4	Stack	$2,633	$0	$989	$0	$0	$3,622	$337	$0	$396	$4,354	$7
7.9	HRSG,Duct & Stack Foundations	$0	$491	$507	$0	$0	$998	$93	$0	$327	$1,419	$2
	SUBTOTAL 7.	**$32,113**	**$1,818**	**$8,213**	**$0**	**$0**	**$42,143**	**$3,882**	**$0**	**$5,069**	**$51,095**	**$84**

Table 12-5 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 5 - PRB - water slurry feed - 1,000 #/MH-hr CO2
Plant Size: 607.2 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$40,940	$0	$6,783	$0	$0	$47,723	$4,219	$0	$5,194	$57,136	$94
8.2	Turbine Plant Auxiliaries	$272	$0	$624	$0	$0	$896	$85	$0	$98	$1,079	$2
8.3	Condenser & Auxiliaries	$3,390	$0	$2,000	$0	$0	$5,390	$503	$0	$589	$6,482	$11
8.4	Steam Piping	$15,935	$0	$6,458	$0	$0	$22,394	$1,682	$0	$6,019	$30,095	$50
8.9	TG Foundations	$0	$1,257	$2,282	$0	$0	$3,539	$334	$0	$1,162	$5,035	$8
	SUBTOTAL 8.	**$60,538**	**$1,257**	**$18,146**	**$0**	**$0**	**$79,941**	**$6,824**	**$0**	**$13,062**	**$99,827**	**$164**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,410	$0	$1,040	$0	$0	$4,450	$413	$0	$729	$5,592	$9
9.2	Circulating Water Pumps	$1,618	$0	$109	$0	$0	$1,726	$149	$0	$281	$2,157	$4
9.3	Circ.Water System Auxiliaries	$150	$0	$21	$0	$0	$171	$16	$0	$28	$215	$0
9.4	Circ.Water Piping	$0	$6,607	$1,619	$0	$0	$8,226	$689	$0	$1,783	$10,698	$18
9.5	Make-up Water System	$347	$0	$482	$0	$0	$829	$76	$0	$181	$1,087	$2
9.6	Component Cooling Water Sys	$757	$906	$627	$0	$0	$2,290	$204	$0	$499	$2,993	$5
9.9	Circ.Water System Foundations	$0	$2,129	$3,887	$0	$0	$6,016	$568	$0	$1,975	$8,559	$14
	SUBTOTAL 9.	**$6,282**	**$9,642**	**$7,785**	**$0**	**$0**	**$23,708**	**$2,114**	**$0**	**$5,477**	**$31,299**	**$52**
10	ASH/SPENT SORBENT HANDLING SYS											
10.1	Slag Dewatering & Cooling	$22,573	$0	$11,132	$0	$0	$33,706	$3,141	$0	$3,685	$40,531	$67
10.2	Gasifier Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.3	Cleanup Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.4	High Temperature Ash Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.5	Other Ash Recovery Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.6	Ash Storage Silos	$750	$0	$816	$0	$0	$1,566	$147	$0	$257	$1,970	$3
10.7	Ash Transport & Feed Equipment	$1,030	$0	$243	$0	$0	$1,273	$113	$0	$208	$1,594	$3
10.8	Misc. Ash Handling Equipment	$1,553	$1,903	$569	$0	$0	$4,025	$372	$0	$660	$5,056	$8
10.9	Ash/Spent Sorbent Foundation	$0	$62	$83	$0	$0	$145	$14	$0	$48	$206	$0
	SUBTOTAL 10.	**$25,906**	**$1,965**	**$12,843**	**$0**	**$0**	**$40,714**	**$3,786**	**$0**	**$4,857**	**$49,357**	**$81**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$1,198	$0	$1,202	$0	$0	$2,399	$224	$0	$262	$2,885	$5
11.2	Station Service Equipment	$5,233	$0	$496	$0	$0	$5,729	$536	$0	$627	$6,892	$11
11.3	Switchgear & Motor Control	$9,659	$0	$1,850	$0	$0	$11,509	$1,081	$0	$1,889	$14,479	$24
11.4	Conduit & Cable Tray	$0	$4,999	$15,585	$0	$0	$20,585	$1,905	$0	$5,622	$28,112	$46
11.5	Wire & Cable	$0	$9,554	$5,931	$0	$0	$15,485	$1,054	$0	$4,135	$20,673	$34
11.6	Protective Equipment	$0	$805	$3,081	$0	$0	$3,886	$372	$0	$639	$4,897	$8
11.7	Standby Equipment	$283	$0	$291	$0	$0	$574	$54	$0	$94	$723	$1
11.8	Main Power Transformers	$21,352	$0	$186	$0	$0	$21,537	$1,663	$0	$3,480	$26,680	$44
11.9	Electrical Foundations	$0	$189	$529	$0	$0	$718	$68	$0	$236	$1,022	$2
	SUBTOTAL 11.	**$37,726**	**$15,547**	**$29,150**	**$0**	**$0**	**$82,423**	**$6,957**	**$0**	**$16,983**	**$106,363**	**$175**

Table 12-5 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 5 - PRB - water slurry feed - 1,000 #/MH-hr CO2
Plant Size: 607.2 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,384	$0	$972	$0	$0	$2,356	$223	$118	$404	$3,101	$5
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$318	$0	$214	$0	$0	$533	$50	$27	$122	$731	$1
12.7	Computer & Accessories	$7,385	$0	$249	$0	$0	$7,633	$713	$382	$873	$9,601	$16
12.8	Instrument Wiring & Tubing	$0	$2,870	$5,543	$0	$0	$8,413	$679	$421	$2,378	$11,891	$20
12.9	Other I & C Equipment	$4,936	$0	$2,520	$0	$0	$7,456	$703	$373	$1,280	$9,812	$16
	SUBTOTAL 12.	**$14,023**	**$2,870**	**$9,498**	**$0**	**$0**	**$26,391**	**$2,369**	**$1,320**	**$5,057**	**$35,137**	**$58**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$129	$2,980	$0	$0	$3,109	$300	$0	$1,023	$4,432	$7
13.2	Site Improvements	$0	$2,285	$3,296	$0	$0	$5,581	$553	$0	$1,840	$7,974	$13
13.3	Site Facilities	$4,095	$0	$4,690	$0	$0	$8,785	$873	$0	$2,898	$12,556	$21
	SUBTOTAL 13.	**$4,095**	**$2,414**	**$10,966**	**$0**	**$0**	**$17,475**	**$1,727**	**$0**	**$5,761**	**$24,962**	**$41**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$319	$186	$0	$0	$505	$44	$0	$110	$659	$1
14.2	Steam Turbine Building	$0	$3,148	$4,631	$0	$0	$7,779	$703	$0	$1,272	$9,754	$16
14.3	Administration Building	$0	$1,136	$851	$0	$0	$1,986	$175	$0	$324	$2,485	$4
14.4	Circulation Water Pumphouse	$0	$203	$111	$0	$0	$314	$27	$0	$51	$392	$1
14.5	Water Treatment Buildings	$0	$472	$476	$0	$0	$948	$84	$0	$155	$1,188	$2
14.6	Machine Shop	$0	$554	$391	$0	$0	$945	$83	$0	$154	$1,182	$2
14.7	Warehouse	$0	$894	$596	$0	$0	$1,490	$130	$0	$243	$1,863	$3
14.8	Other Buildings & Structures	$0	$535	$430	$0	$0	$966	$85	$0	$210	$1,261	$2
14.9	Waste Treating Building & Str.	$0	$1,197	$2,361	$0	$0	$3,558	$325	$0	$777	$4,660	$8
14.10	Coal Prep Building	$0	$19,796	$8,328	$0	$0	$28,124	$2,419	$0	$6,109	$36,652	$60
	SUBTOTAL 14.	**$0**	**$28,253**	**$18,362**	**$0**	**$0**	**$46,615**	**$4,077**	**$0**	**$9,405**	**$60,096**	**$99**
	TOTAL COST	**$879,007**	**$103,597**	**$347,851**	**$0**	**$0**	**$1,330,456**	**$120,427**	**$71,440**	**$237,112**	**$1,759,435**	**$2,898**

Table 12-6 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 6 - PRB - LCO2 slurry feed - 1,000 #/MW-hr CO2
Plant Size: 560.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING	$18,891	$3,647	$15,202	$0	$0	**$37,740**	$3,366	$0	$8,221	**$49,328**	$88
2	COAL & SORBENT PREP & FEED	$46,125	$11,814	$17,074	$0	$0	**$75,012**	$6,546	$2,769	$14,711	**$99,038**	$177
3	FEEDWATER & MISC. BOP SYSTEMS	$11,598	$10,141	$10,577	$0	$0	**$32,316**	$2,938	$0	$7,900	**$43,154**	$77
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$156,221	$0	$85,166	$0	$0	**$241,387**	$21,319	$33,622	$45,391	**$341,719**	$610
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.3	ASU/Oxidant Compression	$229,127	$0	w/equip.	$0	$0	**$229,127**	$21,430	$0	$25,056	**$275,613**	$492
4.4-4.9	Other Gasification Equipment	$27,239	$14,092	$18,543	$0	$0	**$59,874**	$5,614	$0	$14,172	**$79,660**	$142
	SUBTOTAL 4	**$412,587**	**$14,092**	**$103,710**	**$0**	**$0**	**$530,389**	**$48,363**	**$33,622**	**$84,618**	**$696,991**	**$1,245**
5A	GAS CLEANUP & PIPING	$84,630	$3,388	$72,639	$0	$0	**$160,657**	$15,057	$26,142	$40,526	**$242,382**	$433
5B	CO2 COMPRESSION	$21,791	$0	$9,959	$0	$0	**$31,749**	$2,956	$0	$6,941	**$41,647**	$74
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	**$120,642**	$11,086	$12,064	$14,379	**$158,171**	$282
6.2-6.9	Combustion Turbine Other	$0	$935	$1,111	$0	$0	**$2,046**	$192	$0	$671	**$2,909**	$5
	SUBTOTAL 6	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$288**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$29,240	$0	$5,707	$0	$0	**$34,947**	$3,229	$0	$3,818	**$41,994**	$75
7.2-7.9	Ductwork and Stack	$2,669	$1,843	$2,492	$0	$0	**$7,003**	$635	$0	$1,237	**$8,875**	$16
	SUBTOTAL 7	**$31,909**	**$1,843**	**$8,199**	**$0**	**$0**	**$41,950**	**$3,864**	**$0**	**$5,055**	**$50,869**	**$91**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$36,730	$0	$6,086	$0	$0	**$42,816**	$3,786	$0	$4,660	**$51,262**	$92
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$19,040	$1,139	$10,844	$0	$0	**$31,023**	$2,496	$0	$7,633	**$41,152**	$73
	SUBTOTAL 8	**$55,770**	**$1,139**	**$16,931**	**$0**	**$0**	**$73,839**	**$6,282**	**$0**	**$12,293**	**$92,414**	**$165**
9	COOLING WATER SYSTEM	$5,588	$8,659	$7,005	$0	$0	**$21,253**	$1,895	$0	$4,915	**$28,063**	$50
10	ASH/SPENT SORBENT HANDLING SYS	$25,712	$1,952	$12,747	$0	$0	**$40,411**	$3,758	$0	$4,821	**$48,990**	$87
11	ACCESSORY ELECTRIC PLANT	$38,510	$15,810	$29,515	$0	$0	**$83,835**	$7,072	$0	$17,280	**$108,187**	$193
12	INSTRUMENTATION & CONTROL	$13,636	$2,791	$9,235	$0	$0	**$25,663**	$2,303	$1,283	$4,918	**$34,167**	$61
13	IMPROVEMENTS TO SITE	$3,997	$2,356	$10,702	$0	$0	**$17,055**	$1,685	$0	$5,622	**$24,362**	$44
14	BUILDINGS & STRUCTURES	$0	$31,482	$19,405	$0	$0	**$50,887**	$4,441	$0	$10,372	**$65,700**	$117
	TOTAL COST	**$884,608**	**$110,048**	**$350,788**	**$0**	**$0**	**$1,345,444**	**$121,805**	**$75,879**	**$243,243**	**$1,786,371**	**$3,190**

Table 12-6 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 6 - PRB - LCO2 slurry feed - 1,000 #/MW-hr CO2
Plant Size: 560.0 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING											
1.1	Coal Receive & Unload	$5,474	$0	$2,704	$0	$0	$8,178	$716	$0	$1,779	$10,673	$19
1.2	Coal Stackout & Reclaim	$7,073	$0	$1,734	$0	$0	$8,807	$755	$0	$1,912	$11,474	$20
1.3	Coal Conveyors & Yd Crush	$4,623	$0	$575	$0	$0	$5,198	$440	$0	$1,128	$6,766	$12
1.4	Other Coal Handling	$1,721	$0	$397	$0	$0	$2,117	$181	$0	$460	$2,758	$5
1.5	Sorbent Receive & Unload	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.6	Sorbent Stackout & Reclaim	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.7	Sorbent Conveyors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.8	Other Sorbent Handling	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.9	Coal & Sorbent Hnd.Foundations	$0	$3,647	$9,792	$0	$0	$13,440	$1,274	$0	$2,943	$17,657	$32
	SUBTOTAL 1.	**$18,891**	**$3,647**	**$15,202**	**$0**	**$0**	**$37,740**	**$3,366**	**$0**	**$8,221**	**$49,328**	**$88**
2	COAL & SORBENT PREP & FEED											
2.1	Coal Storage & Feed	$9,945	$0	$0	$0	$0	$9,945	$827	$0	$0	$10,772	$19
2.2	Coal Prep & Feed	$1,365	$0	$203	$0	$0	$1,568	$133	$0	$340	$2,041	$4
2.3	Coal Slurry Prep & Feed	$33,515	$6,116	$9,810	$0	$0	$49,441	$4,293	$2,769	$11,300	$67,803	$121
2.4	Misc.Coal Prep & Feed	$1,300	$940	$2,867	$0	$0	$5,107	$458	$0	$1,113	$6,678	$12
2.5	Sorbent Prep Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.6	Sorbent Storage & Feed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.7	Sorbent Injection System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.8	Booster Air Supply System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.9	Coal & Sorbent Feed Foundation	$0	$4,758	$4,194	$0	$0	$8,951	$836	$0	$1,957	$11,744	$21
	SUBTOTAL 2.	**$46,125**	**$11,814**	**$17,074**	**$0**	**$0**	**$75,012**	**$6,546**	**$2,769**	**$14,711**	**$99,038**	**$177**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$4,072	$7,070	$3,732	$0	$0	$14,874	$1,341	$0	$3,243	$19,458	$35
3.2	Water Makeup & Pretreating	$569	$59	$315	$0	$0	$943	$87	$0	$309	$1,338	$2
3.3	Other Feedwater Subsystems	$2,310	$761	$685	$0	$0	$3,756	$322	$0	$816	$4,894	$9
3.4	Service Water Systems	$332	$664	$2,303	$0	$0	$3,299	$311	$0	$1,083	$4,693	$8
3.5	Other Boiler Plant Systems	$1,789	$670	$1,661	$0	$0	$4,120	$374	$0	$899	$5,392	$10
3.6	FO Supply Sys & Nat Gas	$388	$733	$684	$0	$0	$1,805	$169	$0	$395	$2,369	$4
3.7	Waste Treatment Equipment	$774	$0	$480	$0	$0	$1,254	$120	$0	$412	$1,786	$3
3.8	Misc. Power Plant Equipment	$1,365	$184	$717	$0	$0	$2,265	$215	$0	$744	$3,224	$6
	SUBTOTAL 3.	**$11,598**	**$10,141**	**$10,577**	**$0**	**$0**	**$32,316**	**$2,938**	**$0**	**$7,900**	**$43,154**	**$77**

Table 12-6 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 6 - PRB - LCO2 slurry feed - 1,000 #/MW-hr CO2
Plant Size: 560.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$156,221	$0	$85,166	$0	$0	$241,387	$21,319	$33,622	$45,391	$341,719	$610
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$229,127	$0	w/equip.	$0	$0	$229,127	$21,430	$0	$25,056	$275,613	$492
4.4	LT Heat Recovery & FG Saturation	$27,239	$0	$10,302	$0	$0	$37,542	$3,540	$0	$8,216	$49,298	$88
4.5	Misc. Gasification Equipment	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.6	Other Gasification Equipment	$0	$1,905	$775	$0	$0	$2,680	$249	$0	$586	$3,515	$6
4.8	Major Component Rigging	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.9	Gasification Foundations	$0	$12,187	$7,466	$0	$0	$19,653	$1,825	$0	$5,369	$26,847	$48
	SUBTOTAL 4.	**$412,587**	**$14,092**	**$103,710**	**$0**	**$0**	**$530,389**	**$48,363**	**$33,622**	**$84,618**	**$696,991**	**$1,245**
5A	GAS CLEANUP & PIPING											
5A.1	Double Stage Selexol	$70,361	$0	$59,705	$0	$0	$130,066	$12,200	$26,013	$33,656	$201,935	$361
5A.2	Elemental Sulfur Plant	$6,746	$1,322	$8,704	$0	$0	$16,772	$1,582	$0	$3,671	$22,025	$39
5A.3	Mercury Removal	$1,459	$0	$1,111	$0	$0	$2,570	$241	$128	$588	$3,527	$6
5A.4	Shift Reactors	$4,360	$0	$1,755	$0	$0	$6,114	$569	$0	$1,337	$8,020	$14
5A.5	Particulate Removal	w/4.1	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
5A.6	Blowback Gas Systems	$1,704	$287	$161	$0	$0	$2,153	$198	$0	$470	$2,821	$5
5A.7	Fuel Gas Piping	$0	$941	$623	$0	$0	$1,563	$136	$0	$340	$2,039	$4
5A.9	HGCU Foundations	$0	$838	$580	$0	$0	$1,419	$132	$0	$465	$2,016	$4
	SUBTOTAL 5A.	**$84,630**	**$3,388**	**$72,639**	**$0**	**$0**	**$160,657**	**$15,057**	**$26,142**	**$40,526**	**$242,382**	**$433**
5B	CO2 COMPRESSION											
5B.1	CO2 Removal System	w/ 5A.1	$0	w/ 5A.1	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$21,791	$0	$9,959	$0	$0	$31,749	$2,956	$0	$6,941	$41,647	$74
	SUBTOTAL 5B.	**$21,791**	**$0**	**$9,959**	**$0**	**$0**	**$31,749**	**$2,956**	**$0**	**$6,941**	**$41,647**	**$74**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	$120,642	$11,086	$12,064	$14,379	$158,171	$282
6.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$935	$1,111	$0	$0	$2,046	$192	$0	$671	$2,909	$5
	SUBTOTAL 6.	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$288**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$29,240	$0	$5,707	$0	$0	$34,947	$3,229	$0	$3,818	$41,994	$75
7.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$0	$1,345	$976	$0	$0	$2,321	$199	$0	$504	$3,024	$5
7.4	Stack	$2,669	$0	$1,003	$0	$0	$3,671	$341	$0	$401	$4,414	$8
7.9	HRSG,Duct & Stack Foundations	$0	$498	$514	$0	$0	$1,011	$95	$0	$332	$1,438	$3
	SUBTOTAL 7.	**$31,909**	**$1,843**	**$8,199**	**$0**	**$0**	**$41,950**	**$3,864**	**$0**	**$5,055**	**$50,869**	**$91**

Table 12-6 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 6 - PRB - LCO2 slurry feed - 1,000 #/MW-hr CO2
Plant Size: 560.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$36,730	$0	$6,086	$0	$0	$42,816	$3,786	$0	$4,660	$51,262	$92
8.2	Turbine Plant Auxiliaries	$247	$0	$565	$0	$0	$812	$77	$0	$89	$978	$2
8.3	Condenser & Auxiliaries	$3,000	$0	$1,812	$0	$0	$4,812	$449	$0	$526	$5,787	$10
8.4	Steam Piping	$15,793	$0	$6,401	$0	$0	$22,194	$1,667	$0	$5,965	$29,826	$53
8.9	TG Foundations	$0	$1,139	$2,067	$0	$0	$3,206	$302	$0	$1,053	$4,561	$8
	SUBTOTAL 8.	**$55,770**	**$1,139**	**$16,931**	**$0**	**$0**	**$73,839**	**$6,282**	**$0**	**$12,293**	**$92,414**	**$165**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,010	$0	$920	$0	$0	$3,930	$364	$0	$644	$4,939	$9
9.2	Circulating Water Pumps	$1,427	$0	$91	$0	$0	$1,518	$131	$0	$247	$1,896	$3
9.3	Circ.Water System Auxiliaries	$134	$0	$19	$0	$0	$154	$14	$0	$25	$193	$0
9.4	Circ.Water Piping	$0	$5,933	$1,454	$0	$0	$7,387	$619	$0	$1,601	$9,607	$17
9.5	Make-up Water System	$337	$0	$468	$0	$0	$805	$74	$0	$176	$1,054	$2
9.6	Component Cooling Water Sys	$680	$813	$563	$0	$0	$2,056	$183	$0	$448	$2,688	$5
9.9	Circ.Water System Foundations	$0	$1,912	$3,490	$0	$0	$5,403	$510	$0	$1,774	$7,686	$14
	SUBTOTAL 9.	**$5,588**	**$8,659**	**$7,005**	**$0**	**$0**	**$21,253**	**$1,895**	**$0**	**$4,915**	**$28,063**	**$50**
10	ASH/SPENT SORBENT HANDLING SYS											
10.1	Slag Dewatering & Cooling	$22,401	$0	$11,047	$0	$0	$33,449	$3,117	$0	$3,657	$40,222	$72
10.2	Gasifier Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.3	Cleanup Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.4	High Temperature Ash Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.5	Other Ash Recovery Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.6	Ash Storage Silos	$745	$0	$811	$0	$0	$1,555	$146	$0	$255	$1,957	$3
10.7	Ash Transport & Feed Equipment	$1,023	$0	$241	$0	$0	$1,264	$112	$0	$206	$1,583	$3
10.8	Misc. Ash Handling Equipment	$1,543	$1,891	$565	$0	$0	$3,999	$369	$0	$655	$5,023	$9
10.9	Ash/Spent Sorbent Foundation	$0	$61	$83	$0	$0	$144	$14	$0	$47	$205	$0
	SUBTOTAL 10.	**$25,712**	**$1,952**	**$12,747**	**$0**	**$0**	**$40,411**	**$3,758**	**$0**	**$4,821**	**$48,990**	**$87**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$1,162	$0	$1,166	$0	$0	$2,329	$217	$0	$255	$2,800	$5
11.2	Station Service Equipment	$5,332	$0	$505	$0	$0	$5,837	$546	$0	$638	$7,021	$13
11.3	Switchgear & Motor Control	$9,841	$0	$1,884	$0	$0	$11,725	$1,102	$0	$1,924	$14,751	$26
11.4	Conduit & Cable Tray	$0	$5,093	$15,878	$0	$0	$20,972	$1,941	$0	$5,728	$28,641	$51
11.5	Wire & Cable	$0	$9,733	$6,042	$0	$0	$15,776	$1,074	$0	$4,212	$21,062	$38
11.6	Protective Equipment	$0	$801	$3,065	$0	$0	$3,867	$370	$0	$636	$4,872	$9
11.7	Standby Equipment	$276	$0	$284	$0	$0	$560	$53	$0	$92	$705	$1
11.8	Main Power Transformers	$21,898	$0	$179	$0	$0	$22,077	$1,704	$0	$3,567	$27,348	$49
11.9	Electrical Foundations	$0	$182	$511	$0	$0	$693	$65	$0	$227	$986	$2
	SUBTOTAL 11.	**$38,510**	**$15,810**	**$29,515**	**$0**	**$0**	**$83,835**	**$7,072**	**$0**	**$17,280**	**$108,187**	**$193**

Table 12-6 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI — **Report Date:** 2013-Jul-18

Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 6 - PRB - LCO2 slurry feed - 1,000 #/MW-hr CO2

Plant Size: 560.0 MW,net — **Estimate Type:** Conceptual — **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,346	$0	$945	$0	$0	$2,291	$217	$115	$393	$3,015	$5
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$309	$0	$209	$0	$0	$518	$49	$26	$119	$711	$1
12.7	Computer & Accessories	$7,181	$0	$242	$0	$0	$7,422	$693	$371	$849	$9,336	$17
12.8	Instrument Wiring & Tubing	$0	$2,791	$5,390	$0	$0	$8,181	$660	$409	$2,313	$11,563	$21
12.9	Other I & C Equipment	$4,800	$0	$2,450	$0	$0	$7,250	$684	$363	$1,244	$9,541	$17
	SUBTOTAL 12.	**$13,636**	**$2,791**	**$9,235**	**$0**	**$0**	**$25,663**	**$2,303**	**$1,283**	**$4,918**	**$34,167**	**$61**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$125	$2,909	$0	$0	$3,034	$293	$0	$998	$4,326	$8
13.2	Site Improvements	$0	$2,230	$3,217	$0	$0	$5,447	$539	$0	$1,796	$7,782	$14
13.3	Site Facilities	$3,997	$0	$4,577	$0	$0	$8,574	$852	$0	$2,828	$12,254	$22
	SUBTOTAL 13.	**$3,997**	**$2,356**	**$10,702**	**$0**	**$0**	**$17,055**	**$1,685**	**$0**	**$5,622**	**$24,362**	**$44**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$319	$186	$0	$0	$505	$44	$0	$110	$659	$1
14.2	Steam Turbine Building	$0	$2,902	$4,269	$0	$0	$7,172	$648	$0	$1,173	$8,993	$16
14.3	Administration Building	$0	$1,117	$836	$0	$0	$1,953	$172	$0	$319	$2,443	$4
14.4	Circulation Water Pumphouse	$0	$200	$109	$0	$0	$309	$27	$0	$50	$386	$1
14.5	Water Treatment Buildings	$0	$456	$459	$0	$0	$915	$81	$0	$149	$1,146	$2
14.6	Machine Shop	$0	$544	$385	$0	$0	$929	$82	$0	$152	$1,162	$2
14.7	Warehouse	$0	$879	$586	$0	$0	$1,465	$128	$0	$239	$1,832	$3
14.8	Other Buildings & Structures	$0	$526	$423	$0	$0	$950	$84	$0	$207	$1,240	$2
14.9	Waste Treating Building & Str.	$0	$1,177	$2,322	$0	$0	$3,498	$320	$0	$764	$4,582	$8
14.10	Coal Prep Building	$0	$23,363	$9,829	$0	$0	$33,192	$2,855	$0	$7,209	$43,256	$77
	SUBTOTAL 14.	**$0**	**$31,482**	**$19,405**	**$0**	**$0**	**$50,887**	**$4,441**	**$0**	**$10,372**	**$65,700**	**$117**
	TOTAL COST	**$884,608**	**$110,048**	**$350,788**	**$0**	**$0**	**$1,345,444**	**$121,805**	**$75,879**	**$243,243**	**$1,786,371**	**$3,190**

Table 12-7 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 7 - Lignite - water slurry feed 1,000#/MW-hr CO2
Plant Size: 641.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING	$24,275	$4,621	$19,321	$0	$0	**$48,217**	$4,299	$0	$10,503	**$63,019**	$98
2	COAL & SORBENT PREP & FEED	$47,791	$8,052	$23,910	$0	$0	**$79,753**	$6,984	$0	$14,927	**$101,664**	$159
3	FEEDWATER & MISC. BOP SYSTEMS	$12,755	$11,021	$11,757	$0	$0	**$35,533**	$3,232	$0	$8,715	**$47,480**	$74
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$207,920	$0	$116,099	$0	$0	**$324,019**	$28,592	$46,089	$60,720	**$459,420**	$717
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.3	ASU/Oxidant Compression	$280,427	$0	w/equip.	$0	$0	**$280,427**	$26,228	$0	$30,665	**$337,320**	$526
4.4-4.9	Other Gasification Equipment	$30,197	$17,364	$21,520	$0	$0	**$69,082**	$6,475	$0	$16,411	**$91,967**	$143
	SUBTOTAL 4	**$518,544**	**$17,364**	**$137,619**	**$0**	**$0**	**$673,528**	**$61,294**	**$46,089**	**$107,796**	**$888,707**	**$1,386**
5A	GAS CLEANUP & PIPING	$75,186	$3,580	$64,590	$0	$0	**$143,356**	$13,425	$25,693	$36,735	**$219,208**	$342
5B	CO2 COMPRESSION	$22,233	$0	$10,258	$0	$0	**$32,491**	$3,026	$0	$7,103	**$42,620**	$66
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	**$120,642**	$11,086	$12,064	$14,379	**$158,171**	$247
6.2-6.9	Combustion Turbine Other	$0	$935	$1,111	$0	$0	**$2,046**	$192	$0	$671	**$2,909**	$5
	SUBTOTAL 6	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$251**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$28,500	$0	$5,563	$0	$0	**$34,063**	$3,147	$0	$3,721	**$40,932**	$64
7.2-7.9	Ductwork and Stack	$2,739	$1,891	$2,558	$0	$0	**$7,188**	$652	$0	$1,270	**$9,110**	$14
	SUBTOTAL 7	**$31,239**	**$1,891**	**$8,121**	**$0**	**$0**	**$41,251**	**$3,799**	**$0**	**$4,991**	**$50,042**	**$78**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$47,410	$0	$7,854	$0	$0	**$55,264**	$4,886	$0	$6,015	**$66,165**	$103
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$22,165	$1,437	$12,937	$0	$0	**$36,540**	$2,954	$0	$8,933	**$48,427**	$76
	SUBTOTAL 8	**$69,575**	**$1,437**	**$20,792**	**$0**	**$0**	**$91,805**	**$7,840**	**$0**	**$14,948**	**$114,593**	**$179**
9	COOLING WATER SYSTEM	$6,862	$10,292	$8,468	$0	$0	**$25,622**	$2,287	$0	$5,922	**$33,831**	$53
10	ASH/SPENT SORBENT HANDLING SYS	$36,377	$2,651	$18,030	$0	$0	**$57,058**	$5,307	$0	$6,785	**$69,150**	$108
11	ACCESSORY ELECTRIC PLANT	$40,045	$16,712	$31,149	$0	$0	**$87,905**	$7,420	$0	$18,160	**$113,485**	$177
12	INSTRUMENTATION & CONTROL	$14,270	$2,921	$9,665	$0	$0	**$26,855**	$2,410	$1,343	$5,146	**$35,755**	$56
13	IMPROVEMENTS TO SITE	$4,249	$2,504	$11,378	$0	$0	**$18,131**	$1,791	$0	$5,977	**$25,899**	$40
14	BUILDINGS & STRUCTURES	$0	$29,956	$19,865	$0	$0	**$49,821**	$4,360	$0	$10,041	**$64,223**	$100
	TOTAL COST	**$1,017,265**	**$113,938**	**$402,812**	**$0**	**$0**	**$1,534,014**	**$138,753**	**$85,189**	**$272,801**	**$2,030,757**	**$3,168**

Table 12-7 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 7 - Lignite - water slurry feed 1,000#/MW-hr CO2
Plant Size: 641.0 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING											
1.1	Coal Receive & Unload	$6,934	$0	$3,426	$0	$0	$10,360	$907	$0	$2,253	$13,520	$21
1.2	Coal Stackout & Reclaim	$8,960	$0	$2,196	$0	$0	$11,156	$957	$0	$2,423	$14,536	$23
1.3	Coal Conveyors & Yd Crush	$6,202	$0	$791	$0	$0	$6,993	$592	$0	$1,517	$9,102	$14
1.4	Other Coal Handling	$2,180	$0	$503	$0	$0	$2,682	$230	$0	$582	$3,494	$5
1.5	Sorbent Receive & Unload	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.6	Sorbent Stackout & Reclaim	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.7	Sorbent Conveyors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.8	Other Sorbent Handling	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.9	Coal & Sorbent Hnd.Foundations	$0	$4,621	$12,405	$0	$0	$17,025	$1,614	$0	$3,728	$22,367	$35
	SUBTOTAL 1.	**$24,275**	**$4,621**	**$19,321**	**$0**	**$0**	**$48,217**	**$4,299**	**$0**	**$10,503**	**$63,019**	**$98**
2	COAL & SORBENT PREP & FEED											
2.1	Coal Storage & Feed	$11,174	$0	$0	$0	$0	$11,174	$929	$0	$0	$12,103	$19
2.2	Prepared Coal Storage & Feed	$3,040	$723	$482	$0	$0	$4,245	$356	$0	$920	$5,521	$9
2.3	Slurry Prep & Feed (incl. crushing)	$31,905	$0	$14,346	$0	$0	$46,251	$4,035	$0	$10,057	$60,344	$94
2.4	Misc.Coal Prep & Feed	$1,672	$1,209	$3,688	$0	$0	$6,569	$589	$0	$1,432	$8,590	$13
2.5	Sorbent Prep Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.6	Sorbent Storage & Feed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.7	Sorbent Injection System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.8	Booster Air Supply System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.9	Coal & Sorbent Feed Foundation	$0	$6,119	$5,394	$0	$0	$11,514	$1,075	$0	$2,518	$15,106	$24
	SUBTOTAL 2.	**$47,791**	**$8,052**	**$23,910**	**$0**	**$0**	**$79,753**	**$6,984**	**$0**	**$14,927**	**$101,664**	**$159**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$4,379	$7,605	$4,015	$0	$0	$15,999	$1,442	$0	$3,488	$20,929	$33
3.2	Water Makeup & Pretreating	$658	$68	$363	$0	$0	$1,089	$100	$0	$357	$1,546	$2
3.3	Other Feedwater Subsystems	$2,484	$819	$737	$0	$0	$4,040	$347	$0	$877	$5,264	$8
3.4	Service Water Systems	$383	$766	$2,659	$0	$0	$3,809	$359	$0	$1,251	$5,419	$8
3.5	Other Boiler Plant Systems	$2,065	$774	$1,918	$0	$0	$4,757	$431	$0	$1,038	$6,226	$10
3.6	FO Supply Sys & Nat Gas	$419	$791	$738	$0	$0	$1,948	$182	$0	$426	$2,556	$4
3.7	Waste Treatment Equipment	$893	$0	$554	$0	$0	$1,448	$138	$0	$476	$2,062	$3
3.8	Misc. Power Plant Equipment	$1,473	$198	$773	$0	$0	$2,444	$232	$0	$803	$3,479	$5
	SUBTOTAL 3.	**$12,755**	**$11,021**	**$11,757**	**$0**	**$0**	**$35,533**	**$3,232**	**$0**	**$8,715**	**$47,480**	**$74**

Table 12-7 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 7 - Lignite - water slurry feed 1,000#/MW-hr CO2
Plant Size: 641.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$207,920	$0	$116,099	$0	$0	$324,019	$28,592	$46,089	$60,720	$459,420	$717
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$280,427	$0	w/equip.	$0	$0	$280,427	$26,228	$0	$30,665	$337,320	$526
4.4	LT Heat Recovery & FG Saturation	$30,197	$0	$11,421	$0	$0	$41,618	$3,925	$0	$9,108	$54,651	$85
4.5	Misc. Gasification Equipment	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.6	Other Gasification Equipment	$0	$2,617	$1,065	$0	$0	$3,682	$342	$0	$805	$4,829	$8
4.8	Major Component Rigging	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.9	Gasification Foundations	$0	$14,747	$9,035	$0	$0	$23,782	$2,208	$0	$6,498	$32,488	$51
	SUBTOTAL 4.	**$518,544**	**$17,364**	**$137,619**	**$0**	**$0**	**$673,528**	**$61,294**	**$46,089**	**$107,796**	**$888,707**	**$1,386**
5A	GAS CLEANUP & PIPING											
5A.1	Double Stage Selexol	$69,147	$0	$58,675	$0	$0	$127,822	$11,989	$25,564	$33,075	$198,450	$310
5A.2	Elemental Sulfur Plant	$2,097	$411	$2,706	$0	$0	$5,214	$492	$0	$1,141	$6,848	$11
5A.3	Mercury Removal	$1,463	$0	$1,113	$0	$0	$2,576	$241	$129	$589	$3,535	$6
5A.4	Shift Reactors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.5	Particulate Removal	w/4.1	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
5A.6	Blowback Gas Systems	$2,479	$417	$235	$0	$0	$3,130	$288	$0	$684	$4,102	$6
5A.7	Fuel Gas Piping	$0	$1,455	$963	$0	$0	$2,418	$210	$0	$526	$3,154	$5
5A.9	HGCU Foundations	$0	$1,297	$898	$0	$0	$2,195	$204	$0	$720	$3,119	$5
	SUBTOTAL 5A.	**$75,186**	**$3,580**	**$64,590**	**$0**	**$0**	**$143,356**	**$13,425**	**$25,693**	**$36,735**	**$219,208**	**$342**
5B	CO2 COMPRESSION											
5B.1	CO2 Removal System	w/ 5A.1	$0	w/ 5A.1	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$22,233	$0	$10,258	$0	$0	$32,491	$3,026	$0	$7,103	$42,620	$66
	SUBTOTAL 5B.	**$22,233**	**$0**	**$10,258**	**$0**	**$0**	**$32,491**	**$3,026**	**$0**	**$7,103**	**$42,620**	**$66**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	$120,642	$11,086	$12,064	$14,379	$158,171	$247
6.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$935	$1,111	$0	$0	$2,046	$192	$0	$671	$2,909	$5
	SUBTOTAL 6.	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$251**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$28,500	$0	$5,563	$0	$0	$34,063	$3,147	$0	$3,721	$40,932	$64
7.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$0	$1,380	$1,002	$0	$0	$2,382	$205	$0	$517	$3,104	$5
7.4	Stack	$2,739	$0	$1,029	$0	$0	$3,768	$350	$0	$412	$4,530	$7
7.9	HRSG,Duct & Stack Foundations	$0	$511	$527	$0	$0	$1,038	$97	$0	$341	$1,476	$2
	SUBTOTAL 7.	**$31,239**	**$1,891**	**$8,121**	**$0**	**$0**	**$41,251**	**$3,799**	**$0**	**$4,991**	**$50,042**	**$78**

Table 12-7 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 7 - Lignite - water slurry feed 1,000#/MW-hr CO2
Plant Size: 641.0 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$47,410	$0	$7,854	$0	$0	$55,264	$4,886	$0	$6,015	$66,165	$103
8.2	Turbine Plant Auxiliaries	$311	$0	$713	$0	$0	$1,024	$97	$0	$112	$1,234	$2
8.3	Condenser & Auxiliaries	$3,770	$0	$2,286	$0	$0	$6,056	$566	$0	$662	$7,284	$11
8.4	Steam Piping	$18,084	$0	$7,329	$0	$0	$25,414	$1,909	$0	$6,831	$34,153	$53
8.9	TG Foundations	$0	$1,437	$2,609	$0	$0	$4,046	$382	$0	$1,328	$5,756	$9
	SUBTOTAL 8.	**$69,575**	**$1,437**	**$20,792**	**$0**	**$0**	**$91,805**	**$7,840**	**$0**	**$14,948**	**$114,593**	**$179**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,790	$0	$1,160	$0	$0	$4,950	$459	$0	$811	$6,220	$10
9.2	Circulating Water Pumps	$1,731	$0	$120	$0	$0	$1,850	$160	$0	$302	$2,312	$4
9.3	Circ.Water System Auxiliaries	$159	$0	$23	$0	$0	$181	$17	$0	$30	$228	$0
9.4	Circ.Water Piping	$0	$7,000	$1,715	$0	$0	$8,715	$730	$0	$1,889	$11,335	$18
9.5	Make-up Water System	$381	$0	$528	$0	$0	$909	$84	$0	$198	$1,191	$2
9.6	Component Cooling Water Sys	$802	$959	$665	$0	$0	$2,426	$216	$0	$528	$3,171	$5
9.9	Circ.Water System Foundations	$0	$2,333	$4,258	$0	$0	$6,590	$622	$0	$2,164	$9,375	$15
	SUBTOTAL 9.	**$6,862**	**$10,292**	**$8,468**	**$0**	**$0**	**$25,622**	**$2,287**	**$0**	**$5,922**	**$33,831**	**$53**
10	ASH/SPENT SORBENT HANDLING SYS											
10.1	Slag Dewatering & Cooling	$31,881	$0	$15,722	$0	$0	$47,603	$4,436	$0	$5,204	$57,243	$89
10.2	Gasifier Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.3	Cleanup Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.4	High Temperature Ash Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.5	Other Ash Recovery Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.6	Ash Storage Silos	$1,012	$0	$1,101	$0	$0	$2,112	$199	$0	$347	$2,658	$4
10.7	Ash Transport & Feed Equipment	$1,390	$0	$327	$0	$0	$1,717	$152	$0	$280	$2,150	$3
10.8	Misc. Ash Handling Equipment	$2,095	$2,568	$767	$0	$0	$5,430	$501	$0	$890	$6,821	$11
10.9	Ash/Spent Sorbent Foundation	$0	$83	$112	$0	$0	$196	$18	$0	$64	$278	$0
	SUBTOTAL 10.	**$36,377**	**$2,651**	**$18,030**	**$0**	**$0**	**$57,058**	**$5,307**	**$0**	**$6,785**	**$69,150**	**$108**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$1,253	$0	$1,257	$0	$0	$2,511	$234	$0	$274	$3,019	$5
11.2	Station Service Equipment	$5,649	$0	$535	$0	$0	$6,184	$579	$0	$676	$7,438	$12
11.3	Switchgear & Motor Control	$10,426	$0	$1,996	$0	$0	$12,422	$1,167	$0	$2,038	$15,627	$24
11.4	Conduit & Cable Tray	$0	$5,396	$16,821	$0	$0	$22,217	$2,056	$0	$6,068	$30,342	$47
11.5	Wire & Cable	$0	$10,311	$6,401	$0	$0	$16,713	$1,137	$0	$4,463	$22,313	$35
11.6	Protective Equipment	$0	$805	$3,081	$0	$0	$3,886	$372	$0	$639	$4,897	$8
11.7	Standby Equipment	$294	$0	$302	$0	$0	$596	$56	$0	$98	$750	$1
11.8	Main Power Transformers	$22,423	$0	$196	$0	$0	$22,619	$1,746	$0	$3,655	$28,020	$44
11.9	Electrical Foundations	$0	$200	$559	$0	$0	$758	$72	$0	$249	$1,079	$2
	SUBTOTAL 11.	**$40,045**	**$16,712**	**$31,149**	**$0**	**$0**	**$87,905**	**$7,420**	**$0**	**$18,160**	**$113,485**	**$177**

Table 12-7 Capital Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18

Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 7 - Lignite - water slurry feed 1,000#/MW-hr CO2

Plant Size: 641.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,409	$0	$989	$0	$0	$2,397	$227	$120	$412	$3,156	$5
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$324	$0	$218	$0	$0	$542	$51	$27	$124	$744	$1
12.7	Computer & Accessories	$7,515	$0	$253	$0	$0	$7,767	$726	$388	$888	$9,770	$15
12.8	Instrument Wiring & Tubing	$0	$2,921	$5,641	$0	$0	$8,561	$691	$428	$2,420	$12,101	$19
12.9	Other I & C Equipment	$5,023	$0	$2,564	$0	$0	$7,587	$716	$379	$1,302	$9,985	$16
	SUBTOTAL 12.	**$14,270**	**$2,921**	**$9,665**	**$0**	**$0**	**$26,855**	**$2,410**	**$1,343**	**$5,146**	**$35,755**	**$56**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$133	$3,092	$0	$0	$3,226	$312	$0	$1,061	$4,599	$7
13.2	Site Improvements	$0	$2,371	$3,420	$0	$0	$5,791	$574	$0	$1,909	$8,273	$13
13.3	Site Facilities	$4,249	$0	$4,866	$0	$0	$9,115	$906	$0	$3,006	$13,027	$20
	SUBTOTAL 13.	**$4,249**	**$2,504**	**$11,378**	**$0**	**$0**	**$18,131**	**$1,791**	**$0**	**$5,977**	**$25,899**	**$40**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$319	$186	$0	$0	$505	$44	$0	$110	$659	$1
14.2	Steam Turbine Building	$0	$3,514	$5,169	$0	$0	$8,683	$785	$0	$1,420	$10,889	$17
14.3	Administration Building	$0	$1,165	$873	$0	$0	$2,038	$179	$0	$333	$2,550	$4
14.4	Circulation Water Pumphouse	$0	$208	$114	$0	$0	$322	$28	$0	$53	$403	$1
14.5	Water Treatment Buildings	$0	$526	$530	$0	$0	$1,057	$94	$0	$173	$1,323	$2
14.6	Machine Shop	$0	$568	$401	$0	$0	$969	$85	$0	$158	$1,212	$2
14.7	Warehouse	$0	$917	$611	$0	$0	$1,528	$134	$0	$249	$1,911	$3
14.8	Other Buildings & Structures	$0	$549	$442	$0	$0	$991	$87	$0	$216	$1,294	$2
14.9	Waste Treating Building & Str.	$0	$1,228	$2,423	$0	$0	$3,650	$334	$0	$797	$4,781	$7
14.10	Coal Prep Building	$0	$20,961	$9,116	$0	$0	$30,078	$2,590	$0	$6,534	$39,201	$61
	SUBTOTAL 14.	**$0**	**$29,956**	**$19,865**	**$0**	**$0**	**$49,821**	**$4,360**	**$0**	**$10,041**	**$64,223**	**$100**
	TOTAL COST	**$1,017,265**	**$113,938**	**$402,812**	**$0**	**$0**	**$1,534,014**	**$138,753**	**$85,189**	**$272,801**	**$2,030,757**	**$3,168**

Table 12-8 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 8 - Lignite - LCO2 slurry feed - 1,000 #/MW-hr CO2
Plant Size: 578.4 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
1	COAL & SORBENT HANDLING	$23,050	$4,406	$18,360	$0	$0	**$45,816**	$4,085	$0	$9,980	**$59,882**	$104
2	COAL & SORBENT PREP & FEED	$52,777	$13,539	$19,705	$0	$0	**$86,022**	$7,507	$3,155	$17,014	**$113,698**	$197
3	FEEDWATER & MISC. BOP SYSTEMS	$12,220	$10,616	$11,217	$0	$0	**$34,053**	$3,097	$0	$8,339	**$45,489**	$79
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$180,590	$0	$99,584	$0	$0	**$280,174**	$24,733	$39,439	$52,594	**$396,940**	$686
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.3	ASU/Oxidant Compression	$255,049	$0	w/equip.	$0	$0	**$255,049**	$23,854	$0	$27,890	**$306,793**	$530
4.4-4.9	Other Gasification Equipment	$32,490	$16,460	$21,906	$0	$0	**$70,856**	$6,644	$0	$16,751	**$94,251**	$163
	SUBTOTAL 4	**$468,130**	**$16,460**	**$121,489**	**$0**	**$0**	**$606,079**	**$55,231**	**$39,439**	**$97,235**	**$797,984**	**$1,380**
5A	GAS CLEANUP & PIPING	$94,067	$3,675	$79,658	$0	$0	**$177,400**	$16,625	$28,375	$44,637	**$267,036**	$462
5B	CO2 COMPRESSION	$24,716	$0	$10,656	$0	$0	**$35,372**	$3,291	$0	$7,733	**$46,396**	$80
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	**$120,642**	$11,086	$12,064	$14,379	**$158,171**	$273
6.2-6.9	Combustion Turbine Other	$0	$935	$1,111	$0	$0	**$2,046**	$192	$0	$671	**$2,909**	$5
	SUBTOTAL 6	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$279**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$26,500	$0	$5,173	$0	$0	**$31,673**	$2,927	$0	$3,460	**$38,059**	$66
7.2-7.9	Ductwork and Stack	$2,698	$1,863	$2,519	$0	$0	**$7,080**	$642	$0	$1,251	**$8,973**	$16
	SUBTOTAL 7	**$29,198**	**$1,863**	**$7,692**	**$0**	**$0**	**$38,753**	**$3,569**	**$0**	**$4,711**	**$47,032**	**$81**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$41,360	$0	$6,853	$0	$0	**$48,213**	$4,263	$0	$5,248	**$57,723**	$100
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$20,435	$1,269	$11,765	$0	$0	**$33,469**	$2,699	$0	$8,208	**$44,376**	$77
	SUBTOTAL 8	**$61,795**	**$1,269**	**$18,618**	**$0**	**$0**	**$81,682**	**$6,962**	**$0**	**$13,456**	**$102,099**	**$177**
9	COOLING WATER SYSTEM	$6,549	$9,997	$8,078	$0	$0	**$24,624**	$2,196	$0	$5,686	**$32,506**	$56
10	ASH/SPENT SORBENT HANDLING SYS	$34,653	$2,540	$17,176	$0	$0	**$54,369**	$5,057	$0	$6,468	**$65,894**	$114
11	ACCESSORY ELECTRIC PLANT	$41,185	$16,809	$31,288	$0	$0	**$89,283**	$7,528	$0	$18,402	**$115,213**	$199
12	INSTRUMENTATION & CONTROL	$13,872	$2,839	$9,395	$0	$0	**$26,106**	$2,343	$1,305	$5,003	**$34,757**	$60
13	IMPROVEMENTS TO SITE	$4,106	$2,420	$10,995	$0	$0	**$17,521**	$1,731	$0	$5,776	**$25,028**	$43
14	BUILDINGS & STRUCTURES	$0	$32,877	$20,697	$0	$0	**$53,574**	$4,679	$0	$10,911	**$69,164**	$120
	TOTAL COST	**$980,183**	**$120,246**	**$392,912**	**$0**	**$0**	**$1,493,341**	**$135,179**	**$84,338**	**$270,400**	**$1,983,258**	**$3,429**

Table 12-8 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 8 - Lignite - LCO2 slurry feed - 1,000 #/MW-hr CO2
Plant Size: 578.4 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost $	H.O.& Fee	Process	Project	$	$/kW
1	COAL & SORBENT HANDLING											
1.1	Coal Receive & Unload	$6,612	$0	$3,267	$0	$0	$9,879	$865	$0	$2,149	$12,893	$22
1.2	Coal Stackout & Reclaim	$8,544	$0	$2,094	$0	$0	$10,639	$912	$0	$2,310	$13,861	$24
1.3	Coal Conveyors & Yd Crush	$5,815	$0	$690	$0	$0	$6,505	$550	$0	$1,411	$8,467	$15
1.4	Other Coal Handling	$2,078	$0	$479	$0	$0	$2,558	$219	$0	$555	$3,332	$6
1.5	Sorbent Receive & Unload	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.6	Sorbent Stackout & Reclaim	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.7	Sorbent Conveyors	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.8	Other Sorbent Handling	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.9	Coal & Sorbent Hnd.Foundations	$0	$4,406	$11,829	$0	$0	$16,235	$1,539	$0	$3,555	$21,329	$37
	SUBTOTAL 1.	**$23,050**	**$4,406**	**$18,360**	**$0**	**$0**	**$45,816**	**$4,085**	**$0**	**$9,980**	**$59,882**	**$104**
2	COAL & SORBENT PREP & FEED											
2.1	Coal Storage & Feed	$10,722	$0	$0	$0	$0	$10,722	$892	$0	$0	$11,614	$20
2.2	Coal Prep & Feed	$1,550	$0	$226	$0	$0	$1,776	$151	$0	$385	$2,312	$4
2.3	Coal Slurry Prep & Feed	$38,916	$6,572	$10,845	$0	$0	$56,333	$4,883	$3,155	$12,874	$77,245	$134
2.4	Misc.Coal Prep & Feed	$1,589	$1,149	$3,506	$0	$0	$6,245	$560	$0	$1,361	$8,166	$14
2.5	Sorbent Prep Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.6	Sorbent Storage & Feed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.7	Sorbent Injection System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.8	Booster Air Supply System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.9	Coal & Sorbent Feed Foundation	$0	$5,818	$5,128	$0	$0	$10,946	$1,022	$0	$2,393	$14,361	$25
	SUBTOTAL 2.	**$52,777**	**$13,539**	**$19,705**	**$0**	**$0**	**$86,022**	**$7,507**	**$3,155**	**$17,014**	**$113,698**	**$197**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$4,240	$7,363	$3,887	$0	$0	$15,491	$1,396	$0	$3,377	$20,264	$35
3.2	Water Makeup & Pretreating	$618	$64	$342	$0	$0	$1,024	$94	$0	$335	$1,454	$3
3.3	Other Feedwater Subsystems	$2,406	$793	$713	$0	$0	$3,912	$336	$0	$850	$5,097	$9
3.4	Service Water Systems	$360	$721	$2,501	$0	$0	$3,582	$338	$0	$1,176	$5,096	$9
3.5	Other Boiler Plant Systems	$1,942	$728	$1,804	$0	$0	$4,474	$406	$0	$976	$5,855	$10
3.6	FO Supply Sys & Nat Gas	$401	$758	$707	$0	$0	$1,867	$174	$0	$408	$2,450	$4
3.7	Waste Treatment Equipment	$840	$0	$521	$0	$0	$1,362	$130	$0	$448	$1,939	$3
3.8	Misc. Power Plant Equipment	$1,411	$190	$741	$0	$0	$2,342	$223	$0	$769	$3,334	$6
	SUBTOTAL 3.	**$12,220**	**$10,616**	**$11,217**	**$0**	**$0**	**$34,053**	**$3,097**	**$0**	**$8,339**	**$45,489**	**$79**

Table 12-8 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI **Report Date:** 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 8 - Lignite - LCO2 slurry feed - 1,000 #/MW-hr CO2
Plant Size: 578.4 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2012 ($x1000)

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 $/kW
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries (E-GAS)	$180,590	$0	$99,584	$0	$0	$280,174	$24,733	$39,439	$52,594	$396,940	$686
4.2	Syngas Cooling	w/4.1	$0	w/ 4.1	$0	$0	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$255,049	$0	w/equip.	$0	$0	$255,049	$23,854	$0	$27,890	$306,793	$530
4.4	LT Heat Recovery & FG Saturation	$32,490	$0	$12,288	$0	$0	$44,778	$4,223	$0	$9,800	$58,801	$102
4.5	Misc. Gasification Equipment	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.6	Other Gasification Equipment	$0	$2,267	$923	$0	$0	$3,189	$297	$0	$697	$4,183	$7
4.8	Major Component Rigging	w/4.1&4.2	$0	w/4.1&4.2	$0	$0	$0	$0	$0	$0	$0	$0
4.9	Gasification Foundations	$0	$14,193	$8,695	$0	$0	$22,888	$2,125	$0	$6,253	$31,266	$54
	SUBTOTAL 4.	**$468,130**	**$16,460**	**$121,489**	**$0**	**$0**	**$606,079**	**$55,231**	**$39,439**	**$97,235**	**$797,984**	**$1,380**
5A	GAS CLEANUP & PIPING											
5A.1	Double Stage Selexol	$76,387	$0	$64,818	$0	$0	$141,205	$13,245	$28,241	$36,538	$219,229	$379
5A.2	Elemental Sulfur Plant	$7,534	$1,476	$9,720	$0	$0	$18,730	$1,767	$0	$4,099	$24,596	$43
5A.3	Mercury Removal	$1,518	$0	$1,155	$0	$0	$2,672	$250	$134	$611	$3,668	$6
5A.4	Shift Reactors	$6,269	$0	$2,523	$0	$0	$8,792	$817	$0	$1,922	$11,531	$20
5A.5	Particulate Removal	w/4.1	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
5A.6	Blowback Gas Systems	$2,360	$397	$224	$0	$0	$2,980	$274	$0	$651	$3,906	$7
5A.7	Fuel Gas Piping	$0	$953	$630	$0	$0	$1,583	$138	$0	$344	$2,065	$4
5A.9	HGCU Foundations	$0	$849	$588	$0	$0	$1,437	$134	$0	$471	$2,042	$4
	SUBTOTAL 5A.	**$94,067**	**$3,675**	**$79,658**	**$0**	**$0**	**$177,400**	**$16,625**	**$28,375**	**$44,637**	**$267,036**	**$462**
5B	CO2 COMPRESSION											
5B.1	CO2 Removal System	w/ 5A.1	$0	w/ 5A.1	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$24,716	$0	$10,656	$0	$0	$35,372	$3,291	$0	$7,733	$46,396	$80
	SUBTOTAL 5B.	**$24,716**	**$0**	**$10,656**	**$0**	**$0**	**$35,372**	**$3,291**	**$0**	**$7,733**	**$46,396**	**$80**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$113,864	$0	$6,777	$0	$0	$120,642	$11,086	$12,064	$14,379	$158,171	$273
6.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$935	$1,111	$0	$0	$2,046	$192	$0	$671	$2,909	$5
	SUBTOTAL 6.	**$113,864**	**$935**	**$7,888**	**$0**	**$0**	**$122,688**	**$11,278**	**$12,064**	**$15,051**	**$161,081**	**$279**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$26,500	$0	$5,173	$0	$0	$31,673	$2,927	$0	$3,460	$38,059	$66
7.2	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$0	$1,359	$987	$0	$0	$2,346	$202	$0	$510	$3,057	$5
7.4	Stack	$2,698	$0	$1,014	$0	$0	$3,711	$345	$0	$406	$4,462	$8
7.9	HRSG,Duct & Stack Foundations	$0	$503	$519	$0	$0	$1,023	$96	$0	$335	$1,454	$3
	SUBTOTAL 7.	**$29,198**	**$1,863**	**$7,692**	**$0**	**$0**	**$38,753**	**$3,569**	**$0**	**$4,711**	**$47,032**	**$81**

Table 12-8 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 8 - Lignite - LCO2 slurry feed - 1,000 #/MW-hr CO2
Plant Size: 578.4 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$41,360	$0	$6,853	$0	$0	$48,213	$4,263	$0	$5,248	$57,723	$100
8.2	Turbine Plant Auxiliaries	$275	$0	$630	$0	$0	$905	$86	$0	$99	$1,089	$2
8.3	Condenser & Auxiliaries	$3,350	$0	$2,019	$0	$0	$5,369	$501	$0	$587	$6,457	$11
8.4	Steam Piping	$16,810	$0	$6,813	$0	$0	$23,623	$1,775	$0	$6,349	$31,747	$55
8.9	TG Foundations	$0	$1,269	$2,303	$0	$0	$3,572	$337	$0	$1,173	$5,082	$9
	SUBTOTAL 8.	**$61,795**	**$1,269**	**$18,618**	**$0**	**$0**	**$81,682**	**$6,962**	**$0**	**$13,456**	**$102,099**	**$177**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,560	$0	$1,080	$0	$0	$4,640	$430	$0	$761	$5,831	$10
9.2	Circulating Water Pumps	$1,687	$0	$116	$0	$0	$1,803	$156	$0	$294	$2,252	$4
9.3	Circ.Water System Auxiliaries	$155	$0	$22	$0	$0	$177	$16	$0	$29	$223	$0
9.4	Circ.Water Piping	$0	$6,851	$1,678	$0	$0	$8,529	$715	$0	$1,849	$11,092	$19
9.5	Make-up Water System	$361	$0	$501	$0	$0	$863	$79	$0	$188	$1,131	$2
9.6	Component Cooling Water Sys	$785	$939	$650	$0	$0	$2,374	$212	$0	$517	$3,103	$5
9.9	Circ.Water System Foundations	$0	$2,208	$4,030	$0	$0	$6,238	$589	$0	$2,048	$8,874	$15
	SUBTOTAL 9.	**$6,549**	**$9,997**	**$8,078**	**$0**	**$0**	**$24,624**	**$2,196**	**$0**	**$5,686**	**$32,506**	**$56**
10	ASH/SPENT SORBENT HANDLING SYS											
10.1	Slag Dewatering & Cooling	$30,345	$0	$14,965	$0	$0	$45,310	$4,222	$0	$4,953	$54,486	$94
10.2	Gasifier Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.3	Cleanup Ash Depressurization	w/10.1	w/10.1	w/10.1	$0	$0	$0	$0	$0	$0	$0	$0
10.4	High Temperature Ash Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.5	Other Ash Recovery Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.6	Ash Storage Silos	$969	$0	$1,055	$0	$0	$2,024	$190	$0	$332	$2,546	$4
10.7	Ash Transport & Feed Equipment	$1,331	$0	$314	$0	$0	$1,645	$146	$0	$269	$2,060	$4
10.8	Misc. Ash Handling Equipment	$2,008	$2,460	$735	$0	$0	$5,203	$480	$0	$852	$6,535	$11
10.9	Ash/Spent Sorbent Foundation	$0	$80	$108	$0	$0	$187	$18	$0	$62	$267	$0
	SUBTOTAL 10.	**$34,653**	**$2,540**	**$17,176**	**$0**	**$0**	**$54,369**	**$5,057**	**$0**	**$6,468**	**$65,894**	**$114**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$1,202	$0	$1,205	$0	$0	$2,407	$224	$0	$263	$2,895	$5
11.2	Station Service Equipment	$5,677	$0	$538	$0	$0	$6,215	$582	$0	$680	$7,476	$13
11.3	Switchgear & Motor Control	$10,478	$0	$2,006	$0	$0	$12,484	$1,173	$0	$2,049	$15,706	$27
11.4	Conduit & Cable Tray	$0	$5,423	$16,906	$0	$0	$22,329	$2,067	$0	$6,099	$30,494	$53
11.5	Wire & Cable	$0	$10,363	$6,433	$0	$0	$16,797	$1,143	$0	$4,485	$22,425	$39
11.6	Protective Equipment	$0	$834	$3,190	$0	$0	$4,023	$385	$0	$661	$5,070	$9
11.7	Standby Equipment	$284	$0	$292	$0	$0	$576	$55	$0	$95	$725	$1
11.8	Main Power Transformers	$23,545	$0	$186	$0	$0	$23,731	$1,832	$0	$3,834	$29,397	$51
11.9	Electrical Foundations	$0	$190	$531	$0	$0	$721	$68	$0	$237	$1,026	$2
	SUBTOTAL 11.	**$41,185**	**$16,809**	**$31,288**	**$0**	**$0**	**$89,283**	**$7,528**	**$0**	**$18,402**	**$115,213**	**$199**

Table 12-8 Capital Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions continued

Client: EPRI — Report Date: 2013-Jul-18
Project: LCO2/Coal Slurry Economics

TOTAL PLANT COST SUMMARY

Case: Case 8 - Lignite - LCO2 slurry feed - 1,000 #/MW-hr CO2
Plant Size: 578.4 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2012 ($x1000)

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 $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,369	$0	$961	$0	$0	$2,331	$220	$117	$400	$3,068	$5
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$315	$0	$212	$0	$0	$527	$50	$26	$121	$724	$1
12.7	Computer & Accessories	$7,305	$0	$246	$0	$0	$7,551	$705	$378	$863	$9,497	$16
12.8	Instrument Wiring & Tubing	$0	$2,839	$5,484	$0	$0	$8,323	$672	$416	$2,353	$11,763	$20
12.9	Other I & C Equipment	$4,883	$0	$2,492	$0	$0	$7,375	$696	$369	$1,266	$9,706	$17
	SUBTOTAL 12.	**$13,872**	**$2,839**	**$9,395**	**$0**	**$0**	**$26,106**	**$2,343**	**$1,305**	**$5,003**	**$34,757**	**$60**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$129	$2,988	$0	$0	$3,117	$301	$0	$1,026	$4,444	$8
13.2	Site Improvements	$0	$2,291	$3,305	$0	$0	$5,596	$554	$0	$1,845	$7,995	$14
13.3	Site Facilities	$4,106	$0	$4,702	$0	$0	$8,808	$876	$0	$2,905	$12,589	$22
	SUBTOTAL 13.	**$4,106**	**$2,420**	**$10,995**	**$0**	**$0**	**$17,521**	**$1,731**	**$0**	**$5,776**	**$25,028**	**$43**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$319	$186	$0	$0	$505	$44	$0	$110	$659	$1
14.2	Steam Turbine Building	$0	$3,172	$4,667	$0	$0	$7,839	$709	$0	$1,282	$9,830	$17
14.3	Administration Building	$0	$1,138	$852	$0	$0	$1,990	$175	$0	$325	$2,490	$4
14.4	Circulation Water Pumphouse	$0	$203	$111	$0	$0	$315	$27	$0	$51	$393	$1
14.5	Water Treatment Buildings	$0	$495	$499	$0	$0	$994	$88	$0	$162	$1,245	$2
14.6	Machine Shop	$0	$555	$392	$0	$0	$946	$83	$0	$154	$1,184	$2
14.7	Warehouse	$0	$895	$597	$0	$0	$1,492	$131	$0	$243	$1,866	$3
14.8	Other Buildings & Structures	$0	$536	$431	$0	$0	$967	$85	$0	$211	$1,263	$2
14.9	Waste Treating Building & Str.	$0	$1,199	$2,366	$0	$0	$3,565	$326	$0	$778	$4,669	$8
14.10	Coal Prep Building	$0	$24,364	$10,596	$0	$0	$34,960	$3,011	$0	$7,594	$45,565	$79
	SUBTOTAL 14.	**$0**	**$32,877**	**$20,697**	**$0**	**$0**	**$53,574**	**$4,679**	**$0**	**$10,911**	**$69,164**	**$120**
	TOTAL COST	**$980,183**	**$120,246**	**$392,912**	**$0**	**$0**	**$1,493,341**	**$135,179**	**$84,338**	**$270,400**	**$1,983,258**	**$3,429**

13. O&M Cost Estimates for Complete IGCC Plant

The production costs or O&M expenses pertain to those charges associated with operating and maintaining the plant over its expected life. These costs include:

- Operating labor
- Maintenance – material and labor
- Administrative and support labor
- Consumables
- Waste disposal

There are two components of O&M costs: fixed O&M, which is independent of power generation, and variable O&M, which is proportional to power generation.

Operating Labor

Operating labor cost was determined based on of the number of operators required for each specific case. The average base labor rate used to determine annual cost is $15/hr. The associated labor burden is estimated at 25 percent of the base labor rate.

Maintenance Material and Labor

Maintenance cost was evaluated on the basis of relationships of maintenance cost to initial capital cost. This represents a weighted analysis in which the individual cost relationships were considered for each major plant component or section.

Administrative and Support Labor

Labor administration and overhead charges are assessed at rate of 25 percent of the burdened operation and maintenance labor.

Consumables

The cost of consumables will be determined on the basis of individual rates of consumption, the unit cost of each specific consumable commodity, and the plant annual operating hours. Quantities for major consumables such as fuel and sorbent were taken from technology-specific heat and mass balance diagrams developed for each plant application. Other consumables were evaluated on the basis of the quantity required using reference data. The quantities for initial fills and daily consumables were calculated on an 80 percent operating capacity basis. The annual cost for the daily consumables was then adjusted to incorporate the annual plant operating basis, or capacity factor. Initial fills of the consumables, fuels and chemicals, are different from the initial chemical loadings, which are included with the equipment pricing in the capital cost.

Waste Disposal

Waste quantities and disposal costs were determined and evaluated similarly to the consumables. In this study, spent mercury catalyst and slag are considered with the disposal costs.

The O&M cost estimates for the full IGCC plant cases (two coals, two feed systems) are presented in the following tables.

Table 13-1 O&M Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 90% Capture

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Case 1 - PRB - water slurry feed, 90% Capture					Heat Rate-net (Btu/kWh):	10,836
					MWe-net:	537
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
Operating Labor Requirements(O.J.)per Shift:			Total			
	1 unit/mod.		Plant			
Skilled Operator	2.0		2.0			
Operator	10.0		10.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	3.0		3.0			
TOTAL-O.J.'s	16.0		16.0			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$7,470,528	$13.910
Maintenance Labor Cost					$20,638,155	$38.428
Administrative & Support Labor					$7,027,171	$13.085
Property Taxes and Insurance					$37,519,580	$69.862
TOTAL FIXED OPERATING COSTS					**$72,655,433**	**$135.285**
VARIABLE OPERATING COSTS						$/kWh-net
Maintenance Material Cost					**$38,196,221**	**$0.01015**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0	1,980	1.53	**$0**	**$883,370**	**$0.00023**
Chemicals						
MU & WT Chem. (lb)	0	11,796	0.24	$0	$842,058	$0.00022
Carbon (Mercury Removal) (lb)	128,744	35	1.48	$190,978	$15,278	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	16,421	15.00	704.61	$11,570,456	$3,085,455	$0.00082
Selexol Solution (gal)	512,650	1,540	33.58	$17,214,954	$15,100,401	$0.00401
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.87	185.42	$0	$46,914	$0.00001
Subtotal Chemicals				**$28,976,389**	**$19,090,106**	**$0.00507**
Other						
Supplemental Fuel (MBtu)	0	0	0.00	$0	$0	$0.00000
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	$0.00000
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	35	0.59	$0	$6,111	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	700	22.92	$0	$4,687,080	$0.00125
Subtotal Waste Disposal				**$0**	**$4,693,191**	**$0.00125**
By-products & Emissions						
Sulfur (tons)	0	58	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$28,976,389**	**$62,862,888**	**$0.01670**
Fuel (ton)	0	8,155	20.05	**$0**	**$47,743,748**	**$0.01269**

Table 13-2 O&M Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 90% Capture

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Case 2 - PRB - LCO2 slurry feed, 90% Capture					Heat Rate-net (Btu/kWh):	11,420
					MWe-net:	504
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
Operating Labor Requirements(O.J.)per Shift:			Total			
	1 unit/mod.		Plant			
Skilled Operator	2.0		2.0			
Operator	10.0		10.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	3.0		3.0			
TOTAL-O.J.'s	16.0		16.0			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$7,470,528	$14.818
Maintenance Labor Cost					$20,221,611	$40.110
Administrative & Support Labor					$6,923,035	$13.732
Property Taxes and Insurance					$37,800,541	$74.979
TOTAL FIXED OPERATING COSTS					**$72,415,715**	**$143.639**
VARIABLE OPERATING COSTS						
Maintenance Material Cost					**$37,571,406**	**$0.01063**
Consumables	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost		
Water (/1000 gallons)	0	2,729	1.53	**$0**	**$1,217,444**	**$0.00034**
Chemicals						
MU & WT Chem. (lb)	0	16,257	0.24	$0	$1,160,509	$0.00033
Carbon (Mercury Removal) (lb)	137,685	38	1.48	$204,241	$16,339	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	16,426	11.25	704.61	$11,573,979	$2,314,796	$0.00066
Selexol Solution (gal)	548,256	1,645	33.58	$18,410,615	$16,129,974	$0.00457
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.87	185.42	$0	$47,127	$0.00001
Subtotal Chemicals				**$30,188,836**	**$19,668,744**	**$0.00557**
Other						
Supplemental Fuel (MBtu)	0	0	0.00	$0	$0	$0.00000
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	$0.00000
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	38	0.59	$0	$6,536	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	693	22.92	$0	$4,635,925	$0.00131
Subtotal Waste Disposal				**$0**	**$4,642,460**	**$0.00131**
By-products & Emissions						
Sulfur (tons)	0	59	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$30,188,836**	**$63,100,055**	**$0.01786**
Fuel (ton)	0	8,066	20.05	**$0**	**$47,222,735**	**$0.01337**

Table 13-3 O&M Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 90% Capture

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Case 3 - Lignite - water slurry feed, 90% Capture					Heat Rate-net (Btu/kWh):	11,210
					MWe-net:	577
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
Operating Labor Requirements(O.J.) per Shift:	1 unit/mod.		Total Plant			
Skilled Operator	2.0		2.0			
Operator	10.0		10.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	3.0		3.0			
TOTAL-O.J.'s	16.0		16.0			
					Annual Cost $	Annual Unit Cost $/kW-net
Annual Operating Labor Cost					$7,470,528	$12.956
Maintenance Labor Cost					$24,946,315	$43.265
Administrative & Support Labor					$8,104,211	$14.055
Property Taxes and Insurance					$43,533,464	$75.500
TOTAL FIXED OPERATING COSTS					**$84,054,518**	**$145.776**
VARIABLE OPERATING COSTS						
Maintenance Material Cost					**$44,658,462**	**$0.01105**
Consumables	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost		
Water (/1000 gallons)	0	2,930	1.53	**$0**	**$1,307,387**	**$0.00032**
Chemicals						
MU & WT Chem. (lb)	0	17,458	0.24	$0	$1,246,246	$0.00031
Carbon (Mercury Removal) (lb)	136,970	38	1.48	$203,181	$16,254	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	18,105	16.53	704.61	$12,757,025	$3,401,873	$0.00084
Selexol Solution (gal)	545,408	1,636	33.58	$18,314,979	$16,041,725	$0.00397
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	1.06	185.42	$0	$57,527	$0.00001
Subtotal Chemicals				**$31,275,185**	**$20,763,625**	**$0.00514**
Other						
Supplemental Fuel (MBtu)	0	0	0.00	$0	$0	$0.00000
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	$0.00000
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	38	0.59	$0	$6,502	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	1,193	22.92	$0	$7,981,326	$0.00198
Subtotal Waste Disposal				**$0**	**$7,987,828**	**$0.00198**
By-products & Emissions						
Sulfur (tons)	0	73	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$31,275,185**	**$74,717,303**	**$0.01849**
Fuel (ton)	0	11,712	19.91	**$0**	**$68,090,289**	**$0.01685**

Table 13-4 O&M Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 90% Capture

INITIAL & ANNUAL O&M EXPENSES		
	Cost Base (Jun):	2012
Case 4 - Lignite - LCO2 slurry feed, 90% Capture	Heat Rate-net (Btu/kWh):	11,387
	MWe-net:	517
	Capacity Factor (%):	80

OPERATING & MAINTENANCE LABOR			
Operating Labor			
Operating Labor Rate(base):	41.00	$/hour	
Operating Labor Burden:	30.00	% of base	
Labor O-H Charge Rate:	25.00	% of labor	
Operating Labor Requirements(O.J.) per Shift:	1 unit/mod.		Total Plant
Skilled Operator	2.0		2.0
Operator	10.0		10.0
Foreman	1.0		1.0
Lab Tech's, etc.	3.0		3.0
TOTAL-O.J.'s	16.0		16.0

	Annual Cost $	Annual Unit Cost $/kW-net
Annual Operating Labor Cost	$7,470,528	$14.449
Maintenance Labor Cost	$22,968,229	$44.424
Administrative & Support Labor	$7,609,689	$14.718
Property Taxes and Insurance	$42,131,871	$81.489
TOTAL FIXED OPERATING COSTS	**$80,180,318**	**$155.079**

VARIABLE OPERATING COSTS	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost	Annual Cost $	$/kWh-net
Maintenance Material Cost					**$41,691,334**	**$0.01151**
Water (/1000 gallons)	0	2,981	1.53	**$0**	**$1,329,873**	**$0.00037**
Chemicals						
MU & WT Chem. (lb)	0	17,759	0.24	$0	$1,267,680	$0.00035
Carbon (Mercury Removal) (lb)	147,502	40	1.48	$218,804	$17,504	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	17,974	16.41	704.61	$12,664,721	$3,377,259	$0.00093
Selexol Solution (gal)	587,342	1,762	33.58	$19,723,136	$17,277,212	$0.00477
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	1.01	185.42	$0	$54,885	$0.00002
Subtotal Chemicals				**$32,606,661**	**$21,994,541**	**$0.00607**
Other						
Supplemental Fuel (MBtu)	0	0	0.00	$0	$0	$0.00000
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	$0.00000
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	40	0.59	$0	$7,002	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	1,115	22.92	$0	$7,460,299	$0.00206
Subtotal Waste Disposal				**$0**	**$7,467,300**	**$0.00206**
By-products & Emissions						
Sulfur (tons)	0	69	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$32,606,661**	**$72,483,048**	**$0.02000**
Fuel (ton)	0	10,956	19.91	**$0**	**$63,695,116**	**$0.01758**

Table 13-5 O&M Cost Summary – IGCC Plant with Water/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Case 5 - PRB - water slurry feed - 1,000 #/MH-hr CO2					Heat Rate-net (Btu/kWh):	9,130
					MWe-net:	607
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
Operating Labor Requirements(O.J.)per Shift:			Total			
	1 unit/mod.		Plant			
Skilled Operator	2.0		2.0			
Operator	10.0		10.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	3.0		3.0			
TOTAL-O.J.'s	16.0		16.0			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$7,470,528	$12.303
Maintenance Labor Cost					$19,482,721	$32.085
Administrative & Support Labor					$6,738,312	$11.097
Property Taxes and Insurance					$35,188,710	$57.950
TOTAL FIXED OPERATING COSTS					**$68,880,272**	**$113.435**
VARIABLE OPERATING COSTS						
Maintenance Material Cost					**$36,463,072**	**$0.00857**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0	2,299	1.53	**$0**	**$1,025,673**	**$0.00024**
Chemicals						
MU & WT Chem. (lb)	0	13,697	0.24	$0	$977,706	$0.00023
Carbon (Mercury Removal) (lb)	92,691	25	1.48	$137,498	$11,000	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	0	0.00	704.61	$0	$0	$0.00000
Selexol Solution (gal)	369,090	1,110	33.58	$12,394,163	$10,884,055	$0.00256
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.83	185.42	$0	$45,014	$0.00001
Subtotal Chemicals				**$12,531,660**	**$11,917,774**	**$0.00280**
Other						
Supplemental Fuel (MBtu)	0	0	0.00	$0	$0	$0.00000
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	$0.00000
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	25	0.59	$0	$4,400	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	668	22.92	$0	$4,470,975	$0.00105
Subtotal Waste Disposal				**$0**	**$4,475,375**	**$0.00105**
By-products & Emissions						
Sulfur (tons)	0	56	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$12,531,660**	**$53,881,894**	**$0.01266**
Fuel (ton)	0	7,779	20.05	**$0**	**$45,542,582**	**$0.01070**

Table 13-6 O&M Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, PRB Coal, 1000 lb/MWh CO_2 Emissions

INITIAL & ANNUAL O&M EXPENSES						
					Cost Base (Jun):	2012
Case 6 - PRB - LCO2 slurry feed - 1,000 #/MW-hr CO2					Heat Rate-net (Btu/kWh):	9,796
					MWe-net:	560
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
Operating Labor Requirements(O.J.)per Shift:			Total			
	1 unit/mod.		Plant			
Skilled Operator	2.0		2.0			
Operator	10.0		10.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	3.0		3.0			
TOTAL-O.J.'s	16.0		16.0			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$7,470,528	$13.341
Maintenance Labor Cost					$19,340,501	$34.539
Administrative & Support Labor					$6,702,757	$11.970
Property Taxes and Insurance					$35,727,429	$63.804
TOTAL FIXED OPERATING COSTS					**$69,241,216**	**$123.654**
VARIABLE OPERATING COSTS						
Maintenance Material Cost					**$36,249,742**	**$0.00924**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0	2,186	1.53	**$0**	**$975,240**	**$0.00025**
Chemicals						
MU & WT Chem. (lb)	0	13,023	0.24	$0	$929,632	$0.00024
Carbon (Mercury Removal) (lb)	107,640	29	1.48	$159,673	$12,774	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	3,990	2.73	704.61	$2,811,407	$562,281	$0.00014
Selexol Solution (gal)	428,623	1,286	33.58	$14,393,300	$12,609,816	$0.00321
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.83	185.42	$0	$45,120	$0.00001
Subtotal Chemicals				**$17,364,380**	**$14,159,623**	**$0.00361**
Other						
Supplemental Fuel (MBtu)	0	0	0.00	$0	$0	$0.00000
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	$0.00000
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	29	0.59	$0	$5,110	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	660	22.92	$0	$4,417,813	$0.00113
Subtotal Waste Disposal				**$0**	**$4,422,922**	**$0.00113**
By-products & Emissions						
Sulfur (tons)	0	56	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$17,364,380**	**$55,807,527**	**$0.01422**
Fuel (ton)	0	7,687	20.05	**$0**	**$45,001,547**	**$0.01147**

Table 13-7 O&M Cost Summary – IGCC Plant with Water/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions

INITIAL & ANNUAL O&M EXPENSES						
Case 7 - Lignite - water slurry feed 1,000#/MW-hr CO2					Cost Base (Jun):	2012
					Heat Rate-net (Btu/kWh):	9,690
					MWe-net:	641
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
Operating Labor Requirements(O.J.) per Shift:			Total			
	1 unit/mod.		Plant			
Skilled Operator	2.0		2.0			
Operator	10.0		10.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	3.0		3.0			
TOTAL-O.J.'s	16.0		16.0			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$7,470,528	$11.654
Maintenance Labor Cost					$23,584,772	$36.794
Administrative & Support Labor					$7,763,825	$12.112
Property Taxes and Insurance					$40,615,141	$63.362
TOTAL FIXED OPERATING COSTS					**$79,434,266**	**$123.922**
VARIABLE OPERATING COSTS						
Maintenance Material Cost					**$42,616,147**	**$0.00949**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0	2,677	1.53	**$0**	**$1,194,316**	**$0.00027**
Chemicals						
MU & WT Chem. (lb)	0	15,949	0.24	$0	$1,138,462	$0.00025
Carbon (Mercury Removal) (lb)	102,910	28	1.48	$152,656	$12,213	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	0	0.00	704.61	$0	$0	$0.00000
Selexol Solution (gal)	409,800	1,230	33.58	$13,761,218	$12,060,710	$0.00268
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.17	185.42	$0	$9,127	$0.00000
Subtotal Chemicals				**$13,913,874**	**$13,220,512**	**$0.00294**
Other						
Supplemental Fuel (MBtu)	0	0	0.00	$0	$0	$0.00000
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	$0.00000
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	28	0.59	$0	$4,885	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	1,146	22.92	$0	$7,667,810	$0.00171
Subtotal Waste Disposal				**$0**	**$7,672,695**	**$0.00171**
By-products & Emissions						
Sulfur (tons)	0	10	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$13,913,874**	**$64,703,670**	**$0.01440**
Fuel (ton)	0	11,256	19.91	**$0**	**$65,439,232**	**$0.01457**

Table 13-8 O&M Cost Summary – IGCC Plant with Liquid CO_2/Coal Slurry, North Dakota Lignite, 1000 lb/MWh CO_2 Emissions

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun):	2012
Case 8 - Lignite - LCO2 slurry feed - 1,000 #/MW-hr CO2					Heat Rate-net (Btu/kWh):	9,940
					MWe-net:	578
					Capacity Factor (%):	80
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	41.00	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
Operating Labor Requirements(O.J.) per Shift:	1 unit/mod.		Total Plant			
Skilled Operator	2.0		2.0			
Operator	10.0		10.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	3.0		3.0			
TOTAL-O.J.'s	16.0		16.0			
					Annual Cost $	Annual Unit Cost $/kW-net
Annual Operating Labor Cost					$7,470,528	$12.917
Maintenance Labor Cost					$21,889,061	$37.847
Administrative & Support Labor					$7,339,897	$12.691
Property Taxes and Insurance					$39,665,165	$68.583
TOTAL FIXED OPERATING COSTS					**$76,364,651**	**$132.039**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					**$40,072,581**	**$0.00989**
Consumables	Consumption Initial Fill	/Day	Unit Cost	Initial Fill Cost		
Water (/1000 gallons)	0	2,455	1.53	**$0**	**$1,095,379**	**$0.00027**
Chemicals						
MU & WT Chem. (lb)	0	14,627	0.24	$0	$1,044,152	$0.00026
Carbon (Mercury Removal) (lb)	110,870	30	1.48	$164,464	$13,157	$0.00000
COS Catalyst (m3)	0	0	3,424.27	$0	$0	$0.00000
Water Gas Shift Catalyst (ft3)	2,527	2.31	704.61	$1,780,558	$474,815	$0.00012
Selexol Solution (gal)	441,500	1,320	33.58	$14,825,714	$12,943,201	$0.00319
SCR Catalyst (m3)	0	0	0.00	$0	$0	$0.00000
Aqueous Ammonia (ton)	0	0	304.67	$0	$0	$0.00000
Claus Catalyst (ft3)	w/equip.	0.97	185.42	$0	$52,478	$0.00001
Subtotal Chemicals				**$16,770,736**	**$14,527,803**	**$0.00358**
Other						
Supplemental Fuel (MBtu)	0	0	0.00	$0	$0	$0.00000
Gases, N2 etc. (/100scf)	0	0	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	$0.00000
Waste Disposal						
Spent Mercury Catalyst (lb.)	0	30	0.59	$0	$5,263	$0.00000
Flyash (ton)	0	0	0.00	$0	$0	$0.00000
Slag (ton)	0	1,061	22.92	$0	$7,098,679	$0.00175
Subtotal Waste Disposal				**$0**	**$7,103,942**	**$0.00175**
By-products & Emissions						
Sulfur (tons)	0	66	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$16,770,736**	**$62,799,705**	**$0.01549**
Fuel (ton)	0	10,426	19.91	**$0**	**$60,611,519**	**$0.01495**

14. Performance Results for Complete IGCC Plant Cases

This section presents and discusses the performance results for the evaluation of the IGCC plant cases documented in this report. The performance for these cases is the result of a modeling effort using an EPRI ASPEN model modified by WorleyParsons, calibrated to gasifier performance calculated by Phillips 66. The ASPEN models used by DOE and its surrogates and the performance results obtained therefrom were not used because Phillips 66 has modified their gasifier model in recent years.

Performance Modeling

Some historical perspective is presented herein.

In the 2005 to 2007 time frame, the US Department of Energy, National Energy Technology Laboratory (NETL) commissioned an evaluation of different types of fossil fired power plant technology. The performance modeling for that study was done by Research and Development Solutions, LLC (RDS), then the prime off-site support contractor for DOE-NETL. The results of the related modeling effort were published as the Cost and Performance Baseline for Fossil Energy Plants [2].

The study was conducted in two parts as documented in Volume 1, Bituminous Coal and Natural Gas to Electricity, Final Report, November 2010 and Volume 3a, titled Low Rank Coal to Electricity: IGCC Cases. Volume 3a documents the firing of low rank coals (PRB and lignite) in different types of gasifiers that are integrated in an IGCC plant configuration. The Volume 3a report was completed in May 2011. It should be noted that Volume 3a did not include a case for the E-Gas™ gasifier firing lignite.

For the Low Rank Coal Cases documented in Volume 3a, the performance modeling was performed by Booz Allen Hamilton, the present incumbent site support contractor at NETL and the successor to RDS. Booz Allen succeeded RDS at the end of activities associated with fiscal year 2009.

All of the performance modeling discussed above involving the E-Gas™ gasifier (formerly the Conoco Phillips/Destec gasifier) was based on a ***water/coal slurry*** as feedstock. The present study evaluates the same gasifier supplied with a ***liquid CO_2/coal slurry.*** The liquid CO_2/coal slurry case modeling was performed in the following manner:

EPRI developed heat/mass balance models for the E-Gas™ gasifier firing a water/coal slurry. EPRI benchmarked these models against those presented in Volumes 1 and 3a of the Baseline Report to match the performance, using the same design inputs, ambient conditions, gas turbine characteristics, etc. The performance models were then adjusted to reflect ISO ambient conditions (the Low Rank report cases were performed at higher altitude and lower ambient temperatures relative to ISO conditions).

WorleyParsons then modified the EPRI ASPEN models to reflect current E-Gas™ gasifier performance expectations.

Understanding the history and chronology of the performance modeling is important because the thermal performance bears heavily on the determination of economic performance as expressed in the calculation of the COE. Direct comparisons of previous modeling results with the performance data presented herein should not be made due to the changes in the underlying models.

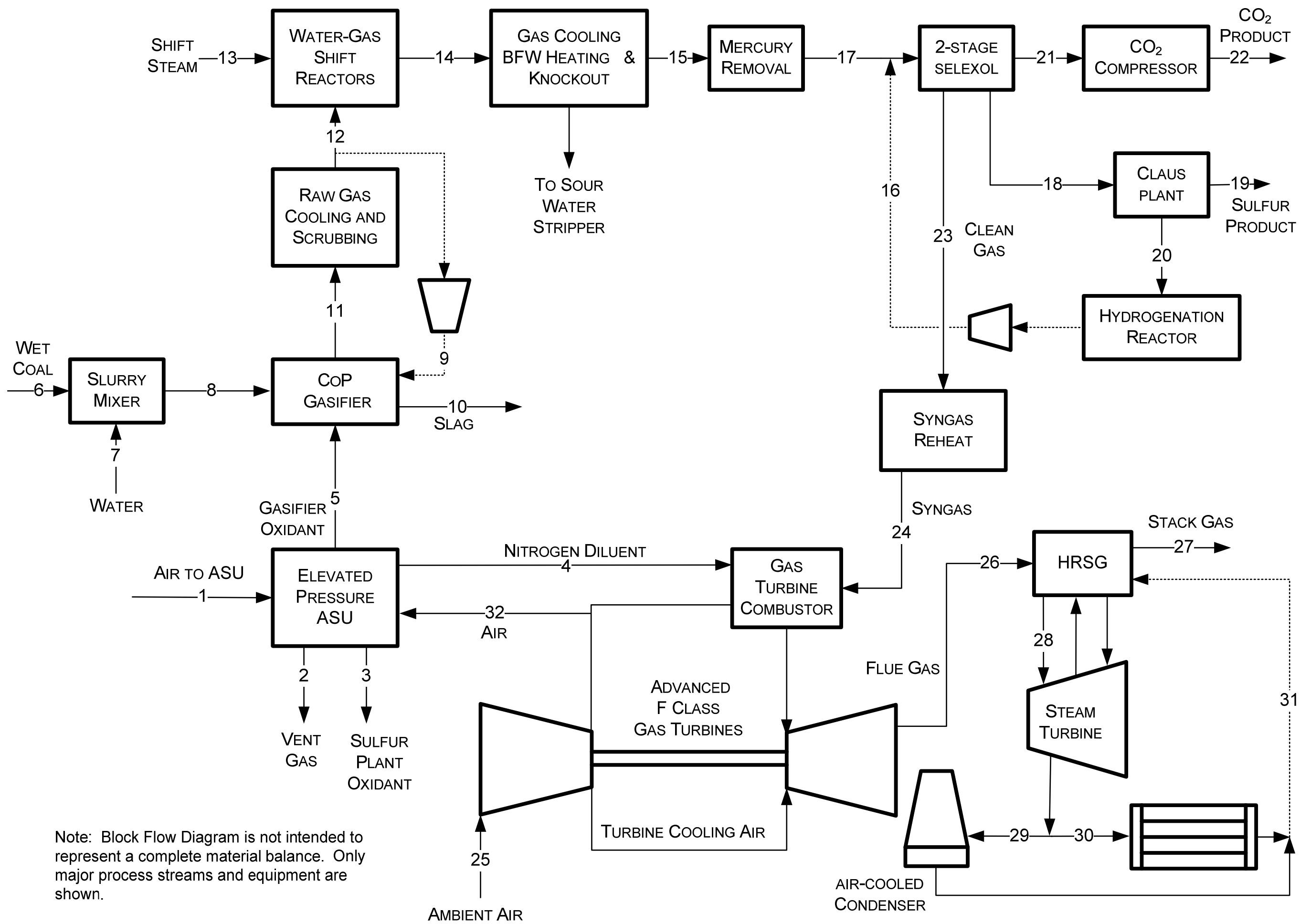
In performing the analysis, the various cases were bound by several physical constraints:

- Site ambient conditions for this report are set at ISO and are the same for all cases.
- Gas turbine generator electrical output is set at 232 MWe.
- CO_2 capture was set at 90 percent initially; a second series of cases were evaluated setting the capture rate to achieve a CO_2 emission rate of 1000 lb/MWh (gross power) in line with the recent proposed EPA guideline. The CO_2 capture rate varies somewhat from case to case but is generally in the range of 36-42%. Plant performance is significantly improved by reducing the capture rate to meet the 1000 lb CO_2/MWh emission value.

The principal governing parameter that calibrates the ASPEN model for the entire IGCC plant for each case is that the gas turbine power output is maintained at 232 MWe, which is based on the shaft torque limit for the GE Frame 7F engine that is an integral part of each case. This in turn dictates the syngas Btu input to the engine, which then influences a large number of upstream parameters in the gasifier and its ancillary systems. The ASPEN models for each case calculate the necessary stream parameters that derive from the above constraints.

Performance Results-Stream Data

Stream data for the principal nodes in the ASPEN model are presented in the following pages. The data is presented in metric and English units for the four cases of interest: PRB water slurry, PRB liquid CO_2 slurry, ND Lignite water slurry, and ND Lignite liquid CO_2 slurry.



Source: NETL

Figure 14-1 IGCC Process Flow Diagram

Table 14-1 Stream Data Tables – IGCC Plant with Water/PRB Coal Slurry

	1	2	3	4	5	6	7	9	10	11	12	13	14	15
V-L Mole Fraction														
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2217	0.0000	0.2421	0.2217	0.0000	0.0077	0.0112
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2356	0.0000	0.2572	0.2356	0.0000	0.3551	0.5139
CO_2	0.0003	0.0037	0.0000	0.0000	0.0000	0.0000	0.0000	0.1684	0.0000	0.1838	0.1684	0.0000	0.3019	0.4367
H_2O	0.0104	0.0620	0.0000	0.0000	0.0000	0.0000	1.0000	0.3344	0.0000	0.2794	0.3344	1.0000	0.3036	0.0014
CH_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0182	0.0000	0.0199	0.0182	0.0000	0.0145	0.0209
Ar	0.0094	0.0121	0.0315	0.0024	0.0315	0.0000	0.0000	0.0070	0.0000	0.0076	0.0070	0.0000	0.0055	0.0080
N_2	0.7722	0.8946	0.0182	0.9922	0.0182	0.0000	0.0000	0.0046	0.0000	0.0050	0.0046	0.0000	0.0037	0.0053
H_2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0021	0.0000	0.0023	0.0021	0.0000	0.0018	0.0025
COS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
NH_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0079	0.0000	0.0025	0.0079	0.0000	0.0063	0.0000
O_2	0.2077	0.0276	0.9503	0.0054	0.9503	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	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	0.0000
C	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	0.0000
S	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	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kgmole/hr)	29,683	2,641	70	20,604	6,221	0	6,853	2,587	0	30,957	31,218	8,127	39,345	27,187
V-L Flowrate (kg/hr)	856,491	73,183	2,257	578,208	200,178	0	123,454	54,412	0	659,814	656,602	146,413	803,017	584,136
Solids Flowrate (kg/hr)	0	0	0	0	0	308,250	0	0	26,474	26,474	0	0	0	0
Temperature (°C)	15	15	32	97	32	15	60	234	339	988	191	288	282	33
Pressure (MPa, abs)	0.10	0.11	0.86	3.07	0.86	0.10	0.10	5.52	4.26	4.27	4.23	4.14	3.80	3.67
Enthalpy (kJ/kg)*	-101.82	-679.22	6.53	74.87	6.53	---	-15,718.53	-7,940.85	---	-6,223.63	-8,009.12	-13,014.33	-9,102.44	-8,153.45
Density (kg/m3)	1.2	1.4	10.9	28.0	10.9	---	959.1	28.1	---	8.7	23.7	18.0	16.9	31.9
V-L Molecular Weight	28.854	27.707	32.176	28.063	32.176	---	18.015	21.033	---	21.314	21.033	18.015	20.410	21.486
V-L Flowrate (lbmole/hr)	65,440	5,823	155	45,423	13,716	0	15,108	5,703	0	68,248	68,824	17,917	86,741	59,937
V-L Flowrate (lb/hr)	1,888,240	161,341	4,976	1,274,730	441,317	0	272,170	119,958	0	1,454,640	1,447,560	322,786	1,770,350	1,287,800
Solids Flowrate (lb/hr)	0	0	0	0	0	679,576	0	0	58,365	58,365	0	0	0	0
Temperature (°F)	59	60	90	207	90	59	140	454	643	1,810	376	550	540	91
Pressure (psia)	14.7	16.4	125.0	445.0	125.0	14.7	14.7	800.0	618.0	620.0	613.0	600.0	551.0	532.0
Enthalpy (Btu/lb)*	-43.8	-292.0	2.8	32.2	2.8	---	-6,757.8	-3,413.9	---	-2,675.7	-3,443.3	-5,595.2	-3,913.3	-3,505.4
Density (lb/ft3)	0.076	0.086	0.682	1.746	0.682	---	59.875	1.756	---	0.543	1.480	1.126	1.058	1.994

* - Aspen Plus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm.

Table 14-1 Stream Data Tables – IGCC Plant with Water/PRB Coal Slurry (continued)

	16	17	18	19	20	22	23	24	25	26	27	28	31	32
V-L Mole Fraction														
CO	0.0002	0.0112	0.0000	0.0000	0.0214	0.0003	0.0195	0.0195	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2	0.0120	0.5139	0.0306	0.0000	0.0192	0.0061	0.8997	0.8997	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.7909	0.4367	0.6399	0.0000	0.4281	0.9915	0.0177	0.0177	0.0003	0.0084	0.0084	0.0000	0.0000	0.0003
H_2O	0.0034	0.0014	0.0081	0.0000	0.4319	0.0008	0.0019	0.0019	0.0104	0.1163	0.1163	1.0000	1.0000	0.0104
CH_4	0.0151	0.0209	0.0003	0.0000	0.0001	0.0008	0.0364	0.0364	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ar	0.0130	0.0080	0.0012	0.0000	0.0072	0.0005	0.0139	0.0139	0.0094	0.0090	0.0090	0.0000	0.0000	0.0094
N_2	0.1342	0.0053	0.0004	0.0000	0.0749	0.0001	0.0108	0.0108	0.7722	0.7609	0.7609	0.0000	0.0000	0.7722
H_2S	0.0311	0.0025	0.3193	0.0000	0.0168	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COS	0.0001	0.0000	0.0003	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NH_3	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	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2077	0.1054	0.1054	0.0000	0.0000	0.2077
SO_2	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C	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	0.0000
S	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kgmole/hr)	185	27,187	233	9	331	11,696	15,444	15,444	110,263	139,249	139,249	40,083	40,083	0
V-L Flowrate (kg/hr)	7,485	584,136	9,154	2,201	10,025	511,158	71,307	71,307	3,181,556	3,831,073	3,831,073	722,105	722,105	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	137	33	45	179	160	126	28	196	15	551	168	533	329	431
Pressure (MPa, abs)	5.50	3.60	0.18	0.14	0.14	15.27	3.47	3.28	0.10	0.10	0.10	12.51	12.64	1.86
Enthalpy (kJ/kg)*	-7,674.71	-8,153.45	-6,604.40	143.27	-8,954.43	-8,935.29	-2,656.88	-1,567.71	-101.82	-550.96	-988.33	-12,540.00	-13,296.43	330.30
Density (kg/m3)	70.5	31.4	2.7	5,277.2	1.2	268.7	6.3	3.9	1.2	0.4	0.8	36.8	75.2	9.2
V-L Molecular Weight	40.484	21.486	39.329	256.528	30.248	43.705	4.617	4.617	28.854	27.512	27.512	18.015	18.015	28.854
V-L Flowrate (lbmole/hr)	408	59,937	513	19	731	25,784	34,047	34,047	243,088	306,991	306,991	88,368	88,368	0
V-L Flowrate (lb/hr)	16,501	1,287,800	20,182	4,852	22,101	1,126,910	157,206	157,206	7,014,130	8,446,070	8,446,070	1,591,970	1,591,970	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0		0	0	0
Temperature (°F)	278	91	113	354	320	259	82	385	59	1,024	334	992	624	808
Pressure (psia)	798.0	522.0	26.0	20.4	20.4	2,214.7	504.0	475.0	14.7	15.2	15.2	1,814.7	1,834.0	269.9
Enthalpy (Btu/lb)*	-3,299.5	-3,505.4	-2,839.4	61.6	-3,849.7	-3,841.5	-1,142.3	-674.0	-43.8	-236.9	-424.9	-5,391.2	-5,716.4	142.0
Density (lb/ft3)	4.400	1.957	0.168	329.448	0.074	16.775	0.395	0.242	0.076	0.026	0.049	2.297	4.693	0.573

* - Aspen Plus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm.

Table 14-2 Stream Data Tables – IGCC Plant with Liquid CO_2/PRB Coal Slurry

	1	2	3	4	5	6	7	9	10	11	12	13	14	15
V-L Mole Fraction														
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.3558	0.0000	0.3783	0.3558	0.0000	0.0108	0.0146
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0185	0.2064	0.0000	0.2193	0.2063	0.0000	0.3480	0.4705
CO_2	0.0003	0.0064	0.0000	0.0000	0.0000	0.0000	0.9764	0.2117	0.0000	0.2250	0.2118	0.0000	0.3516	0.4753
H_2O	0.0104	0.1082	0.0000	0.0000	0.0000	0.0000	0.0005	0.1780	0.0000	0.1292	0.1780	1.0000	0.2589	0.0015
CH_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0033	0.0268	0.0000	0.0285	0.0268	0.0000	0.0171	0.0231
Ar	0.0094	0.0191	0.0315	0.0024	0.0315	0.0000	0.0006	0.0084	0.0000	0.0089	0.0084	0.0000	0.0054	0.0073
N_2	0.7722	0.8228	0.0182	0.9921	0.0182	0.0000	0.0001	0.0063	0.0000	0.0066	0.0062	0.0000	0.0040	0.0054
H_2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0025	0.0000	0.0026	0.0025	0.0000	0.0018	0.0024
COS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0003	0.0000	0.0000	0.0000
NH_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0039	0.0000	0.0012	0.0039	0.0000	0.0025	0.0000
O_2	0.2077	0.0435	0.9503	0.0055	0.9503	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	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	0.0000
C	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	0.0000
S	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	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kgmole/hr)	28,606	1,459	66	20,942	5,997	0	2,358	2,385	0	25,847	25,091	14,227	39,318	29,080
V-L Flowrate (kg/hr)	825,411	40,042	2,126	587,711	192,963	0	101,652	57,284	0	630,593	602,656	256,308	858,963	674,524
Solids Flowrate (kg/hr)	0	0	0	0	0	304,887	0	0	26,185	26,185	0	0	0	0
Temperature (°C)	15	17	32	97	32	15	-26	207	343	1,043	162	288	285	33
Pressure (MPa, abs)	0.10	0.11	0.86	3.07	0.86	0.10	1.96	5.52	4.26	4.27	4.12	4.14	3.79	3.65
Enthalpy (kJ/kg)*	-101.82	-1,202.03	6.53	74.86	6.53	---	-9,228.44	-6,759.14	---	-5,161.10	-6,822.20	-13,014.33	-8,910.97	-8,233.22
Density (kg/m3)	1.2	1.4	10.9	28.0	10.9	---	262.3	33.3	---	9.5	27.7	18.0	17.9	34.6
V-L Molecular Weight	28.854	27.436	32.176	28.064	32.176	---	43.113	24.016	---	24.397	24.019	18.015	21.846	23.196
V-L Flowrate (lbmole/hr)	63,066	3,218	146	46,169	13,221	0	5,198	5,258	0	56,984	55,316	31,366	86,682	64,110
V-L Flowrate (lb/hr)	1,819,720	88,277	4,688	1,295,680	425,410	0	224,105	126,289	0	1,390,220	1,328,630	565,063	1,893,690	1,487,070
Solids Flowrate (lb/hr)	0	0	0	0	0	672,160	0	0	57,728	57,728	0	0	0	0
Temperature (°F)	59	63	90	207	90	59	-15	405	650	1,910	324	550	546	91
Pressure (psia)	14.7	16.4	125.0	445.0	125.0	14.7	284.5	800.0	618.0	620.0	598.0	600.0	549.0	530.0
Enthalpy (Btu/lb)*	-43.8	-516.8	2.8	32.2	2.8	---	-3,967.5	-2,905.9	---	-2,218.9	-2,933.0	-5,595.2	-3,831.0	-3,539.6
Density (lb/ft3)	0.076	0.088	0.682	1.746	0.682	---	16.377	2.081	---	0.595	1.730	1.126	1.119	2.162

* - Aspen Plus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm.

Table 14-2 Stream Data Tables – IGCC Plant with Liquid CO_2/PRB Coal Slurry (continued)

	16	17	18	19	20	22	23	24	25	26	27	28	31	32
V-L Mole Fraction														
CO	0.0003	0.0146	0.0000	0.0000	0.0194	0.0003	0.0279	0.0279	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2	0.0356	0.4705	0.1192	0.0000	0.0478	0.0099	0.8982	0.8982	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.7038	0.4753	0.3164	0.0000	0.2449	0.9869	0.0060	0.0060	0.0003	0.0085	0.0085	0.0000	0.0000	0.0003
H_2O	0.0034	0.0015	0.1623	0.0000	0.6100	0.0007	0.0001	0.0001	0.0104	0.1144	0.1144	1.0000	1.0000	0.0104
CH_4	0.0860	0.0231	0.0445	0.0000	0.0174	0.0018	0.0428	0.0428	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ar	0.0266	0.0073	0.0013	0.0000	0.0095	0.0003	0.0138	0.0138	0.0094	0.0089	0.0089	0.0000	0.0000	0.0094
N_2	0.1313	0.0054	0.0004	0.0000	0.0468	0.0001	0.0111	0.0111	0.7722	0.7630	0.7630	0.0000	0.0000	0.7722
H_2S	0.0131	0.0024	0.3554	0.0000	0.0037	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0004	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NH_3	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	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2077	0.1052	0.1052	0.0000	0.0000	0.2077
SO_2	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C	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	0.0000
S	0.0000	0.0000	0.0000	1.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kgmole/hr)	90	29,080	197	9	253	11,583	15,032	15,032	110,263	139,314	139,314	39,701	39,701	0
V-L Flowrate (kg/hr)	3,397	674,524	5,916	2,211	6,203	504,068	66,280	66,280	3,181,556	3,835,550	3,835,550	715,224	715,224	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	138	32	45	178	160	126	28	196	15	551	166	533	336	431
Pressure (MPa, abs)	5.50	3.59	0.18	0.14	0.14	15.27	3.46	3.28	0.10	0.10	0.10	12.51	13.89	1.86
Enthalpy (kJ/kg)*	-7,462.96	-8,233.64	-5,974.87	142.67	-9,891.12	-8,932.06	-1,945.59	-817.98	-101.82	-535.12	-974.24	-12,540.00	-13,326.33	330.30
Density (kg/m3)	64.5	34.0	2.3	5,278.8	1.0	266.1	6.0	3.7	1.2	0.4	0.8	36.8	86.0	9.2
V-L Molecular Weight	37.681	23.196	30.006	256.528	24.550	43.519	4.409	4.409	28.854	27.532	27.532	18.015	18.015	28.854
V-L Flowrate (lbmole/hr)	199	64,110	435	19	557	25,536	33,140	33,140	243,088	307,134	307,134	87,526	87,526	0
V-L Flowrate (lb/hr)	7,489	1,487,070	13,042	4,875	13,675	1,111,280	146,123	146,123	7,014,130	8,455,940	8,455,940	1,576,800	1,576,800	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0		0	0	0
Temperature (°F)	280	90	113	353	320	259	82	385	59	1,024	330	992	637	808
Pressure (psia)	798.0	520.0	26.0	20.4	20.4	2,214.7	502.0	475.0	14.7	15.2	15.2	1,814.7	2,015.0	269.9
Enthalpy (Btu/lb)*	-3,208.5	-3,539.8	-2,568.7	61.3	-4,252.4	-3,840.1	-836.5	-351.7	-43.8	-230.1	-418.8	-5,391.2	-5,729.3	142.0
Density (lb/ft3)	4.027	2.124	0.145	329.542	0.060	16.613	0.375	0.231	0.076	0.026	0.049	2.297	5.367	0.573

* - Aspen Plus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm.

Table 14-3 Stream Data Tables – IGCC Plant with Water/ND Lignite Coal Slurry

	1	2	3	4	5	6	7	9	10	11	12	13	14	15
V-L Mole Fraction														
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1722	0.0000	0.1745	0.1722	0.0000	0.0065	0.0098
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2006	0.0000	0.2034	0.2006	0.0000	0.3200	0.4787
CO_2	0.0003	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000	0.1917	0.0000	0.1942	0.1917	0.0000	0.3123	0.4670
H_2O	0.0104	0.0228	0.0000	0.0000	0.0000	0.0000	1.0000	0.3991	0.0000	0.3936	0.3991	1.0000	0.3293	0.0015
CH_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0178	0.0000	0.0180	0.0178	0.0000	0.0156	0.0233
Ar	0.0094	0.0062	0.0315	0.0023	0.0315	0.0000	0.0000	0.0073	0.0000	0.0074	0.0073	0.0000	0.0064	0.0096
N_2	0.7722	0.9556	0.0182	0.9925	0.0182	0.0000	0.0000	0.0054	0.0000	0.0055	0.0054	0.0000	0.0047	0.0071
H_2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0022	0.0000	0.0022	0.0022	0.0000	0.0020	0.0030
COS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
NH_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0036	0.0000	0.0010	0.0036	0.0000	0.0032	0.0000
O_2	0.2077	0.0141	0.9503	0.0052	0.9503	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	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	0.0000
C	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	0.0000
S	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	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kgmole/hr)	37,915	9,195	80	20,497	7,956	0	8,852	4,169	0	41,505	37,904	5,372	43,275	28,926
V-L Flowrate (kg/hr)	1,094,019	256,878	2,583	575,164	255,993	0	159,479	90,566	0	903,851	823,488	96,772	920,257	661,764
Solids Flowrate (kg/hr)	0	0	0	0	0	442,895	0	0	45,084	45,084	0	0	0	0
Temperature (°C)	15	14	32	97	32	15	60	245	339	1,017	199	363	281	33
Pressure (MPa, abs)	0.10	0.11	0.86	3.07	0.86	0.10	0.10	5.52	4.30	4.31	4.16	4.14	3.80	3.67
Enthalpy (kJ/kg)*	-101.82	-242.41	6.53	74.87	6.53	---	-15,718.53	-8,552.77	---	-7,093.95	-8,623.39	-12,841.86	-9,214.18	-8,182.43
Density (kg/m3)	1.2	1.3	10.9	28.0	10.9	---	959.1	28.8	---	8.8	24.0	15.2	17.8	34.2
V-L Molecular Weight	28.854	27.937	32.176	28.061	32.176	---	18.015	21.726	---	21.777	21.726	18.015	21.265	22.878
V-L Flowrate (lbmole/hr)	83,589	20,271	177	45,188	17,540	0	19,516	9,190	0	91,503	83,563	11,843	95,406	63,770
V-L Flowrate (lb/hr)	2,411,900	566,318	5,694	1,268,020	564,368	0	351,591	199,663	0	1,992,650	1,815,480	213,346	2,028,820	1,458,940
Solids Flowrate (lb/hr)	0	0	0	0	0	976,416	0	0	99,393	99,393	0	0	0	0
Temperature (°F)	59	56	90	207	90	59	140	472	643	1,862	390	685	538	91
Pressure (psia)	14.7	16.4	125.0	445.0	125.0	14.7	14.7	800.0	623.0	625.0	603.0	600.0	551.0	532.0
Enthalpy (Btu/lb)*	-43.8	-104.2	2.8	32.2	2.8	---	-6,757.8	-3,677.0	---	-3,049.8	-3,707.4	-5,521.0	-3,961.4	-3,517.8
Density (lb/ft3)	0.076	0.083	0.682	1.746	0.682	---	59.875	1.799	---	0.546	1.497	0.948	1.109	2.138

* - Aspen Plus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm.

Table 14-3 Stream Data Tables – IGCC Plant with Water/ND Lignite Coal Slurry (continued)

	16	17	18	19	20	22	23	24	25	26	27	28	31	32
V-L Mole Fraction														
CO	0.0003	0.0098	0.0000	0.0000	0.0307	0.0002	0.0181	0.0181	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2	0.0276	0.4787	0.0999	0.0000	0.0403	0.0120	0.8824	0.8824	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.7606	0.4670	0.3537	0.0000	0.2663	0.9843	0.0263	0.0263	0.0003	0.0098	0.0098	0.0000	0.0000	0.0003
H_2O	0.0034	0.0015	0.1332	0.0000	0.5907	0.0007	0.0001	0.0001	0.0104	0.1156	0.1156	1.0000	1.0000	0.0104
CH_4	0.0470	0.0233	0.0368	0.0000	0.0110	0.0021	0.0414	0.0414	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ar	0.0215	0.0096	0.0014	0.0000	0.0082	0.0005	0.0177	0.0177	0.0094	0.0094	0.0094	0.0000	0.0000	0.0094
N_2	0.1095	0.0071	0.0005	0.0000	0.0418	0.0001	0.0140	0.0140	0.7722	0.7601	0.7601	0.0000	0.0000	0.7722
H_2S	0.0302	0.0030	0.3742	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0003	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NH_3	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	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2077	0.1051	0.1051	0.0000	0.0000	0.2077
SO_2	0.0000	0.0000	0.0000	0.0000	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C	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	0.0000
S	0.0000	0.0000	0.0000	1.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kgmole/hr)	115	28,926	238	11	302	13,315	15,488	15,488	110,263	139,309	139,309	48,453	48,453	0
V-L Flowrate (kg/hr)	4,526	661,764	7,522	2,747	7,755	578,113	80,651	80,651	3,181,556	3,837,373	3,837,373	872,893	872,893	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	137	33	45	179	160	126	28	196	15	551	143	533	329	431
Pressure (MPa, abs)	5.50	3.60	0.18	0.14	0.14	15.27	3.47	3.28	0.10	0.10	0.10	12.51	12.64	1.86
Enthalpy (kJ/kg)*	-7,660.06	-8,182.43	-5,864.86	143.28	-9,743.00	-8,928.31	-2,957.73	-1,994.94	-101.82	-562.87	-1,026.55	-12,540.00	-13,296.43	330.30
Density (kg/m3)	68.1	33.6	2.4	5,277.2	1.0	264.7	7.1	4.4	1.2	0.4	0.8	36.8	75.2	9.2
V-L Molecular Weight	39.307	22.878	31.600	256.528	25.696	43.419	5.207	5.207	28.854	27.546	27.546	18.015	18.015	28.854
V-L Flowrate (lbmole/hr)	254	63,770	525	24	665	29,354	34,145	34,145	243,088	307,123	307,123	106,820	106,820	0
V-L Flowrate (lb/hr)	9,978	1,458,940	16,583	6,056	17,096	1,274,520	177,806	177,806	7,014,130	8,459,960	8,459,960	1,924,400	1,924,400	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0		0	0	0
Temperature (°F)	278	91	113	354	320	260	82	385	59	1,024	290	992	624	808
Pressure (psia)	798.0	522.0	26.0	20.4	20.4	2,214.7	504.0	475.0	14.7	15.2	15.2	1,814.7	1,834.0	269.9
Enthalpy (Btu/lb)*	-3,293.2	-3,517.8	-2,521.4	61.6	-4,188.7	-3,838.5	-1,271.6	-857.7	-43.8	-242.0	-441.3	-5,391.2	-5,716.4	142.0
Density (lb/ft3)	4.253	2.098	0.148	329.447	0.063	16.524	0.445	0.273	0.076	0.026	0.052	2.297	4.693	0.573

* - Aspen Plus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm.

Table 14-4 Stream Data Tables – IGCC Plant with Liquid CO_2/ND Lignite Coal Slurry

	1	2	3	4	5	6	7	9	10	11	12	13	14	15
V-L Mole Fraction														
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.2597	0.0000	0.2932	0.2597	0.0000	0.0100	0.0138
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0160	0.1616	0.0000	0.1824	0.1616	0.0000	0.3249	0.4487
CO_2	0.0003	0.0019	0.0000	0.0000	0.0000	0.0000	0.9799	0.2112	0.0000	0.2384	0.2112	0.0000	0.3646	0.5033
H_2O	0.0104	0.0324	0.0000	0.0000	0.0000	0.0000	0.0005	0.3250	0.0000	0.2480	0.3250	1.0000	0.2668	0.0014
CH_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0024	0.0159	0.0000	0.0179	0.0159	0.0000	0.0126	0.0175
Ar	0.0094	0.0076	0.0315	0.0023	0.0315	0.0000	0.0006	0.0072	0.0000	0.0081	0.0072	0.0000	0.0057	0.0079
N_2	0.7722	0.9407	0.0182	0.9924	0.0182	0.0000	0.0002	0.0043	0.0000	0.0049	0.0043	0.0000	0.0034	0.0048
H_2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0022	0.0000	0.0024	0.0022	0.0000	0.0019	0.0026
COS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0003	0.0002	0.0000	0.0000	0.0000
NH_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0126	0.0000	0.0043	0.0126	0.0000	0.0100	0.0000
O_2	0.2077	0.0174	0.9503	0.0053	0.9503	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	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	0.0000
C	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	0.0000
S	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	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kgmole/hr)	33,110	5,646	50	20,283	6,968	0	3,190	3,445	0	33,346	34,201	8,821	43,022	31,153
V-L Flowrate (kg/hr)	955,374	157,421	1,609	569,177	224,198	0	137,970	81,704	0	815,686	811,227	158,912	970,139	756,619
Solids Flowrate (kg/hr)	0	0	0	0	0	413,954	0	0	42,138	42,138	0	0	0	0
Temperature (°C)	15	14	32	97	32	15	-26	234	339	1,017	189	288	284	33
Pressure (MPa, abs)	0.10	0.11	0.86	3.07	0.86	0.10	1.96	5.52	4.30	4.31	4.16	4.14	3.80	3.67
Enthalpy (kJ/kg)*	-101.82	-348.61	6.53	74.87	6.53	---	-9,235.75	-7,836.11	---	-6,135.24	-7,900.16	-13,014.33	-8,940.20	-8,297.65
Density (kg/m3)	1.2	1.3	10.9	28.0	10.9	---	296.7	31.9	---	9.8	26.5	18.0	18.6	36.6
V-L Molecular Weight	28.854	27.881	32.176	28.062	32.176	---	43.247	23.716	---	24.461	23.719	18.015	22.550	24.287
V-L Flowrate (lbmole/hr)	72,996	12,448	110	44,715	15,361	0	7,033	7,595	0	73,516	75,401	19,447	94,848	68,680
V-L Flowrate (lb/hr)	2,106,240	347,055	3,548	1,254,820	494,271	0	304,172	180,126	0	1,798,280	1,788,450	350,340	2,138,790	1,668,060
Solids Flowrate (lb/hr)	0	0	0	0	0	912,612	0	0	92,898	92,898	0	0	0	0
Temperature (°F)	59	57	90	207	90	59	-15	453	643	1,862	372	550	544	91
Pressure (psia)	14.7	16.4	125.0	445.0	125.0	14.7	284.5	800.0	623.0	625.0	603.0	600.0	551.0	532.0
Enthalpy (Btu/lb)*	-43.8	-149.9	2.8	32.2	2.8	---	-3,970.7	-3,368.9	---	-2,637.7	-3,396.5	-5,595.2	-3,843.6	-3,567.3
Density (lb/ft3)	0.076	0.084	0.682	1.746	0.682	---	18.524	1.990	---	0.614	1.657	1.126	1.163	2.285

* - Aspen Plus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm.

Table 14-4 Stream Data Tables – IGCC Plant with Liquid CO_2/ND Lignite Coal Slurry (continued)

	16	17	18	19	20	22	23	24	25	26	27	28	31	32
V-L Mole Fraction														
CO	0.0005	0.0138	0.0000	0.0000	0.1373	0.0003	0.0273	0.0273	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2	0.0083	0.4487	0.0291	0.0000	0.0218	0.0090	0.8824	0.8824	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.8112	0.5033	0.8158	0.0000	0.4871	0.9882	0.0241	0.0241	0.0003	0.0100	0.0100	0.0000	0.0000	0.0003
H_2O	0.0034	0.0014	0.0423	0.0000	0.2617	0.0007	0.0001	0.0001	0.0104	0.1154	0.1154	1.0000	1.0000	0.0104
CH_4	0.0510	0.0175	0.0091	0.0000	0.0010	0.0014	0.0353	0.0353	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ar	0.0040	0.0079	0.0004	0.0000	0.0029	0.0003	0.0155	0.0155	0.0094	0.0092	0.0092	0.0000	0.0000	0.0094
N_2	0.1171	0.0048	0.0001	0.0000	0.0850	0.0001	0.0153	0.0153	0.7722	0.7599	0.7599	0.0000	0.0000	0.7722
H_2S	0.0045	0.0026	0.1030	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NH_3	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	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2077	0.1055	0.1055	0.0000	0.0000	0.2077
SO_2	0.0000	0.0000	0.0000	0.0000	0.0029	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C	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	0.0000
S	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kgmole/hr)	788	31,153	824	10	1,087	12,290	15,637	15,637	110,263	139,105	139,105	43,422	43,422	0
V-L Flowrate (kg/hr)	31,698	756,619	33,310	2,611	35,612	535,425	81,609	81,609	3,181,556	3,832,343	3,832,343	782,256	782,256	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	136	33	45	181	160	126	28	196	15	552	152	533	329	431
Pressure (MPa, abs)	5.50	3.60	0.18	0.14	0.14	15.27	3.47	3.28	0.10	0.10	0.10	12.51	12.64	1.86
Enthalpy (kJ/kg)*	-7,980.10	-8,297.65	-8,251.02	144.71	-8,128.98	-8,933.24	-2,890.96	-1,932.95	-101.82	-562.90	-1,018.60	-12,540.00	-13,296.43	330.30
Density (kg/m3)	70.3	35.9	2.8	5,273.6	1.3	266.8	7.1	4.4	1.2	0.4	0.8	36.8	75.2	9.2
V-L Molecular Weight	40.205	24.287	40.408	256.528	32.761	43.568	5.219	5.219	28.854	27.550	27.550	18.015	18.015	28.854
V-L Flowrate (lbmole/hr)	1,738	68,680	1,817	22	2,397	27,094	34,474	34,474	243,088	306,674	306,674	95,729	95,729	0
V-L Flowrate (lb/hr)	69,882	1,668,060	73,435	5,757	78,511	1,180,410	179,918	179,918	7,014,130	8,448,870	8,448,870	1,724,580	1,724,580	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0		0	0	0
Temperature (°F)	276	91	113	358	320	259	82	385	59	1,026	305	992	624	808
Pressure (psia)	798.0	522.0	26.0	20.4	20.4	2,214.7	504.0	475.0	14.7	15.2	15.2	1,814.7	1,834.0	269.9
Enthalpy (Btu/lb)*	-3,430.8	-3,567.3	-3,547.3	62.2	-3,494.8	-3,840.6	-1,242.9	-831.0	-43.8	-242.0	-437.9	-5,391.2	-5,716.4	142.0
Density (lb/ft3)	4.388	2.243	0.172	329.221	0.080	16.655	0.446	0.273	0.076	0.026	0.051	2.297	4.693	0.573

* - Aspen Plus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm.

In addition to the stream data presented for each case, a table is presented that allows easy comparison between cases of specific parameters of interest. This table is presented in Table 14-5 below for 90% capture of CO_2.

Table 14-5 Comparison Performance Data for the Four Study Cases

	PRB-H_2O Slurry	PRB-CO_2 Slurry	Lign.-H_2O Slurry	Lign.-CO_2 Slurry
Air Separation Unit				
Oxygen, tpd	5,355	5,161	6,840	5,973
Aux Load, MWe	75	71.3	95.6	84.3
Capital Cost MM$	241	237	289	263
Oxygen Usage (lb/lb Coal)	0.657	0.640	0.584	0.545
Oxygen Usage (lb/MMBtu Coal)	76.7	74.7	88.2	82.4
Coal Preparation and Feed				
Coal Feed, lb/hr X 1000	679.5	672.2	976.4	912.6
Coal Feed, MMBtu/hr	5,819	5,756	6,464	6,041
Auxiliary Load, kWe	4,020	18,160	5,220	23,870
Capital Cost, MM$	66	75	82	87
Coal Slurry Water				
Slurry Water Flow (lb/hr)	272,170	n/a	351,420	n/a
Water Flow for Slurry (lb/lb Coal)	0.401	n/a	0.360	n/a
Slurry Water Flow (lb/MMBtu Coal)	46.8	n/a	54.4	n/a
CO_2 System (Note 2)				
CO_2 Required for Coal Feed, tpd	n/a	2,689	n/a	3,650
CO_2 Refrigeration and Recompression				
Chiller/ReComp Load, kWe	n/a	10,120	n/a	13,280
Chiller/ReComp Load (kW/lb Coal)	n/a	0.015	n/a	0.015
Chiller/ReComp Load (kW/MMBtu Coal)	n/a	1.758	n/a	2.198
Process Q Lost Due to Chiller (Btu/hr)	n/a	48,650,000	n/a	66,633,200
Process Q Lost to Chiller (Btu/hr/lb Coal)	n/a	72	n/a	73
Gas Cooler Duty, MMBtu/hr	761	691	1,112	891
Cold Gas Efficiency, %	74.5	75.9	68.6	72.1
Steam to Shift				
Steam to Shift, lb/hr	322,786	565,063	197,444	350,340
Shift Steam (lb/lb Coal)	0.475	0.841	0.202	0.384
Shift Steam (lb/MMBtu Coal)	55	98	31	58
Shift Steam to Dry Gas Ratio	0.9	0.9	0.9	0.9
Shift CO Conversion	95.6	95.1	95.7	95.2
CTG Simple Cycle Efficiency, %	37.1	37.2	36.6	36.6
Throttle Steam, lb/hr	1,592,000	1,577,000	1,922,000	1,724,600

Performance Results-Integrated Plant Thermal Performance

The table below presents the performance for each case evaluated based on 90 percent capture. Some of the data (power values) are rounded to three figures.

Table 14-6 Selected Performance Data for the Four Study Cases - 90% Capture

	Case 1	Case 2	Case 3	Case 4
Coal type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Coal In (lb/hr)	679,576	672,160	976,416	912,612
Gross MW	741	718	822	762
ST Output (MW)	277	254	358	298
GT Output @ ISO (MW) - each	232	232	232	232
Aux Load (MW)	204	213	246	245
Net Plant Power	537	504	577	517
Net Plant Heat Rate (Btu/kWh)	10,836	11,420	11,210	11,680

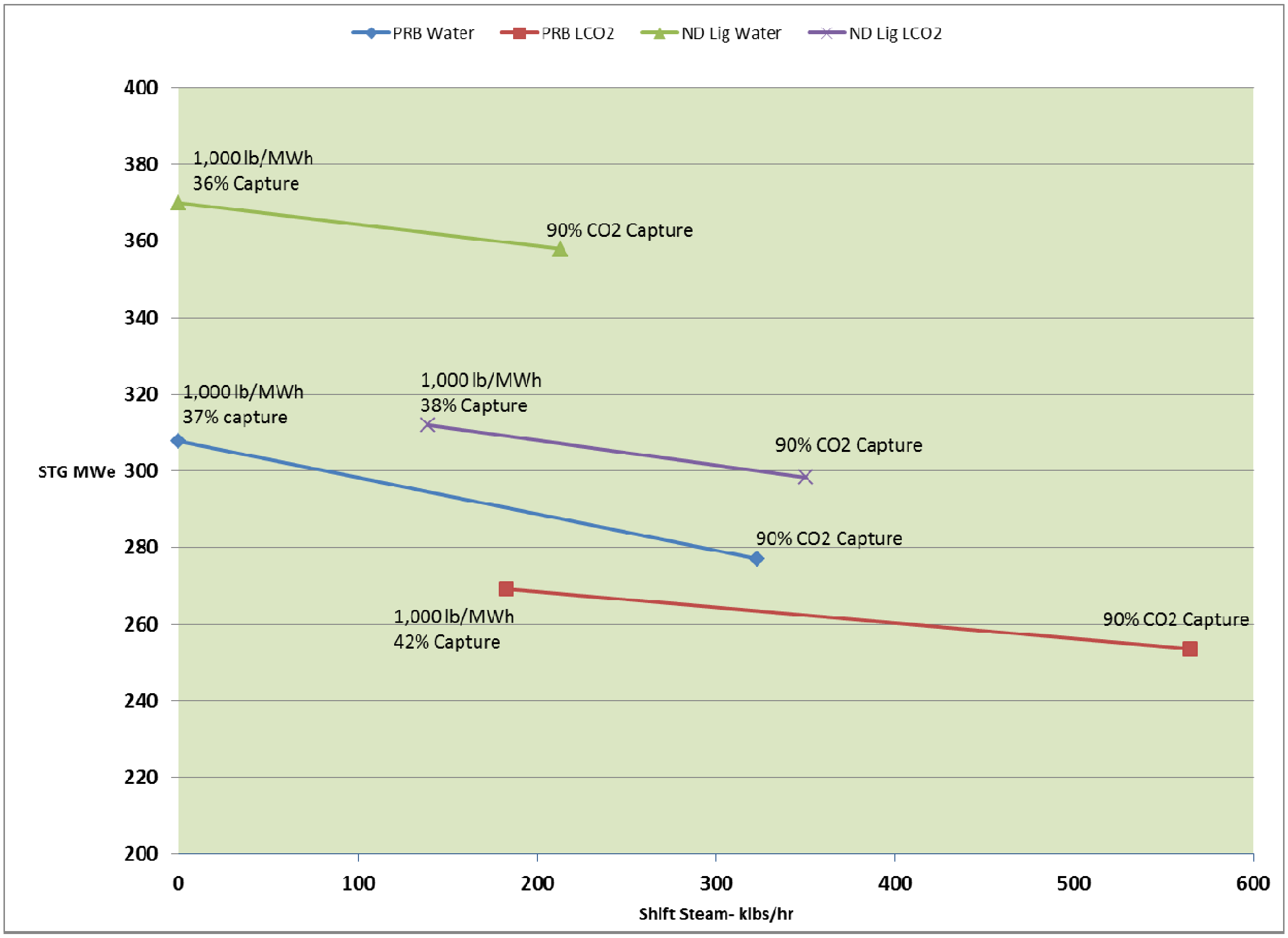
The next table presents performance for the 1000 lb CO_2/MWh (gross) cases. The percent capture varies somewhat from case to case. Overall, plant performance improves significantly with the reduction in the burden of capturing a significant portion of the CO_2 produced.

Table 14-7 Selected Performance Data for the Four Study Cases - 1000 lb CO_2/MWh (gross)

	Case 5	Case 6	Case 7	Case 8
Coal type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Coal In (lb/hr)	647,225	640,544	938,000	868,831
Percent CO_2 Capture	37	42	36	38
Gross MW	772	733	834	776
ST Output (MW)	308	269	370	312
GT Output @ ISO (MW) - each	232	232	232	232
Aux Load (MW)	163	173	195	199
Net Plant Power	609	560	640	577
Net Plant Heat Rate (Btu/kWh)	9,130	9,796	9,700	9,960

The water slurry cases inherently introduce more hydrogen to the gasifier than do the CO_2 slurry cases as a consequence of the hydrogen in the water that constitutes the slurry. Therefore, the water slurry cases tend to require less shift steam, resulting in increased steam turbine generator output. The reduction in CO_2 capture to meet the 1000 lb CO_2/MWh (gross) EPA target further reduces the amount of shift steam, and also reduces auxiliary loads to a significant degree. Overall plant performance is improved commensurately.

Figure 14-2 below shows the relationship for the eight cases evaluated.



Source: WorleyParsons Group, Inc.

Figure 14-2 Effect of Shift Reactor Steam Flow on Steam Generator Power Output

15. Cost of Electricity Estimates for Complete IGCC Plant

This section presents the financial results of the evaluation of the liquid CO_2/coal slurry feed IGCC cases compared with the water/coal slurry cases. The financial results are calculated based on the methodology described in Cost Estimation methodology for NETL Assessments of Power Plant Performance [3].

The calculation includes an amortization of the plant capital costs along with a complete accounting of O&M costs, and fuel costs. For this report, first year cost of electricity is presented, although the methodology also enables calculation of a levelized COE.

The capital costs used in the COE calculation begin with the Total Plant Costs (TPC) presented in Section 12 of this report. Owners Costs and Financing costs are added to the TPC costs to arrive at Total Overnight Cost (TOC) which is the basis for the annualized capital cost component of the total COE. Additional financing costs are included by factoring the TOC to generate the Total As-Spent Cost (TASC) estimate.

Table 15-1 below summarizes the build-up of costs from TPC to TASC and shows the major categories of Owners Costs for the 90% capture cases. Table 15-2 presents the same data for the cases with CO_2 emissions limited to 1000 lb CO_2/MWh (gross).

Table 15-1 Capital Cost Build-up - 90% Capture Cases

	Case 1	Case 2	Case 3	Case 4
Coal Type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Total Plant Cost (TPC)	$1,876	$1,890	$2,177	$2,107
Pre-Production Cost	$63	$63	$73	$70
Inventory Capital	$23	$23	$29	$28
Initial Catalysts & Chemicals	$29	$30	$31	$33
Land	$1	$1	$1	$1
Other Owners Cost	$281	$284	$327	$314
Financing Costs	$51	$51	$59	$57
Total Overnight Cost	$2,324	$2,342	$2,697	$2,612
TASC Multiplier	1.14	1.14	1.14	1.14
Total As Spent Cost	$2,649	$2,670	$3,074	$2,977

Costs in million 2012 dollars

Table 15-2 Capital Cost Build-up - 1000 lb CO_2/MWh Capture Cases

	Case 5	Case 6	Case 7	Case 8
Coal Type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Total Plant Cost (TPC)	$1,759	$1,786	$2,031	$1,983
Pre-Production Cost	$59	$59	$68	$66
Inventory Capital	$21	$21	$27	$26
Initial Catalysts & Chemicals	$13	$17	$14	$17
Land	$1	$1	$1	$1
Other Owners Cost	$264	$268	$305	$297
Financing Costs	$48	$48	$55	$54
Total Overnight Cost	$2,164	$2,202	$2,500	$2,444
TASC Multiplier	1.14	1.14	1.14	1.14
Total As Spent Cost	$2,467	$2,510	$2,850	$2,788

Costs in million 2012 dollars

With the Total Overnight Cost values calculated, and having the O&M costs and fuel costs from the appropriate tabulation, the DOE methodology enables calculation of the all-in COE values for each case. Table 15-3 presents the values of COE and other pertinent parameters of interest. Table 15-4 presents values for the 1000 lb CO_2/MWh cases.

Table 15-3 Cost of Electricity and Cost of CO_2 Captured/Avoided - 90% Capture

	Case 1	Case 2	Case 3	Case 4
Coal Type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Net MWe	537.1	504.2	576.6	517.0
Total Overnight Cost $/kW	4,327	4,645	4,677	5,051
COE, $/MWh	125.26	133.92	138.90	149.09
COE, $/MWh (inc. T&S)	147.52	157.29	153.86	164.88
CO_2 emitted, lb/MWh (gross)	169.0	172.1	168.6	162.0
Cost of CO_2 Captured, $/metric ton	54.48	60.54	58.08	64.86
Cost of CO_2 Avoided, $/metric ton	98.56	112.34	90.37	105.02

Costs in 2012 dollars

Cost of CO_2 captured/avoided reference is baseline supercritical pulverized coal plant without CO_2 capture using the same fuel.

Table 15-4 Cost of Electricity and Cost of CO_2 Captured/Avoided - 1000 lb CO_2/MWh (gross)

	Case 5	Case 6	Case 7	Case 8
Coal Type	PRB	PRB	Lignite	Lignite
Slurry Type	Water Slurry	CO_2 Slurry	Water Slurry	CO_2 Slurry
Net MWe	607.2	560.0	641.0	578.4
Total Overnight Cost $/kW	3,564	3,932	3,900	4,225
COE, $/MWh	102.60	112.90	115.66	124.05
COE, $/MWh (inc. T&S)	109.85	121.37	121.21	129.86
CO_2 emitted, lb/MWh (gross)	1000	1000	1000	1000
Cost of CO_2 Captured, $/metric ton	94.32	109.03	92.72	110.57
Cost of CO_2 Avoided, $/metric ton	129.52	181.72	124.80	161.75

Costs in 2012 dollars

16. Evaluation Results Summary

It is feasible to design and build a practical liquid CO_2/coal slurry preparation and feed system for use with an E-Gas™ gasifier. The capital costs and operating costs of the liquid CO_2/coal slurry prep and feed system are the same order of magnitude but somewhat larger than those for a water/coal slurry system of comparable capacity.

The liquid CO_2 prep and feed system may be assembled using commercially available components, and the system occupies about the same amount of physical space as that for a water slurry system. Electrical loads to drive the equipment comprising the liquid CO_2 system are significantly greater than those for a water slurry system, but these are still relatively modest compared to other IGCC plant auxiliary loads.

Overall plant performance results show reduced output and reduced efficiency for PRB coal-liquid CO_2 slurry feed to the gasifier relative to water slurry feed. For this study, the gasifier cold gas efficiency is increased slightly with a liquid CO_2 slurry feed, relative to a similar case with a water slurry feed. This increase in cold gas efficiency is more than compensated for by an increase in low pressure steam taken from the steam turbine to drive the water gas shift reactions and also by the increased parasitic loads associated with the coal and CO_2 chilling equipment necessary to produce the slurry.

In comparing the results of this study with previous studies, it is noted that the water content of the slurry used herein is reduced relative to previous studies. This reduction in water content tends to increase cold gas efficiency by reducing the burden of evaporating and heating the added water content. As noted in section 14 of this report, the slurry composition used in this report was set by Phillips 66 in their gasifier model simulations.

Comparing the results of this study with those of previous studies must consider the slurry composition (as discussed above) and also the other bases that governed this study which include, but may not be limited to, the following:

- Gas turbine model represented by a Frame 7 machine operating at 232 MWe
- Ambient conditions, as stated elsewhere in this report
- Accounting for all auxiliary loads, including ASU, refrigeration for chilling CO_2 and coal, etc.
- Shift steam consequences for steam turbine generator power generation

The ND Lignite cases using liquid CO_2 slurry feed also exhibit similar reductions in net output and efficiency relative to water slurry feed.

For both fuels and both types of slurry feed, performance improves significantly when CO_2 capture is limited to achieving 1000 lb CO_2/MWh (gross) emissions compared to setting a flat 90% capture rate.

Some of the performance differences observed herein can be attributed to the variation in the amount of steam that must be diverted from the steam turbine expansion path (thereby reducing power generation). For the liquid CO_2 slurry cases, this is likely the consequence of increased need for steam to drive the water-gas shift reaction.

The capital costs for the complete plant are higher for the liquid CO_2 slurry cases for PRB coal, but about the same for ND lignite relative to the corresponding water slurry cases for each coal. On a dollar/kWe basis, both fuels exhibit increased costs, principally due to the reduction in net power production.

The cost of electricity computed for the liquid CO_2/coal slurry cases is greater for PRB coal relative to the water slurry case; this is also the case for the liquid CO_2/ND Lignite case vs. the water/ND Lignite case.

Of prime significance in evaluating the results of this study is the fact that the CO_2 capture rate was initially set at 90 percent of the total amount produced. This is in line with virtually all prior studies of power generating plants firing coal. However, recent events have forced consideration of a different value for setting CO_2 capture. In March 2012, proposed EPA rules established a metric of 1000 lb CO_2 emitted per MWh of gross electric generation. This is equivalent to a capture rate of between 36 percent and 42 percent of CO_2 produced for the cases evaluated in this study.

Setting the CO_2 emissions at 1,000 lb/MWh in lieu of the flat 90 percent capture rate used in the DOE Baseline study significantly impacts the results, with a meaningful improvement for the performance of all cases. Less steam is extracted from power production to drive the shift reaction necessary to produce hydrogen in the syngas delivered to the gas turbine. In addition, less steam is extracted from the steam turbine for regeneration of the amine CO_2 capture sorbent. Both of these factors result in a significant increase in gross electric generation. Finally, CO_2 compression loads are significantly reduced, enabling the net electric generation to increase further.

It does not appear that there is any overall benefit to using liquid CO_2/coal slurries for feeding low rank coals to the E-Gas™ gasifier. Any incidental benefits in improved cold gas efficiency are more than compensated for in higher overall plant costs, increased complexity, and reduced power output and efficiency. The comparison of results of this study and previous published studies is presented in the following section.

17. Comparison of Study Results with Previous Analyses

The results of the ASPEN analyses are compared with other published analyses in Table 17-1 below, which presents cold gas efficiencies and selected other parameters for the various studies recently completed. Several points are evident in this table.

1. There is a very small increase in cold gas efficiencies with the ASPEN model that was used in this report as compared with the MIT study [4] and the 2010 EPRI study [5]. The model that was used here was based in part on a revised Phillips 66 ASPEN model of the E-Gas™ technology battery limit. The new model differed significantly from the model that was used in the earlier DOE Low Rank Coal baseline report in that the oxygen use for the water slurry feed was reduced and the cold gas efficiency increased from 70% to 74%. Coal concentration in the water slurry was significantly higher in the newer model and was almost the same as for the CO_2 slurry.

2. Auxiliary loads were somewhat higher for the CO_2 slurry in the present study mainly due to refrigeration loads.

3. The Phillips 66 model showed relatively small reductions in oxygen usage when CO_2 slurry was used instead of water slurry, contrary to the MIT study and the earlier EPRI reports.

4. Though there was a sizable increase in shift steam for the CO_2 slurry, the shift steam differential between the water and CO_2 slurry cases is about the same for PRB in both this study and the MIT study.

5. There is a sizable increase in net efficiency for the CO_2 slurry feed in the MIT analyses. The impact of a significant increase in cold gas efficiency when CO_2 is used, as was the case for the MIT and earlier EPRI programs, is to produce more syngas Btu's per unit of coal. This contributes significantly to increased plant efficiencies. Factors contributing to the cold gas efficiency include the syngas composition, water content in the slurry, and oxygen consumption. For the present study, these factors were provided by Phillips 66. The performance parameters of the gasifier were established by Phillips 66 and provided to the study team. These parameters also included data on the amount of oxygen feed required. The water slurry PRB coal loading of 53wt% was specified by Phillips 66. Rheology testing did not indicate that such a high concentration was achievable for the PRB coal. Also the oxygen consumption, as specified by Phillips 66, was much less for the water slurry than that used in the MIT and DOE analyses. This lower oxygen consumption for the coal water slurry also contributed to a lower efficiency differential between the water and the CO_2 slurry than expected based on other studies.

The cold gas efficiency of the higher water content slurry in Case S4B is lower than the cold gas efficiency resulting from analyses of the 53wt% bone dry slurry. The slurry and gasifier performance appears to benefit from a lower slurry water content and a lower oxygen feed requirement compared with previous studies. As Phillips 66 have recently modified their gasifier model, these parameter changes were accepted as valid for this study.

The selection of water content of the coal slurry has an impact on the performance of the gasifier and also of the entire integrated system. In general, it is believed to be advantageous to minimize the water content of the coal slurry, since the water must be evaporated and superheated in the gasifier to the gas discharge temperature of the gasifier. This energy must be provided by feeding additional coal to the unit. The added energy is recovered in the hot gas cooler and made available to the steam cycle as intermediate pressure steam which is heated to the design temperature 565°C (1050°F) for reheat steam in the gas turbine HRSG.

The additional water content of the syngas at the gasifier exit is also beneficial as it helps drive the water-gas shift reaction in the shift reactor. Reducing the amount of shift steam will result in higher net generation. This is because more steam is available to expand to condenser pressure in the LP section of the steam turbine.

The cold gas efficiency of a higher water content slurry is lower than the cold gas efficiency resulting from the use of a lower water content slurry. Coal content somewhat greater than 47% may be possible by utilizing additives to promote good flow characteristics and minimize the tendency of PRB coal to agglomerate if the coal concentration gets too high. The coal content of the water and carbon dioxide slurries for the lignite case are almost the same. However, increasing the coal content differential between the two slurries, as seems possible from the rheology testing, could result in an additional efficiency increase with the CO_2 slurries of 1% or more. Additional rheology testing on these coals would help in maximizing the slurry coal concentrations. In summary, the results of these analyses are clearly model-dependent and demonstrate the need for additional testing and analyses.

It is not possible to state with any accuracy the overall net impact of coal slurry concentration on system performance, as virtually all stream parameters will change in a complete ASPEN modeling of the system. This report presents specific results based on the stated inputs. The results do not indicate any significant advantage for firing an E-Gas™ gasifier with a liquid CO_2 slurry relative to a water slurry. However as indicated in Table 17-1, the use of liquid CO_2 may prove a significant advantage in a different type of gasifier (i.e., single stage entrained flow with radiant quench section), and a more detailed technical and economic evaluation should be conducted to validate the advantage.

Table 17-1 Comparison of ASPEN Performance Analyses of Coal Slurry Feed Options (90% CO_2 Capture)

ASPEN analysis	EPRI-1		MIT								DOE S4B	EPRI/WP			
Gasifier	**GE**		**GE-Radiant Quench**				**GE-Full Quench**				**E-Gas™**	**E-Gas™**			
Coal	**PRB**		**PRB**		**Lignite**		**PRB**		**Lignite**		**PRB**	**PRB**		**Lignite**	
Slurry	H_2O	CO_2	H_2O	CO_2	H_2O	CO_2	H_2O	CO_2	H_2O	CO_2	H_2O	H_2O	CO_2	H_2O	CO_2
Slurry bone dry solids wt%	48.3	55	51	58	48	54	51	58	48	54	48.7	53	55.7	47	48
CGE (%HHV)	[N2]	7	63	75	60	72	63	75	60	72	70	74.4	76	67.8	71.4
Aux. Power as % of gross power	31	28.9	28[N1]	26[N1]	31[N1]	27[N1]	28[N1]	26[N1]	31[N1]	27[N1]	29.2	27.5	29.7	28	30.4
Shift steam (lb/lbcoal)	NA	NA	0	0.45	0	0.215	0	0	0	0	0.27	0.475	0.845	0.218	0.384
O_2 (lb/lbcoal)	NA	NA	0.798	0.695	0.646	0.539	0.798	0.695	0.646	0.539	0.719	0.613	0.598	0.546	0.512
% reduction of O_2	[N2]	13	[N2]	13	[N2]	17	[N2]	13	[N2]	17	[N2]	[N2]	2.4	[N2]	6.2
Net efficiency (%)	29.8	32.6	26.5	29	24.2	28.4	22.7	27	20	25	30.4	31.5	29.9	31.5	30

N1 = Includes specific power consumption of ASU, Selexol, and CO_2 compression train only

N2 = Data not available

18. Technology Development

Based on results of analyses to date, some key questions remain unanswered that can validate the potential improvement of gasifier performance using liquid carbon dioxide slurries in place of coal water slurries for low rank coal. These include:

- What are the best estimates of the effect of using CO_2 instead of water on syngas composition and cold gas efficiency?
- What is the optimum slurry preparation and slurry handling system with respect to energy usage and capital/operating costs?
- What is the potential for improved atomization on gasifier performance including single pass carbon conversion?

In order to provide a path to answering these questions, a technology development roadmap has been developed. This roadmap includes the following sequence of analyses.

18.1 Resolving Some Fundamental Issues

All analyses to date show that benefits of using CO_2 instead of water as the slurrying medium depend on an increase in cold gas efficiency, which is dependent on several factors including the relative solids contents of the coal-water slurries. A significantly higher coal content in the Low Rank Coal (LRC)/CO_2 slurries relative to the LRC/water slurries leads to an increase in the cold gas efficiency and therefore more heat output from the gasified coal. Additional factors are the gas compositions of the syngas produced with LRC/CO_2 slurries and the LRC/water slurries. These depend on several factors including reaction kinetics and carbon conversion. Although there is data available on some coals for the coal loadings for both types of slurries, primarily generated by the collaboration between DIPE and Columbia University's Combustion and Catalysis Laboratory (CCL), there is not sufficient data on the maximum possible coal concentration in the slurries for the coals selected for the various studies that have been performed. Additionally, there is a paucity of data on the effect of the CO_2 on the syngas compositions, gasification kinetics, and carbon conversion and the little that does exist has been produced by DIPE and CCL in the recent past. In order to address these issues, some laboratory analyses should be initiated which include:

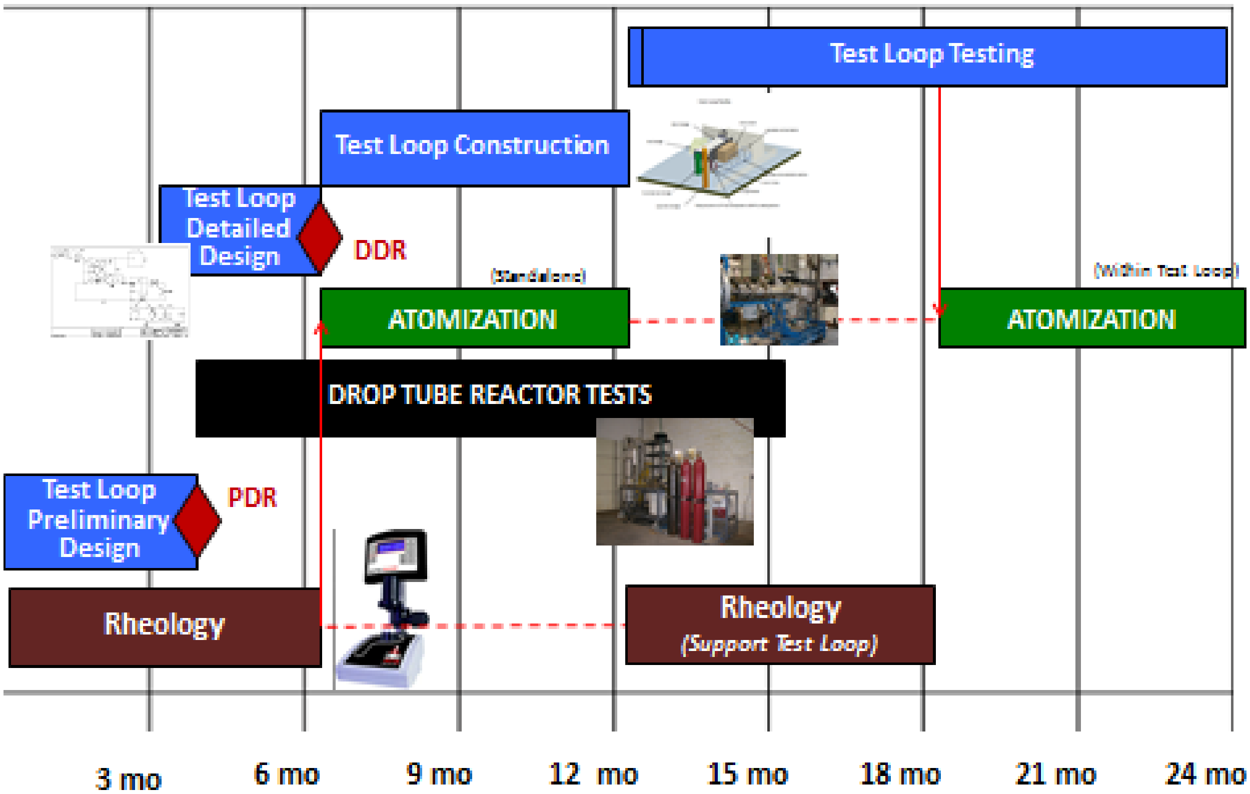
- A rheological test program to quantitatively evaluate slurry preparation and handling for LRC/CO_2 including experiments to evaluate preparation systems. Comparisons with coal water slurries using the same series of test coals should be included.
- An experimental program on CO_2 assisted gasification in order to obtain the most relevant experimental data from drop tube furnace studies to aid in verifying the potential advantages of direct feed of LRC/liquid CO_2 as gasifier feedstocks.

18.2 Operational Aspects of Using LRC-CO_2 Slurries

The equipment and systems used in preparing, handling, and gasifying LRC/CO_2 slurries are essential elements in determining the costs, energy usage, and potential benefits of using LRC/CO_2 slurries in place of LRC/water slurries. In order to best assess these factors, the additional elements of the technology development roadmap should include:

- An experimental program using a flow test loop to evaluate equipment performance and handling properties of LRC/liquid CO_2 slurries for gasifier feedstocks on a scale sufficient to predict full scale operating parameters.
- Spray atomization studies necessary to evaluate the effect of atomization properties of LRC/liquid CO_2 slurries that could be significantly different than those of water/coal slurries.

These elements are discussed in more detail in the sections that follow, and the following chart shows the flow of the roadmap elements.



Source: John Dooher, Adelphi University

Figure 18-1 Technology development roadmap flow sheet

18.2.1 Rheology Testing

There are regions in the carbon dioxide phase diagram which could be important to have information on depending on the method of approach for preparing the slurry and in plant handling dictated by the gasification systems being analyzed. For example, if the gasifier pressure is less than 6.89 MPa (1000 psig), it may be important to drop the slurry feed pressure in the nozzle feed line which could put the system close to the liquid–vapor saturation curve. Also, there could be pressure drops due to unanticipated plant conditions. This could lead to potential line clogging if vaporization of the liquid CO_2 occurs. Unstable rheology was noted in some samples when this condition was present. Also, some of the more advanced concepts that are being looked at for slurry preparation rely on increasing the CO_2 vapor pressure to liquefy the carbon dioxide/coal system. In addition, near the supercritical saturation point, the liquid density should drop significantly which would affect volumetric packing and therefore the slurry viscosity. More data points in the supercritical region are needed to examine this potential effect as it was not observed in the first series of laboratory tests. It would also be important to evaluate the rheology at the point of maximum coal concentration, where it should become unstable, to see just what is the maximum pumpable coal concentration is, especially in light of claims in the ADL report of concentrations observed above maximum packing [6]. It will also be important to conduct supporting laboratory rheology tests at conditions expected in actual plant operation. Tests at low temperatures in the -23.3°C to -28.9°C (-10°F to -20°F) region as well as in the supercritical region and at higher temperatures should be conducted.

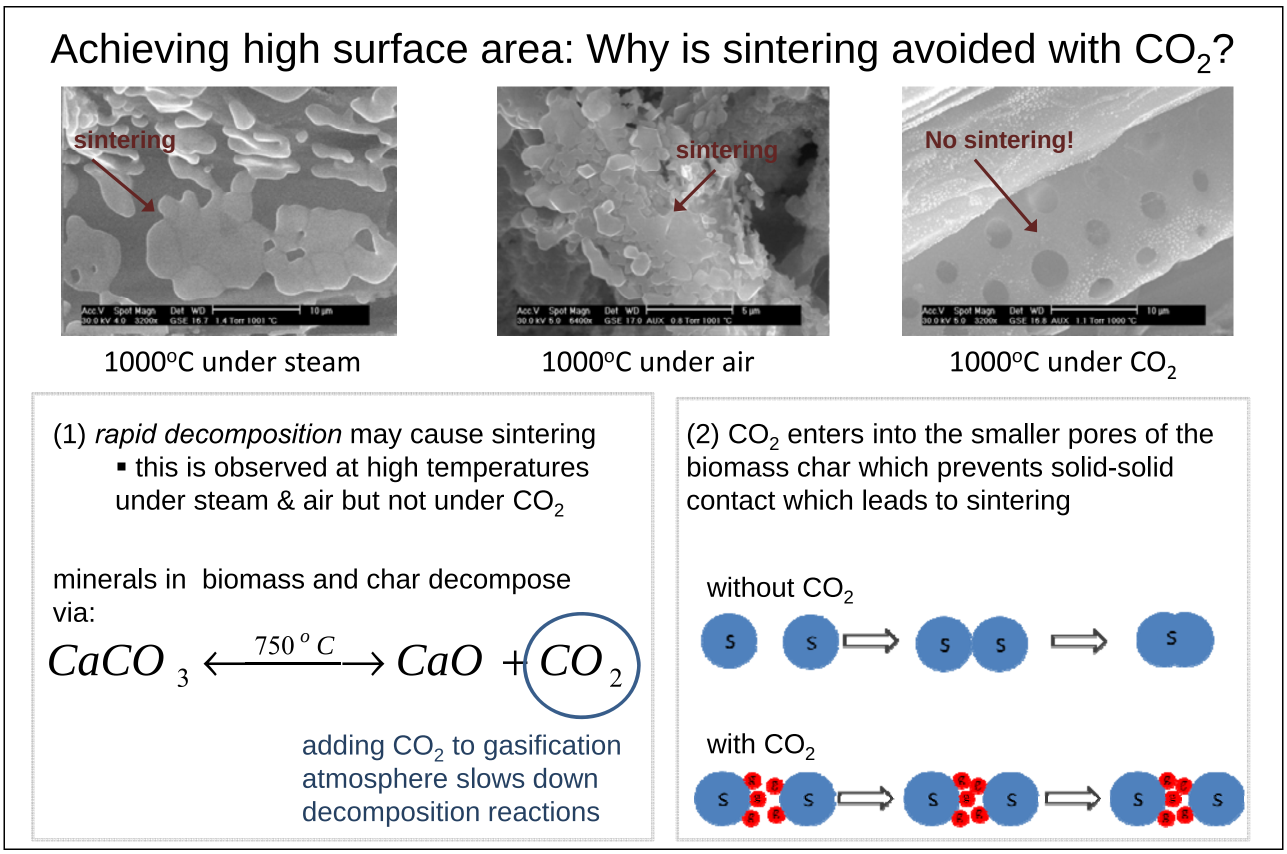
Rheology testing would include:

- Evaluating effects of solids loading on slurry rheology
- Determination of maximum coal loading as a function of coal properties
- Determining effect of coal loadings on phase transformation
- Rheology of coal slurries with supercritical CO_2
- Evaluation of slurryabilities as a function of coal properties
- Determining effects of temperature and pressure on slurryability
- Evaluation of slurryability in the supercritical phase
- Effect of different slurry preparation techniques

In addition, in order to achieve higher concentrations of coal in the slurry that can be achieved in the annular region in pressure cell system used in the present rheometer configuration, a premix chamber and flow-through set can be developed which can then be used to obtain as-received solids approaching 80 percent by weight. Supplemental testing will include coal drying to evaluate if there is water migration from the coal pores into the liquid carbon dioxide carrier fluid.

18.2.2 Drop Tube Reactor Tests

ASPEN simulations, drop tube furnace studies, and thermo-gravimetric analyses (TGA) done at the Combustion and Catalysis Laboratory (CCL) by M. Castaldi as part of the earlier DIPE program implied an enhancement of coal gasification in terms of higher cold gas efficiencies, higher carbon conversions, and lower oxygen/coal ratios when liquid CO_2 was employed as a feed in place of water [7,8]. When a full IGCC simulation was run by EPRI, the overall thermal efficiency of the plant was shown to increase by almost three percentage points [9]. However, recent studies by Botero have indicated the possibility that the presence of CO_2 in the slurry feed stream can modify the gasification kinetics such that carbon conversion could be adversely affected [10]. The Botero paper was a modeling study which used as input semi-empirical kinetic correlations that tended to show slower reactivity for the gasification with CO_2 than with steam. However, as pointed out in the paper, other correlations exist which could show the opposite effect [11]. The kinetic expression by Roberts and Harris [11] was not considered because of the absence of terms accounting for the retarding effect of CO and H_2. This is a critical aspect to evaluate the relative difference between H_2O and CO_2 gasification since in such a modeling study the kinetics will be determined based on pre-selected literature results. Finally, some parameters used in the Botero study involved an extrapolation to high temperatures and pressures which contributed significantly to the uncertainty in the kinetic analysis as was recognized by the authors. The effect of finer atomization on carbon conversion and increased coal porosity on the reactivity by the use of carbon dioxide (see Figure 18-2) which were not considered in this study need to be further investigated. Slurry atomization, which can have a significant effect on carbon conversion, is expected to be much better for liquid CO_2 slurries than for coal water slurries, and this should improve carbon conversion for liquid CO_2 slurries as compared to coal water slurries. In the model used in the paper, a reactivity factor representing the effect of char porosity and gas diffusion was used based on coal water slurry gasification data for both the liquid CO_2 analyses and the steam gasification analyses. However, data taken at CCL both in a TGA and drop tube furnace indicated that CO_2 increased char porosity significantly which would enhance carbon conversion [12].



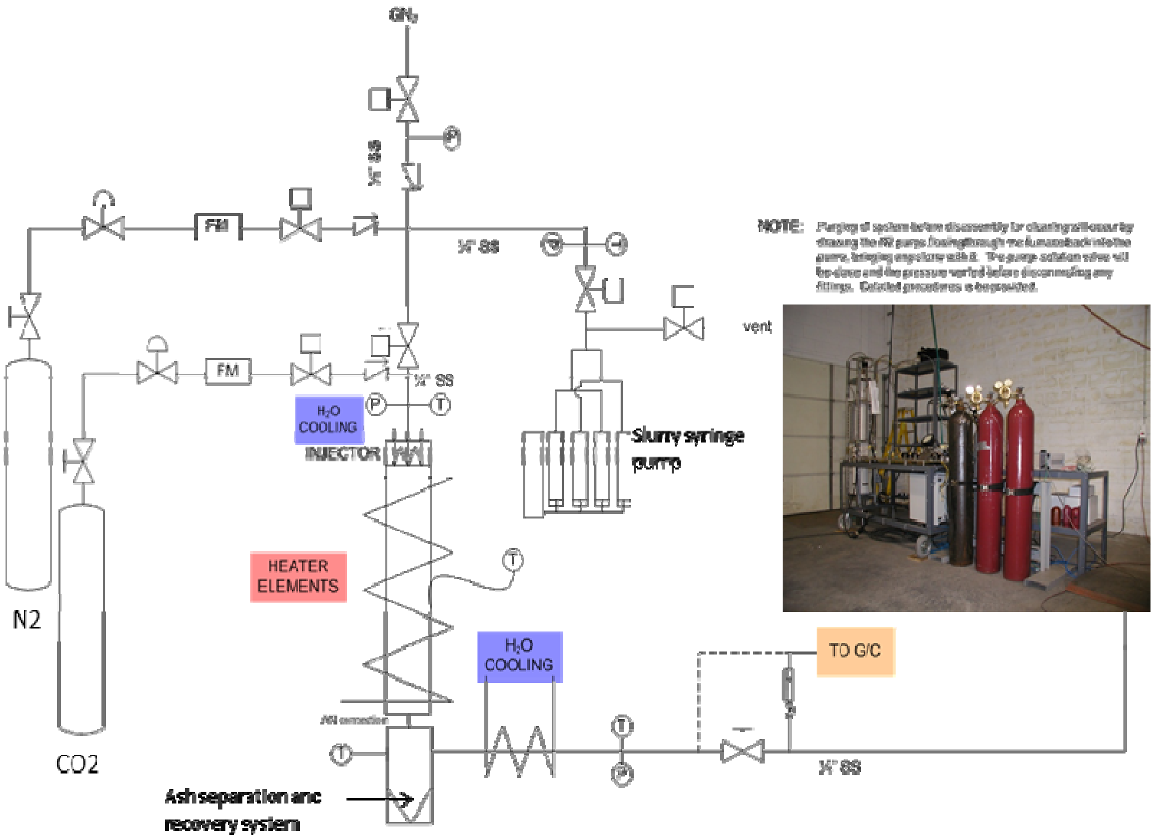
Source: John Dooher, Adelphi University

Figure 18-2 Char Surface Interactions with CO_2 During Gasification

In the end, these issues can best be resolved by further experimental studies as well as expanded modeling analyses.

In order to verify the effect of additional CO_2 on coal gasification, additional drop tube reactor studies should be conducted at elevated pressures. Gasification studies should be done varying O_2 /coal ratios and varying CO_2 mixtures. Gas evolution data on CO, CO_2, H_2, and CH_4 can be obtained with a Gas Chromatograph (GC) as well as kinetics of the gasification reactions. In addition, carbon burnout should be determined. These experiments should be conducted in a pressure range at least of the order of 1-10-20 bar.

Below is a description of a pressurized slurry drop tube furnace system presently being set up by DIPE at the Combustion and Catalysis Laboratory (see Figure 18-3).



Source: John Dooher, Adelphi University

Figure 18-3 Pressurized CO_2 Slurry Gasification System at the Combustion and Catalysis Laboratory

The main component of the gasification unit consists of a vertical drop-tube reactor, manufactured from Haynes 230, and capable of continuous operation at a simultaneous pressure and temperature of 20 atmospheres (300 psia) and 1,100°C (2,012°F) at the reactor wall, respectively. The drop-tube is five feet long, and has an inner and outer diameter of three inches and three and a half inches, respectively. The reactor wall inner surface is externally heated up to 1,100°C (2,012°F), uniformly, with no axial (stream-wise) temperature gradient, over a length of four feet using two annular ceramic radiant electric heaters employing resistive heating elements to provide the energy required for the endothermic gasification process utilizing radiation as the primary mode of heat transfer from the reactor wall to the reactants. A burner for partial oxidation can be inserted through the top flange. Reactor temperature is controlled by modulating electrical power to the ceramic heaters as well as adjusting combustion oxygen levels. With the addition of refractory liners and additional modifications, higher reactor temperatures can be achieved.

The flanged drop-tube reactor exit is connected to a solid phase separation and recovery system which utilizes gravity and aerodynamic drag as means for separating any solid particles from the gases exiting the reactor. The recovery system also serves as a first stage condenser for separating water vapor from the reactor gases. A face seal configuration utilizing elastomeric seals is employed for reliable high pressure sealing between the drop-tube reactor and the ash recovery system. A fine needle valve is used to supply backpressure onto the reactor and control desired reactor operating pressure. A small vacuum pump is utilized for extraction of dry gas samples from the exhaust line, and the samples are in turn sent to an Agilent 3000A micro-gas chromatograph and analyzed in real time to determine type and amount of species found in the reactor exhaust gas.

A slurry injection system is found at the top of the drop-tube reactor. Slurry is delivered to the injection system utilizing a precision, stepper motor-driven, syringe pump capable of high pressure (~5.52 MPa [800 psig]) fluid delivery. Control is provided over the flow rate (and therefore momentum), thus allowing for the formation of micron-sized slurry droplet diameters. The gas-assisted atomization of the slurry is achieved in a manner similar to liquid fuel injectors found in aerospace propulsion applications. A coaxial tube within tube geometry is employed with slurry located centrally while atomizing gas is introduced through the resulting annulus around the slurry tube. A copper slurry tube with an inside diameter of 1.78 mm (0.070 inches) is utilized in conjunction with an annulus height 0.18 mm (0.007 inches). The resulting geometry produces slurry droplet diameters on the order of 0.08 mm (0.003 inches), with corresponding coal slurry and atomizing gas (CO_2) flow rates of 1-4 gram per minute and 3 SLPM, respectively. In some instances, carbon dioxide and nitrogen gases are delivered to the gasification system from standard high pressure bottles connected to computer controlled mass flow meters to aid in atomization of the slurry. If needed, CO_2 can be used exclusively to study CO formation through the Boudouard reaction. System instrumentation consists of thermocouples and pressure transducers monitoring temperatures and pressures at various locations throughout the system. All instrumentation is attached to a computer controlled data acquisition system sampling at 5 hertz per channel. All instrumentation (pressure, temperature, and gas composition) is attached to a computer controlled data acquisition system sampling at 5 hertz per channel.

18.2.3 Flow Test Loop

18.2.3.1 Flow Test Loop Overview

A test loop can be constructed based on the capability of simulating power plant operation and should include evaluating performance of major equipment including pumps, flow meters, instrumentation, valves, tanks, compressors, tanks, agitators, etc. There have been earlier studies with test loops for both coal/water slurries and coal/liquid CO_2 slurries [6,13,14]. This system will be significantly different than that used for the early studies of coal/CO_2 slurries, not only in the use of state of the art equipment, but also in that measurements of the actual coal solids content will be performed using a series of load cells, weight loss feeders, and flow meters. The resulting deliverables of this work will include analyses of slurry handling properties which will include handling and monitoring equipment selection and performance.

The technical objectives of the test loop program include:

- Evaluate the performance of slurry handling equipment with LRC/liquid CO_2

- Assess the ability to control LRC/liquid CO_2 flow to a gasifier
- Generate engineering design information on LRC/liquid CO_2 handling as applied to in-plant handling of LRC/liquid CO_2
- Evaluate performance of instrumentation for flow monitoring and control
- Determine special requirements including safety when using LRC/liquid CO_2
- Ascertain erosion-corrosion aspects of using LRC/liquid CO_2
- Evaluate various systems for LRC/liquid CO_2 preparation
- Determine maximum coal content of LRC/liquid CO_2 obtainable at the commercial scale

Preliminary schematics of the test loop facility including a conceptual process flow diagram are shown in Figure 18-4 and Figure 18-5. The site selected for the test loop design is a large outdoor area at the ATK-GASL research facility on Long Island, NY. The basic elements of the loop include at least 100 feet of straight runs of 3-inch carbon steel pipe as well as 20-foot vertical sections of pipe. The loop is for testing purposes and is to be designed to full scale. Provisions can be made to test a variety of slurry pumps including positive displacement and centrifugal pumps. In addition, removable test sections can be employed for erosion-corrosion testing as well as other special test requirements. For the main loop pump, intMPE of Canada supplied a bid for this application. This centrifugal pump consists of wet end parts that are constructed of ASTM A532 Class II chrome iron. The pump is rated at 17.24 MPa (2500 psig) and 6.31 l/s (100 gpm). Any equivalent centrifugal pump would be appropriate as well as positive displacement pumps with elastomers (if required) suitable for liquid CO_2.

The loop is designed for pump flow rates in the range of 6.31-15.8 l/s (100-250 gpm) and will operate at loop pressures up to 13.8 MPa (2000 psig) with variable frequency drives so that flow rates can be varied according to the dictates of the test program. The testing proposed is to represent the intended commercial operating facility as closely as possible. The system is designed to assess operation as if it were under a continuous operation. The use of an eductor creates a smooth continuous introduction of coal particles from the pressurized hopper into the loop which will operate the same regardless of the supply feed system. Operating pressure is designed to be 13.8 MPa (2000 psig), but the loop can operate at lower pressures near the critical point.

Instrumentation consists of a coriolis mass flow meter which can measure both mass flow and slurry density, and various temperature and pressure sensors. In addition, the amount of coal fed into the hopper can be measured by a load cell or weight loss feeder and the carbon dioxide flow is measured. The refrigeration and heating systems are introduced for rigorous temperature control. The refrigeration system was chosen based on jacketing around the outside of the pipe. There are options within this approach to proceed with cooling only or cooling and heating. The size of the system is determined by the flow rate of the fluids within the pipe. This flow rate was determined by the minimum transport velocity needed to keep particles suspended in the system. The desired operating temperature is also influenced by the refrigeration system selection. The jacketing will utilize cold ethylene glycol as the heat transfer medium. Burst plates and pressure relief valves avoid over pressurizing the loop due to possible upset conditions.

One of the major elements of the test program will be to run the loop with slurries at different coal concentrations including the maximum achievable which is expected to be over 80% by weight as-received coal with this scale of operation [6]. The primary focus is the maximum suspension of coal particles in the slurry. Laboratory tests from PRB coal showed concentrations of 68 wt% coal for liquid CO_2 compared to 55 wt% for water. In the laboratory system, the maximum amount of coal that could be put into the carbon dioxide slurry was limited by the size of the sample cell. With PRB, it is estimated that as much as 75 to more than 80 wt% slurries are achievable in commercial applications. Different concentrations of coal levels will be experimented to assess the influence of the effect of the concentration on the viscosity of the system. The desired outcome is to have an understanding of the behavior of flow allowing for the development of the optimum operating pressures and temperatures. The use of the test loop will allow for advanced testing of instrumentation in a super-critical CO_2 coal slurry service and to asses performance.

18.2.3.2 Loop Testing

Some of the important testing that can be done with the test loop could include:

- Testing around the critical point with LRC/liquid CO_2. Observations should be made as rate of change of pressure and temperature and where there are unpredictable changes. Pressure should be increased until there is a steady state operation. Parameters should be established and provided to operators.
- When increasing the pressure around the critical point, small temperature changes can have a large effect on system pressure. The jacketed cooling system will help to stabilize these temperature fluctuations and will remove an additional variable within the test system.
- Establish rate of heating and pressurization safely around critical point, while also considering over pressurization and flashing. Tests should be done to monitor the rate of pressure increase with incremental increases of rate of heating and pressurizing until a rapid change begins to occur.
- Along with testing of different coals, the testing of different coal particle size distributions with different geometric packing densities could be done and compared with the rheological data. The minimum settling velocity of the coal particles can be reassessed with revised particle sizes.
- The dense phase supercritical CO_2 is less viscous and less abrasive on pipe walls and can have better suspension capability in comparison with water in the turbulent region. The testing will determine how the coal particles suspend, travel, and identify any issues that may be found in transportation of particles for this application.
- The introduction of coal particles with the eductor is also an area requiring further examination. Changes in nozzles can be explored to determine the effect of nozzle size, exit velocity, and system capacity if desired. Different sized eductors can also be used in establishing maximum rates, capabilities, pressure drops, and limitations of certain types and sizes of nozzles.
- Flow, pressure, and temperature instrumentation should be evaluated as well as density measurements with the coriolis meter.
- Erosion and corrosion testing can provide useful information on in plant use of liquid carbon dioxide. Material selection requires consideration when dealing with dense phase

CO_2. It is highly invasive and can dissolve materials at a rapid rate if not operated correctly. This is primarily done by avoiding any water content in the system. Special consideration should be given to seals, gaskets, and packing, to ensure compatibility with CO_2 service.

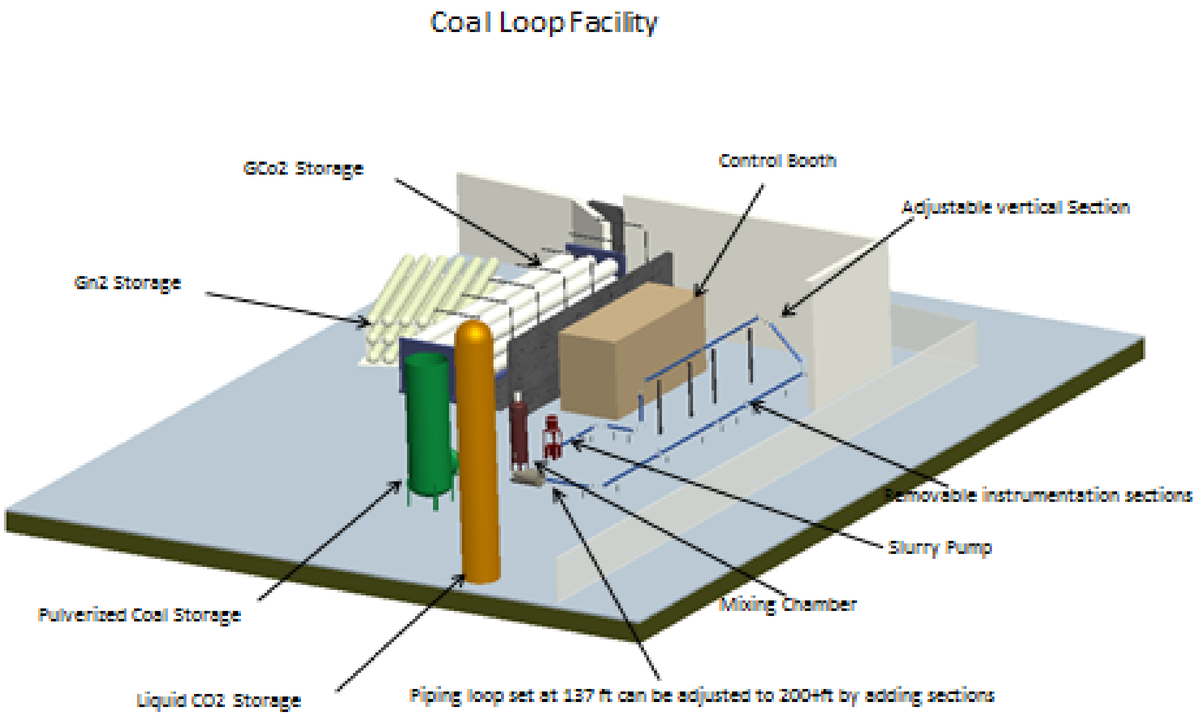
- Elastomer evaluation. Most elastomers as seals are not all suitable for CO_2 service. Some recommended types include Hydrogenated Nitrile Butadiene rubber (HNBR) also known as Highly Saturated Nitrile (HSN) and Perfluroelastomers (FFKM); these O-rings are recommended high durometer (Shore A 90) as they are resistive to explosive decompression.
- Evaluation of valves and fittings. When designing and constructing the loop, consideration of likely places for collection of particles to occur should be taken into account. This would include the use of bends with a radius of 20 diameters and the use of an eductor as well as other non-plugging components. A Purge Separator should be constructed for venting at start up when purging air from the loop at the highest point of the vertical section and at the top of the hopper.

18.2.3.3 Safety

The final design process should include consideration for depressurizing of the loop, removal of the particles, cleaning and dewatering of the loop, and finally removal of any dry ice or hydrate blockages. A hazard and operability (HAZOP) analysis should be conducted to review uncontrolled depressurizations, safety scenarios, evacuations, and operational safety.

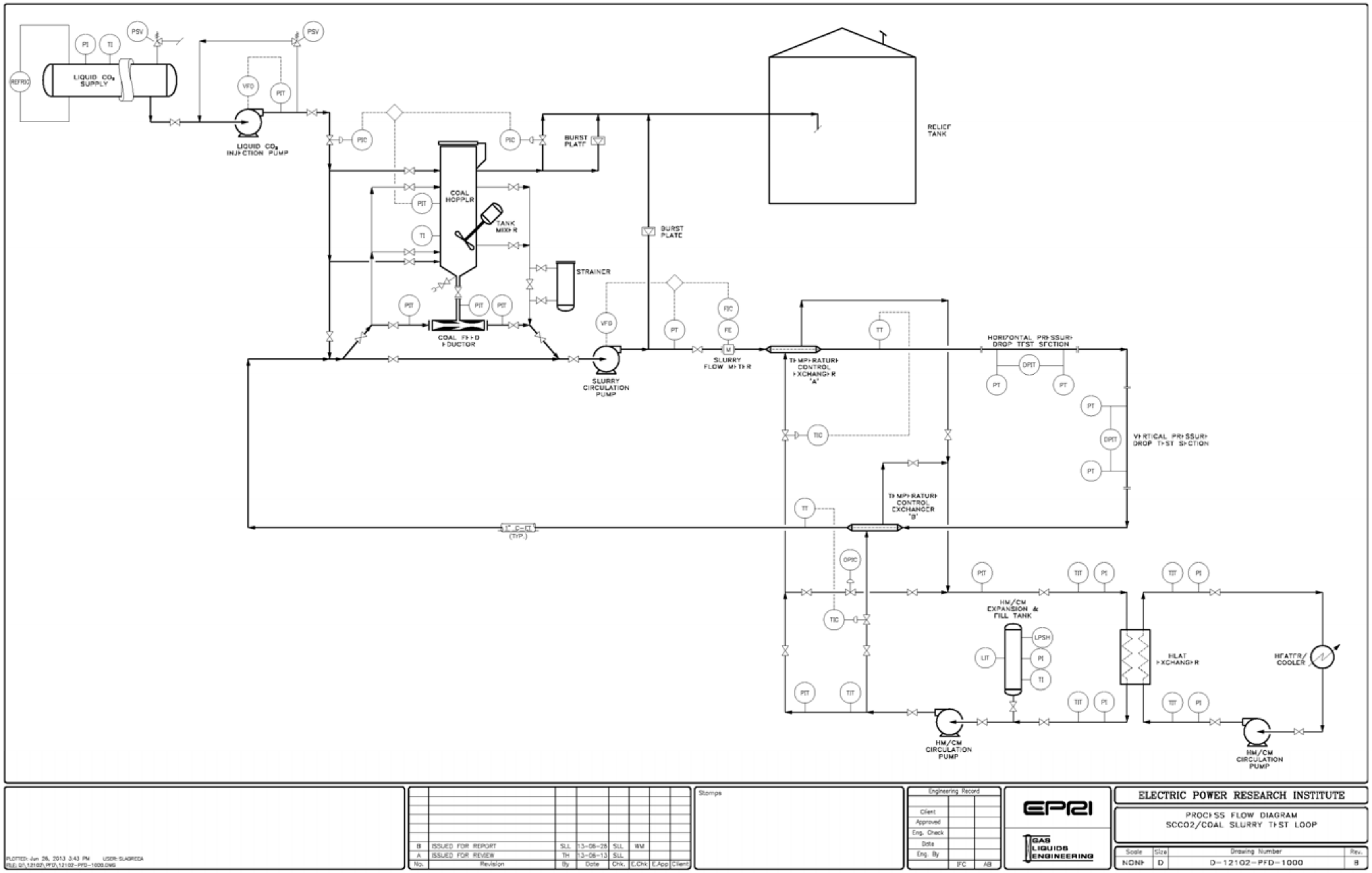
To date, there are no recommended practices or guidelines on transmission of supercritical CO_2. There are codes and standards available for pipeline design including the U.S. Federal Code of Regulations, ASME Standards B31.4 and B31.8, IP6, BS EN 14161, BS PD 8010, ISO13623, API RP1111 and DNV OS-F101.

A HAZOP and Failure Modes and Effects Analysis (FMEA) are recommended and should be performed for the test facility and appropriate safety measures established. Once the dense phase CO_2 particle transport methodology is moved into a commercial environment, an additional HAZOP analysis is warranted.



Source: John Dooher, Adelphi University

Figure 18-4 Coal Slurry Test Loop



Source: Gas Liquids Engineering

Figure 18-5 Test Loop Concept Process Flow Diagram

18.2.4 Atomization Studies

18.2.4.1 Overview

For fuel oil combustion, well-defined correlations exist relating atomization properties, such as Sauter mean diameter, to the physical properties of the oil, i.e., viscosity [15]. However, such relationships do not exist for coal slurries. Unlike oils, which are essentially Newtonian fluids fully characterized by a few basic physical parameters, such as viscosity, density, and surface tension, coal slurries are complex structures with large numbers of internal degrees of freedom and are usually non-Newtonian. When coal slurries were first being considered as an alternate boiler-furnace fuel to oil, the importance of atomization had not been clearly delineated. Since a coal/water fuel is a suspension of finely ground coal in water, it was not unreasonable to assume that in a furnace environment the water would vaporize leaving the coal to be burned in a configuration similar to that of a pulverized coal furnace. If this were the case, then the combustion properties would be influenced mainly by the particle size distribution of the suspended coal and not the atomization properties of the suspension. This was also the assumption about performance of slurry fed gasification systems. However, extensive tests comparing micronized coal water fuels with pulverized coal combustion of micronized coal showed that:

- Carbon burnout was generally poorer for coal slurry combustion than pulverized coal combustion in the same furnace configuration [16,17].
- Coal slurry combustion efficiency could be improved significantly by extensive heating of the fuel prior to atomization including explosive atomization where the fuel was heated under pressure to temperatures above 100°C [18,19].
- Analysis of particulate fly ash indicated that coal in the droplets of coal water fuel tended to agglomerate in a furnace environment. Hence, atomization droplet size was a better indicator of combustion duration than coal particle size distribution. This conclusion was also reinforced by single droplet experiments [20].
- Reducing coal particle size for the slurry fed gasifier at Tampa Electric Company did not result in an expected increase in single pass carbon conversion (Hornick, M.J., Tampa Electric Company private communication, 2007)

Although there have been several studies on coal slurry atomization for boiler furnace combustion applications, there have been very few relevant studies for gasification applications [18,20,21,22,23].

In a model for gas-assisted slurry atomization based on droplet agglomeration and breakup developed for coal slurries, which has shown good agreement with experimental results, the equation for Sauter mean diameter (SMD), d, is given by [24]:

$$d = K_0^{3/2}\left(\frac{\dot{m}_F}{\dot{m}_G}\right)^{1/2}\left(\frac{a^2}{\Sigma^{1/2}}\right)Z^{1/2}D_0^{1/2}We^{\frac{-67}{80}} \qquad (1)$$

Where $\dot{m}_F$ is the fuel mass flow rate, $\dot{m}_G$ is the atomizing gas mass flow rate and

$$Z = \frac{We^{1/2}}{\mathrm{Re}}, We = \frac{\rho_G a V_G^2}{\sigma}, \mathrm{Re} = \frac{\rho_G a V_G}{\eta}$$

V_G is the relative gas velocity which is generally taken as the gas nozzle exit velocity and

η Is the slurry viscosity

$$D_0 = \left(\frac{a\sigma}{\rho_G^{17/25} \rho^{8/25} v_G^2} \right)^{25/40} \qquad (2)$$

v_G is the gas kinematic viscosity

a =characteristic dimension

ρ_G =gas density in a pressurized reactor

ρ = coal slurry density

σ = surface tension

K_0 is a numerical constant

The following equation is used in the analyses for the cross sectional area of the spray at an axial distance z from the nozzle exit.

$$\Sigma = z^2 tan\theta_p{}^2 \qquad (3)$$

θ_p is the spray cone half angle.

At -10°C (14°F), the surface tension of liquid carbon dioxide is at least one tenth that of room temperature water. Using Eq. 1, this would yield drop sizes for liquid carbon dioxide slurry sprays 10 times smaller than those in coal water slurry sprays. Including the effect of a lower viscosity for liquid carbon dioxide slurries could yield drop sizes 20-30 times smaller than the coal water slurries. If true, this will allow slurry-fed gasifiers to achieve much higher carbon conversion rates at a given gasifier temperature, or will allow for operation at a lower temperature (yielding longer refractory life) while maintaining acceptable carbon conversion rates. However, the variation of temperature and pressure in the injector can affect the slurry properties (for example the CO_2 could transit through a supercritical phase which might affect atomization properties).

It is important to verify these atomization properties as well as other implications of the gasifier environment including the effect of pressure and temperature on atomization. For example, if the fuel to atomizing gas ratio is held constant and the ambient pressure is increased from 1 bar to 60 bar, Eq.1 predicts an increase by approximately a factor of 4 of the SMD. Also, there are indications that the cone angle will be reduced at elevated pressures yielding a further increase in drop spray droplet sizes (see Eq.1) [11]. The cone angle can also be reduced if the fuel to gas ratio is increased since the slurry momentum along the spray axis will increase relative to the particle momentum transverse to the spray axis. Elevated temperatures may in part compensate but at gasifier temperatures, agglomerates form and water and liquid carbon dioxide could yield very different results, especially if the initial slurry drop size is much smaller for the CO_2 slurries.

To evaluate these differences, high pressure atomization studies should be done using a high pressure test rig with the capability of also varying the ambient temperature. A variety of nozzle configurations could also be tested. A high pressure atomization rig, such as the one currently at ATK at its test facilities on Long Island, NY (see Figure 18-6 and Figure 18-7) could be modified to conduct appropriate atomization studies. The batch slurry preparation system proposed for the test loop could also provide the required slurries for atomization studies.

Source: John Dooher, Adelphi University

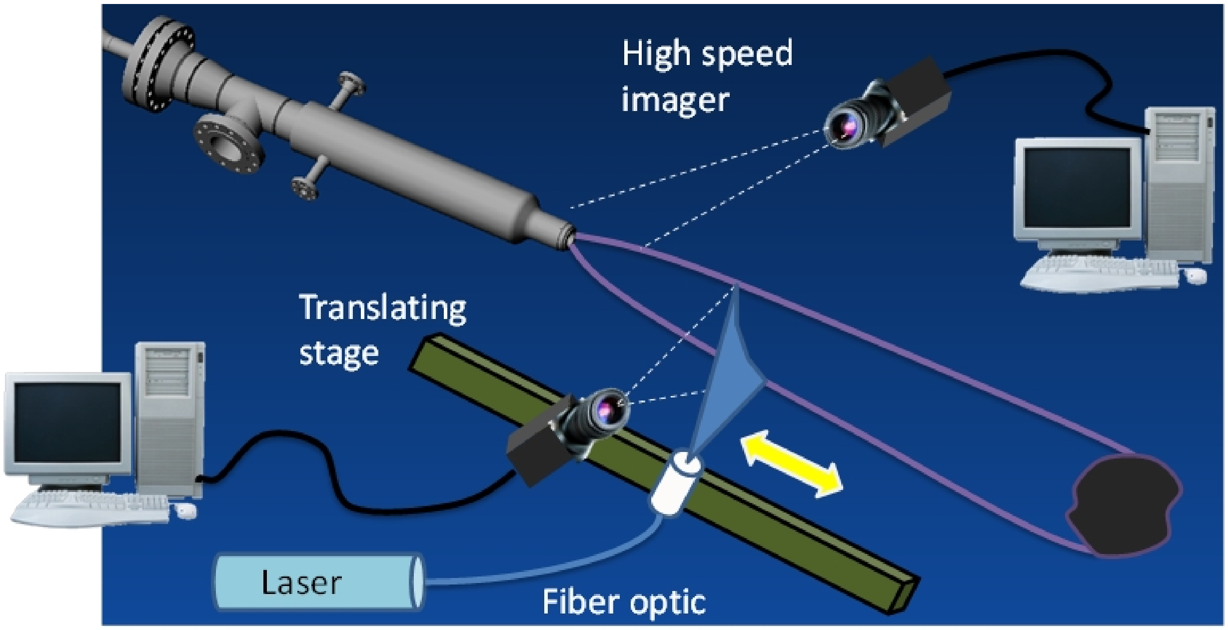
Figure 18-6 High Pressure Atomization Test Chamber (HPATC)

Source: John Dooher, Adelphi University

Figure 18-7 Close-up View of High Pressure Atomization Test Chamber (HPATC)

Properties of HPATC include:

- Spool diameter 20-25 cm (8-10 in)
- Has optical access ports for visualization
- Can take up to 3.45 MPa (500 psig) and higher with modifications
- Stainless steel construction
- Will need a CO_2 slurry preparation and capture system(similar to test loop system-test loop system can provide for atomization studies)
- Also provisions for coal water slurry testing
- Recommended fuel flow of 4-40 kg/h
- Laser diagnostics available to assess spray patterns [PIV (particle image velocimetry), PLIF (planer laser induced fluorescence), LIF (laser induced fluorescence), high speed camera, PDA (phase Doppler anemometer), laser diffraction. etc.]



Source: John Dooher, Adelphi University

Figure 18-8 Spray Visualization System

For spray studies, the spray visualization system is shown in Figure 18-8. The approach involves using high speed imaging and laser-enhanced imaging of the slurry jet edges to generate jet expansion topology maps under the various operating and initial conditions. The system would utilize two orthogonal views, to simultaneously scan and generate 3D time-averaged edge topology.

It would also be important to refine the atomization model using data from the testing. A reliable model for atomization in a slurry-fed gasifier could be a valuable design tool for improving gasification efficiency.

18.2.4.2 Proposed Test Matrix Outline (for both liquid CO_2/coal and water/coal slurries)

- Measure surface tension, density, and rheological properties
- Atomization testing at 1 bar (at room temperature, and at least two higher chamber temperatures)
- Vary fuel (F)/atomizing gas(A) ratio at fixed fuel flow
- Vary fuel flow at fixed F/A
- Measure SMD, drop size distribution, spray cone angle, particle velocities
- Effect of pressure (vary pressure from 1-30 bar at room temperature and at least two higher chamber temperatures)
- Effect of increasing pressure (P) on SMD at fixed F/A

- Effect on SMD of increasing fuel flow via F=kP where k is a constant at fixed F/A since the main reason for increasing pressure is to be able to increase throughput for a fixed reactor configuration
- Consider varying pressure at constant *We* by adjusting orifice size and configuration
- Spray cone angle and drop size distributions
- Also droplet distributions if measured can be analyzed
- Velocity measurements can also be useful

18.3 Cost Estimation

Table 18-1 Cost Estimation

Item	Cost, $USD
Flow Loop AACE Class 3 estimate including capital, construction, and project services +15% contingency	2,800,000
Loop testing	1,000,000
Rheology testing	200,000
Atomization testing	450,000
Drop tube testing	350,000

Costs in 2012 dollars

18.4 Recommendations for Further Study

Detailed investigations on the use of liquid CO_2/coal gasifier feed slurries can potentially lead to significant benefits in other types of gasifiers that use slurry feed systems as indicated in Table 17-1. These may be evaluated using the same techniques described herein for the design and operation of liquid CO_2 slurry preparation and feed systems. Another line of investigation that may improve the results obtained with liquid CO_2 slurries would be optimization of the liquid CO_2 slurry preparation and feed system. If rotary valves or mixing vessels with higher pressure capabilities were available, higher slurry temperatures could be employed, resulting in lower refrigeration parasitic power and cost of components. The technology development roadmap presented in this report is recommended as the optimal method for resolving those issues necessary for evaluation of the technology.

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21 Jakobs, T., Djordjevic, N., Fleck, S., Mancini, M., Weber, R., Kolb, T. International Journal of Applied Energy (2012) DOI: ttp://dx.doi.org/10.1016/j.apenergy.2011.12.026.

22 Jakobs, T., Djordjevic, N., Fleck, S., Zarzalis, N., Kolb, T. Tagungsband 25. Deutscher Flammentag (2011).

23 Jakobs, T., Fleck, S., Mancini, M., Weber, R., Kolb, T. Tagungsband 36th International Conference on Clean Coal, USA (2011).

24 Dooher, J. P. Application of a Phenomenological Model to the Atomization of Slurry Feedstocks in Entrained flow Gasifiers at Elevated Pressures, The 36th International Technical Conference of Coal Utilization & Fuel Systems June 5 – June 9, 2011, Sheraton Sand Key, Clearwater, Florida, USA

Appendix A

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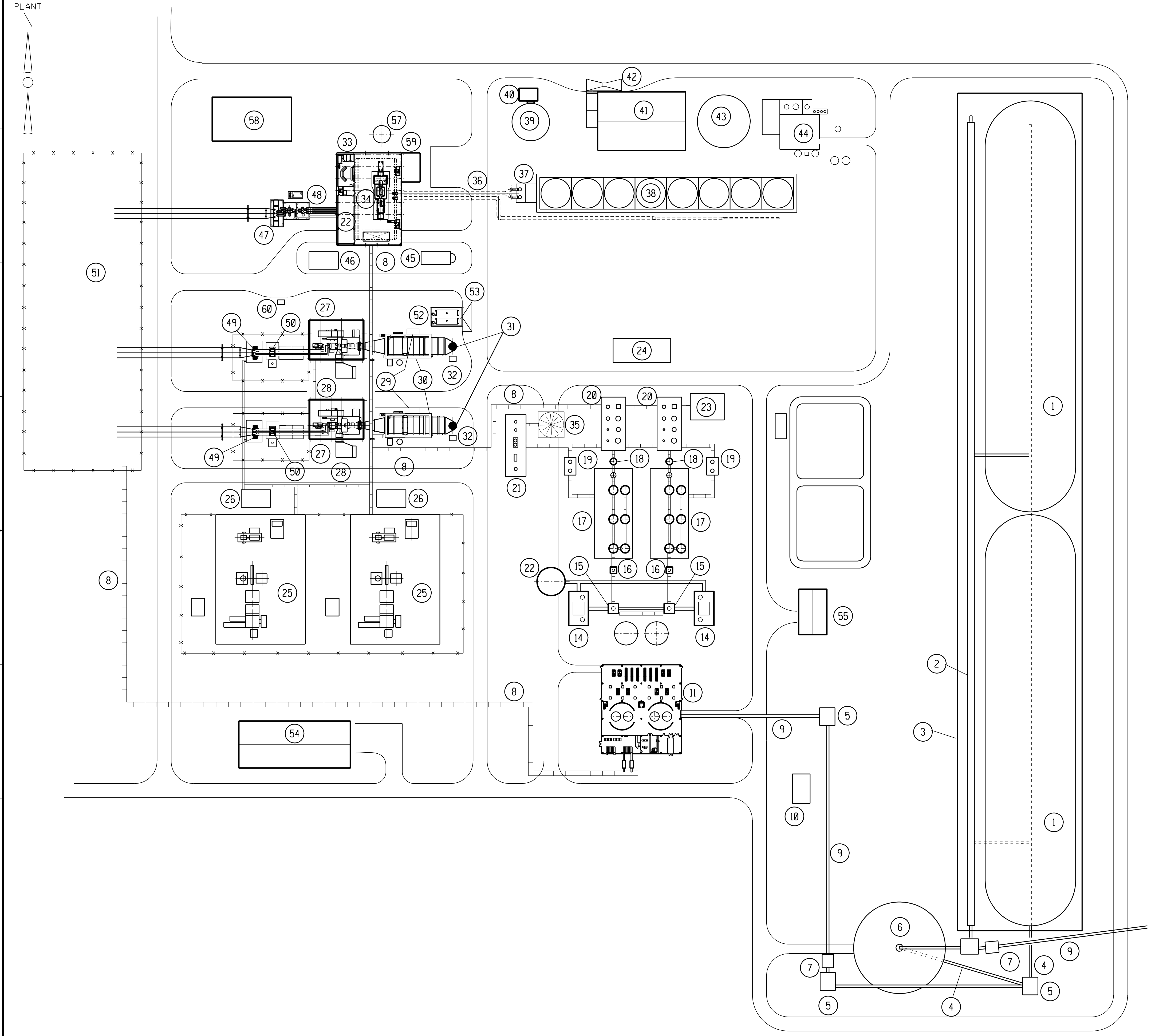
1. Appendix A-1 Water/Coal Slurry Drawings

1. **IGCC Plant with Water / Coal Slurry Site Plan (EPRI-1-SK-111-002-600)**
2. **Water / Coal Slurry/Feed Batch Process Plan at Grade Elevation 100 ft (EPRI-1-SK-156-002-601)**
3. **Water / Coal Slurry/Feed Batch Process Plan at Grade Elevation 154 ft 6 in (EPRI-1-SK-156-002-602)**
4. **Water / Coal Slurry/Feed Continuous Process Vertical Section (EPRI-1-SK-156-002-603)**



PLAN VIEW

PLANT SITE DESCRIPTION

1 COAL STORAGE
2 COAL TRAVELING STACKER
3 COAL STORAGE BUILDING
4 COAL RECLAIM CONVEYOR
5 COAL TRANSFER STRUCTURE
6 EMERGENCY COAL PILE
7 COAL SAMPLE SYSTEM
8 UTILITY BRIDGE (TYPICAL)
9 BELT CONVEYOR (TYPICAL)
10 COAL ELECTRICAL BUILDING
11 COAL DRY LOCK-HOPPER PROCESS BUILDING
12 NOT USED
13 NOT USED
14 SLAG PROCESSING AREA AND WATER HANDLING
15 GASIFIER
16 GAS SCRUBBER
17 SHIFT REACTION SECTION
18 MERCURY REMOVAL
19 SOUR WATER STRIPPERS
20 ACID GAS REMOVAL
21 CLAUS PLANT
22 SLAG SILO
23 CO2 COMPRESSION
24 ELECTRICAL ROOM/ELECTRICAL BUILDING
25 AIR SEPARATION UNIT (ASU)
26 ASU ELECTRICAL BUILDING
27 COMBUSTION TURBINE (CT)
28 AIR INLET FILTER
29 SCR SKID
30 HEAT RECOVERY STEAM GENERATOR (HRSG)
31 STACK
32 CEMS ENCLOSURE
33 CONTROL ROOM
34 STEAM TURBINE GENERATOR
35 SULFUR STORAGE
36 CIRCULATING WATER PIPING
37 CIRCULATING WATER PUMPS
38 COOLING TOWER
39 FIRE/SERVICE WATER TANK
40 FIRE/SERVICE WATER PUMP HOUSE
41 WATER TREATMENT FACILITY
42 CHEMICAL TRUCK UNLOADING
43 RAW WATER STORAGE TANK
44 ZERO LIQUID DISCHARGE
45 AUXILIARY BOILER
46 EMERGENCY DIESEL GENERATOR
47 STG STEP-UP TRANSFORMER
48 GENERATOR CIRCUIT BREAKER
49 CTG STEP-UP TRANSFORMER
50 AUXILIARY TRANSFORMER
51 SWITCHYARD
52 AMMONIA STORAGE TANKS & PUMPS
53 AMMONIA TRUCK UNLOADING AREA
54 WAREHOUSE
55 VEHICLE MAINTENANCE GARAGE
56 STORM WATER POND
57 DEMINERALIZED WATER TANK
58 ADMINISTRATION/VISITORS BUILDING
59 WORKSHOP & STORES
60 OILY WATER SEPARATOR

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
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80 0 80 160 240
SCALE: 1" = 80'

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A	10 22 12	INITIAL ISSUE	JEV		JEV	HNG			HNG

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ENGINEER/TECH SPECIALIST: HN GOLDSTEIN
PROJECT ENGINEERING MANAGER:
PROJECT MANAGER: HN GOLDSTEIN

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LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365S/C18469

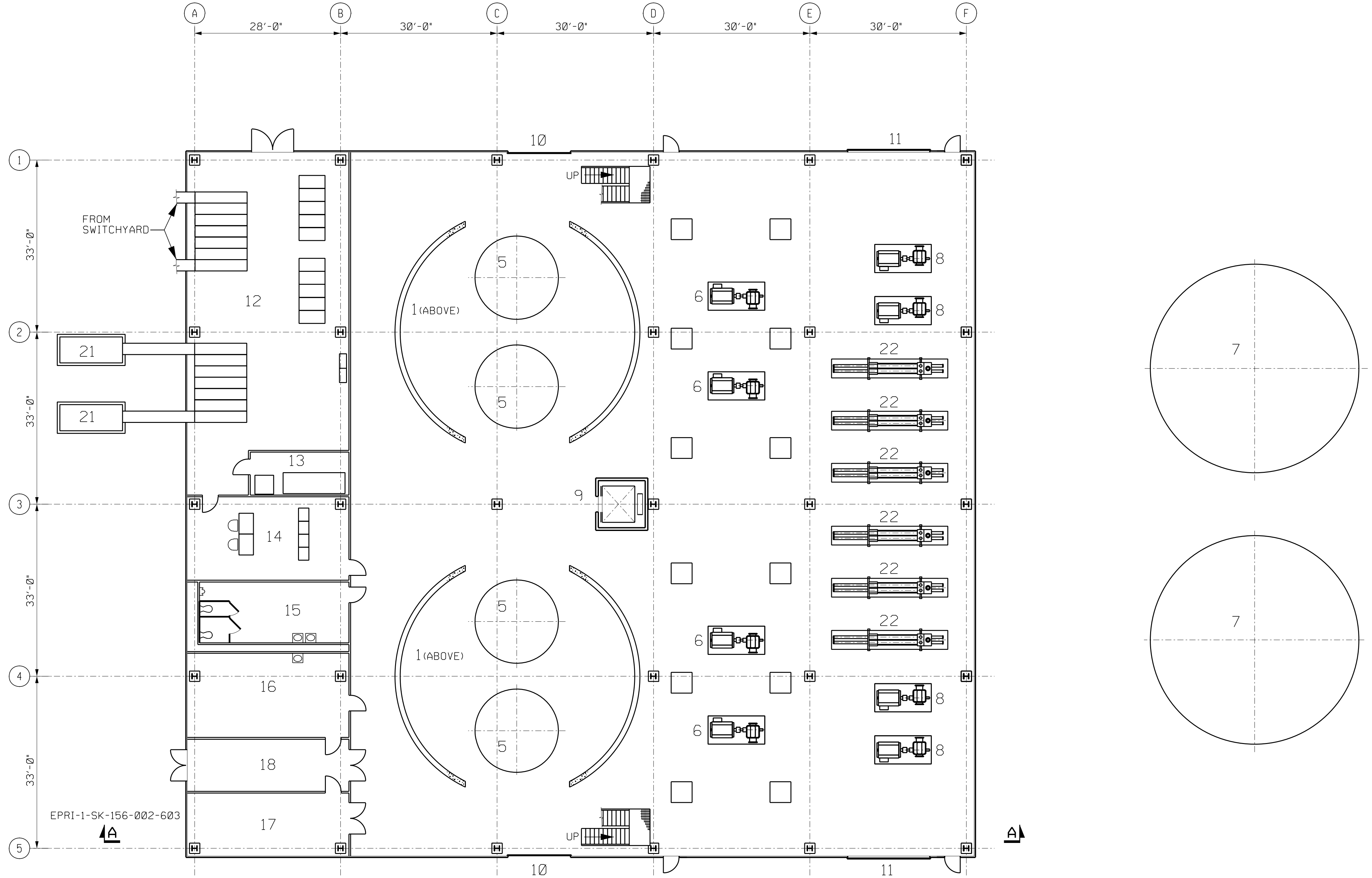
2x1 COP GASIFIER IGCC
SITE PLAN
PRB COAL/WATER SLURRY CASE

SCALE: 1"=80'
DRAWING SIZE: ARCH D (36" x 24")
WORLEYPARSONS DWG. NO.: EPRI-1-SK-111-002-600
REV: B

\epri-1-sk-111-002-600.dgn 2/11/2013 2:00:34 PM

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SLURRY BATCH TANK
6 SLURRY RECYCLE PUMP
7 SLURRY STORAGE TANK
8 SLURRY FORWARDING PUMP
9 ELEVATOR
10 ROLL UP DOOR
11 SLIDING DOOR
12 ELECTRICAL ROOM
13 BATTERY ROOM
14 CONTROL ROOM
15 LAVATORY
16 MEETING ROOM
17 STORAGE ROOM
18 VESTIBULE
19 TRIPPER CONVEYOR
20 BIN VENT FILTER
21 TRANSFORMER
22 SLURRY FEED PUMP
23 MONORAIL



PLAN AT ELEV. 100'-0"

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SCALE: 3/32" = 1'

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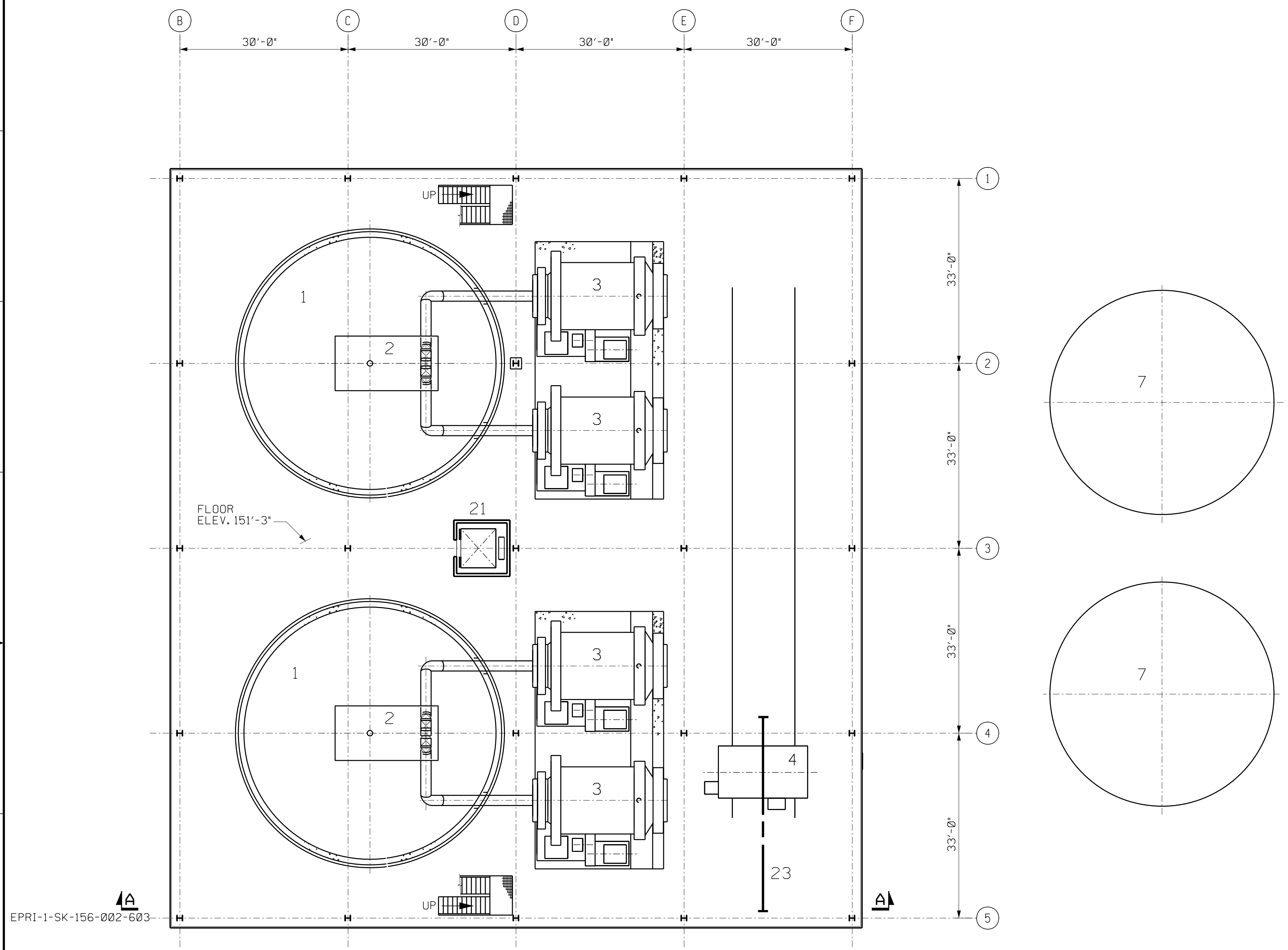
GENERAL ARRANGEMENT
PRB COAL/WATER SLURRY PREP & FEED
PLAN AT GRADE ELEV. 100'-0"

SCALE: 3/32"=1'-0"
DRAWING SIZE: ARCH D (36" x 24")
WORLEYPARSONS DWG. NO.: EPRI-1-SK-156-002-601
REV: B



PLAN AT ELEV. 151'-3"

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SLURRY BATCH TANK
6 SLURRY RECYCLE PUMP
7 SLURRY STORAGE TANK
8 SLURRY FORWARDING PUMP
9 ELEVATOR
10 ROLL UP DOOR
11 SLIDING DOOR
12 ELECTRICAL ROOM
13 BATTERY ROOM
14 CONTROL ROOM
15 LAVATORY
16 MEETING ROOM
17 STORAGE ROOM
18 VESTIBULE
19 TRIPPER CONVEYOR
20 BIN VENT FILTER
21 TRANSFORMER
22 SLURRY FEED PUMP
23 MONORAIL

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
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10 0 10 20 30
SCALE: 3/32" = 1'

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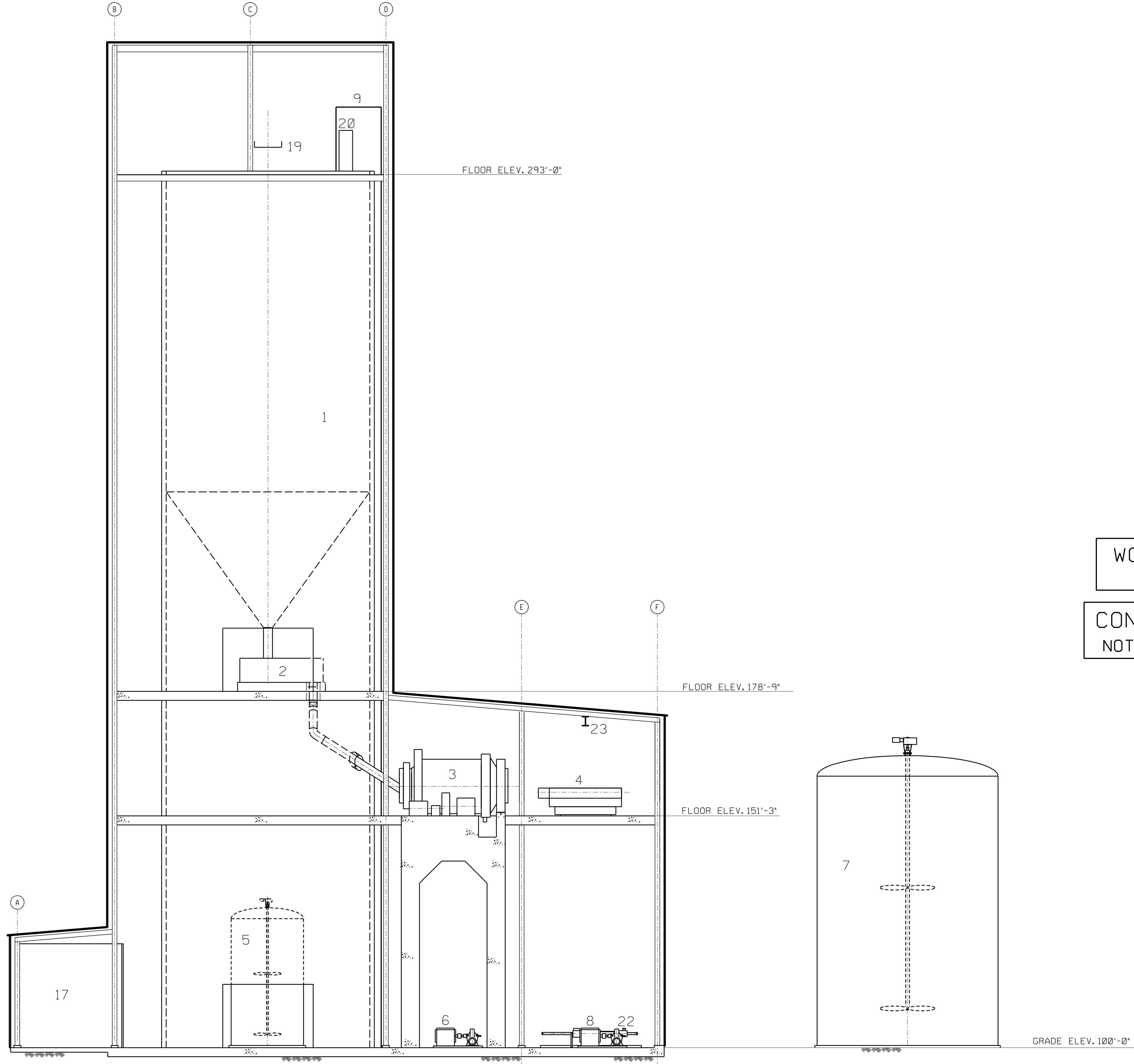
GENERAL ARRANGEMENT
PRB COAL/WATER SLURRY PREP & FEED
PLAN AT ELEV. 154'-6" & 220'-0"

SCALE 3/32"=1'-0" | DRAWING SIZE ARCH D (36" x 24")
WORLEYPARSONS DWG. NO. EPRI-1-SK-156-002-602 | REV B

2/11/2013



SECTION A-A

SCALE: 3/32" = 1'

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SLURRY BATCH TANK
6 SLURRY RECYCLE PUMP
7 SLURRY STORAGE TANK
8 SLURRY FORWARDING PUMP
9 ELEVATOR
10 ROLL UP DOOR
11 SLIDING DOOR
12 ELECTRICAL ROOM
13 BATTERY ROOM
14 CONTROL ROOM
15 LAVATORY
16 MEETING ROOM
17 STORAGE ROOM
18 VESTIBULE
19 TRIPPER CONVEYOR
20 BIN VENT FILTER
21 TRANSFORMER
22 SLURRY FEED PUMP
23 MONORAIL

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
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LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
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GENERAL ARRANGEMENT
PRB COAL/WATER SLURRY PREP & FEED
SECTION

SCALE: 3/32"=1'-0"
DRAWING SIZE: ARCH D (36" x 24")
WORLEYPARSONS DWG. NO.: EPRI-1-SK-156-002-603
REV: B

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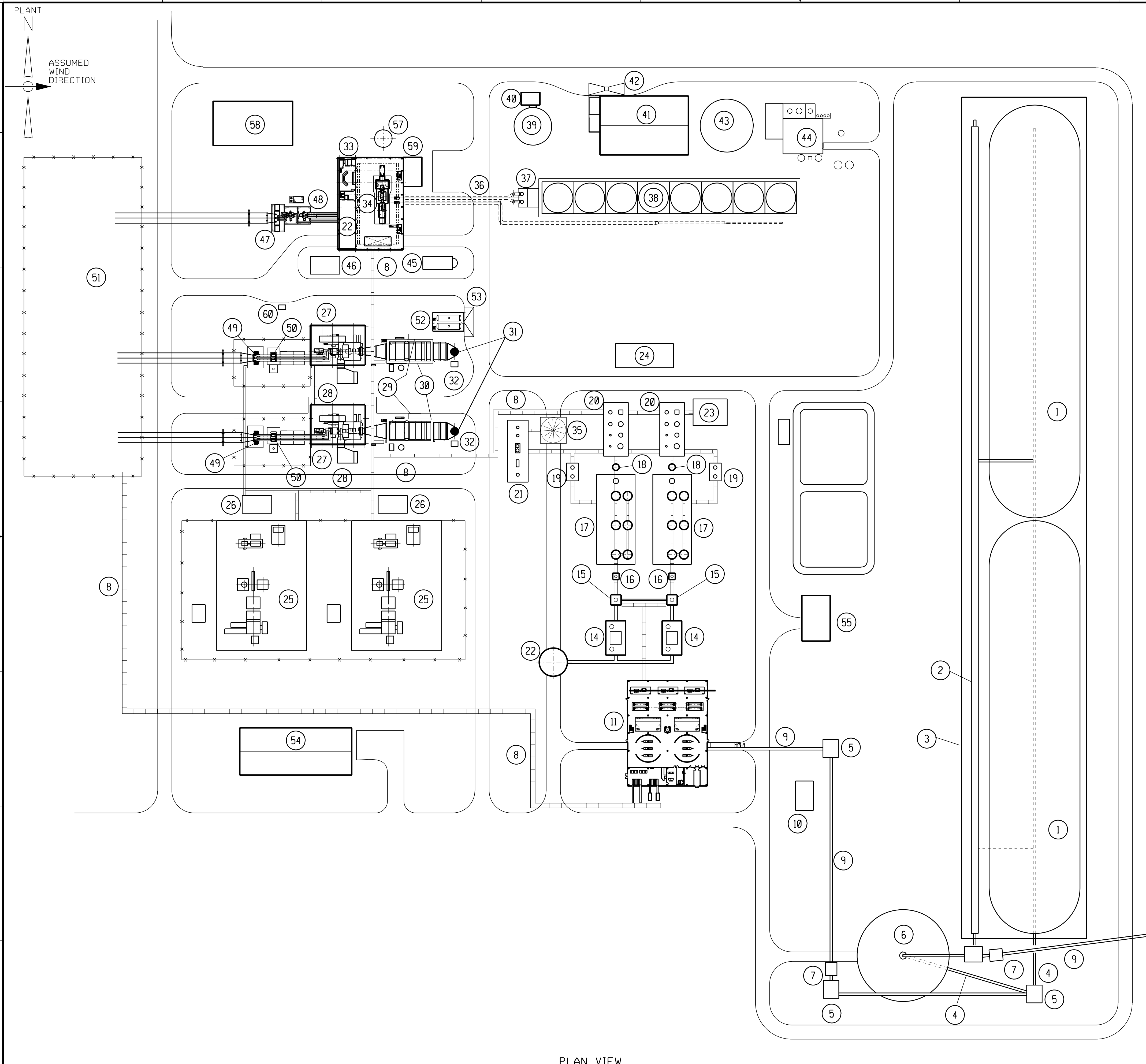
2. Appendix A-2 Liquid CO_2 / Coal Slurry Drawings

1. **IGCC Plant with Liquid CO_2 / Coal Slurry Site Plan (EPRI-1-SK-111-002-101)**
2. **Liquid CO_2 / Coal Slurry/Feed Batch Process Plan at Grade Elevation 100 ft (EPRI-1-SK-156-002-100)**
3. **Liquid CO_2 / Coal Slurry/Feed Batch Process Plan at Grade Elevation 127 ft (EPRI-1-SK-156-002-101)**
4. **Liquid CO_2 / Coal Slurry/Feed Batch Process Plan at Grade Elevation 154 ft 6 in (EPRI-1-SK-156-002-102)**
5. **Liquid CO_2 / Coal Slurry/Feed Batch Process Plan at Grade Elevation 218 ft 6 in (EPRI-1-SK-156-002-103)**
6. **Liquid CO_2 / Coal Slurry/Feed Batch Process Plan at Grade Elevation 293 ft 6 in (EPRI-1-SK-156-002-104)**
7. **Liquid CO_2 / Coal Slurry/Feed Batch Process Vertical Section A-A (EPRI-1-SK-156-002-105)**
8. **Liquid CO_2 / Coal Slurry/Feed Batch Process Vertical Section B-B (EPRI-1-SK-156-002-106)**
9. **Liquid CO_2 / Coal Slurry/Feed Batch Process Vertical Section C-C (EPRI-1-SK-156-002-107)**
10. **Liquid CO_2 / Coal Slurry/Feed Continuous Process Vertical Section B-B (EPRI-1-SK-156-002-206)**



PLANT SITE DESCRIPTION

1 COAL STORAGE
2 COAL TRAVELING STACKER
3 COAL STORAGE BUILDING
4 COAL RECLAIM CONVEYOR
5 COAL TRANSFER STRUCTURE
6 EMERGENCY COAL PILE
7 COAL SAMPLE SYSTEM
8 UTILITY BRIDGE (TYPICAL)
9 BELT CONVEYOR (TYPICAL)
10 COAL ELECTRICAL BUILDING
11 COAL SLURRY BATCH-PROCESS BUILDING
12 NOT USED
13 NOT USED
14 SLAG PROCESSING AREA AND WATER HANDLING
15 GASIFIER
16 GAS SCRUBBER
17 SHIFT REACTION SECTION
18 MERCURY REMOVAL
19 SOUR WATER STRIPPERS
20 ACID GAS REMOVAL
21 CLAUS PLANT
22 SLAG SILO
23 CO2 COMPRESSION
24 ELECTRICAL ROOM/ELECTRICAL BUILDING
25 AIR SEPARATION UNIT (ASU)
26 ASU ELECTRICAL BUILDING
27 COMBUSTION TURBINE (CT)
28 AIR INLET FILTER
29 SCR SKID
30 HEAT RECOVERY STEAM GENERATOR (HRSG)
31 STACK
32 CEMS ENCLOSURE
33 CONTROL ROOM
34 STEAM TURBINE GENERATOR
35 SULFUR STORAGE
36 CIRCULATING WATER PIPING
37 CIRCULATING WATER PUMPS
38 COOLING TOWER
39 FIRE/SERVICE WATER TANK
40 FIRE/SERVICE WATER PUMP HOUSE
41 WATER TREATMENT FACILITY
42 CHEMICAL TRUCK UNLOADING
43 RAW WATER STORAGE TANK
44 ZERO LIQUID DISCHARGE
45 AUXILIARY BOILER
46 EMERGENCY DIESEL GENERATOR
47 STG STEP-UP TRANSFORMER
48 GENERATOR CIRCUIT BREAKER
49 CTG STEP-UP TRANSFORMER
50 AUXILIARY TRANSFORMER
51 SWITCHYARD
52 AMMONIA STORAGE TANKS & PUMPS
53 AMMONIA TRUCK UNLOADING AREA
54 WAREHOUSE
55 VEHICLE MAINTENANCE GARAGE
56 STORM WATER POND
57 DEMINERALIZED WATER TANK
58 ADMINISTRATION/VISITORS BUILDING
59 WORKSHOP & STORES
60 OILY WATER SEPARATOR

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
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C	02 07 13	ISSUED FOR INFORMATION	VJB		VJB	HNG			HNG
B	06 27 12	GENERAL UPDATE	JEV		JEV	HNG			HNG
A	04 30 12	INITIAL ISSUE	JEV		JEV	HNG			HNG

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LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365S/C18469

2x1 COP GASIFIER IGCC
SITE PLAN
LIQUID CO2/PRB SLURRY CASE

SCALE: 1"=80'
DRAWING SIZE: ARCH D (36" x 24")
WORLEYPARSONS DWG. NO.: EPRI-1-SK-111-002-101
REV: C

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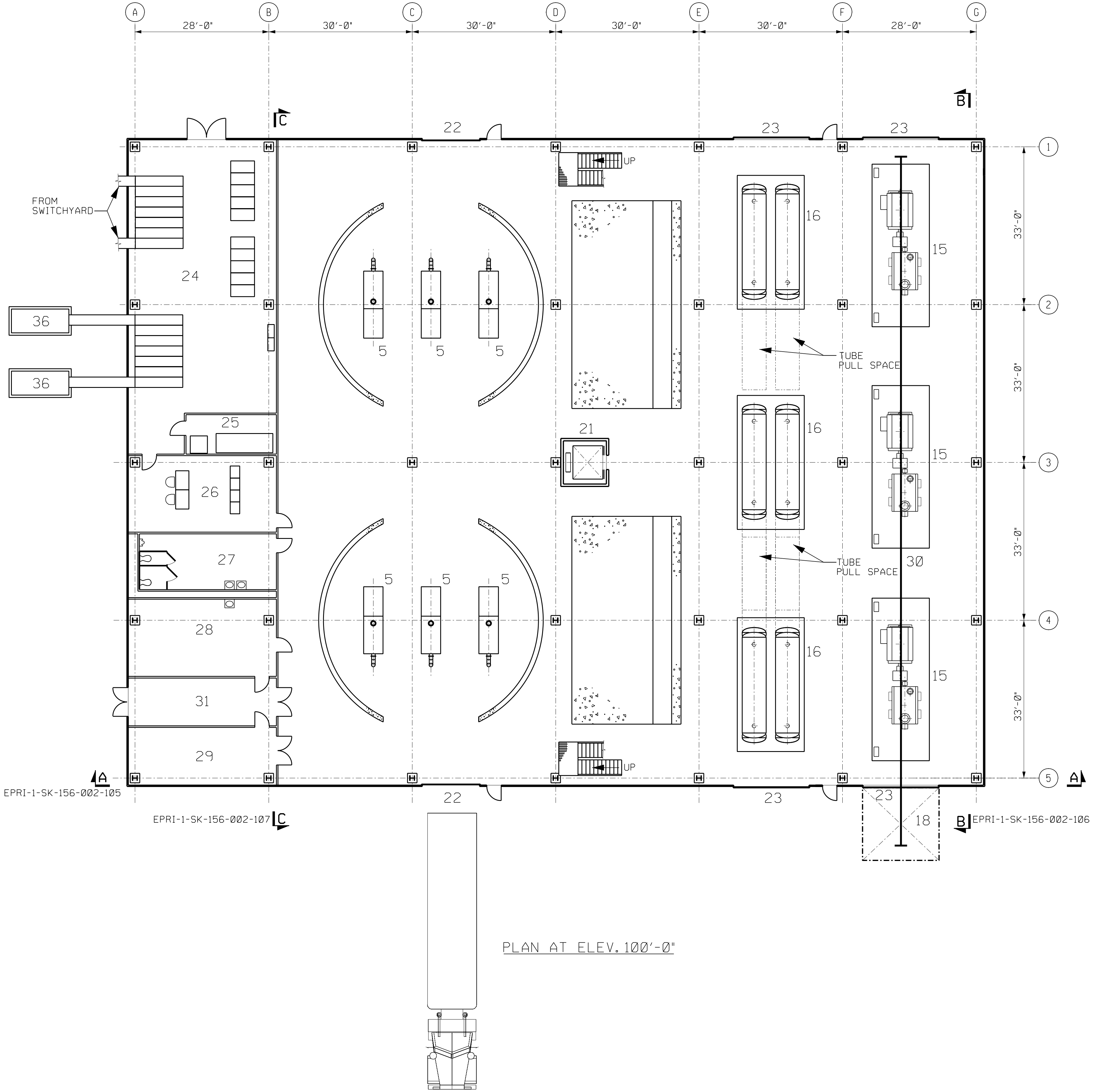

PLAN AT ELEV. 100'-0"

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SCREW PUMP
6 BULK SOLIDS COOLER
7 ROTARY FEEDER
8 FLOP GATE
9 MIXING VESSEL
10 GASIFIER SLURRY FEED PUMP
11 BAG FILTER
12 VENT FAN
13 NOT USED
14 NOT USED
15 REFRIGERATION COMPRESSOR DRIVELINE
16 REFRIGERATION HEAT TRANSFER SKID
17 EXPANSION HEAD TANK
18 DROP ZONE
19 CO2 EXPANSION TURBINE
20 CO2 CONDENSER W/DESUPERHEATER
21 ELEVATOR
22 ROLL UP DOOR
23 SLIDING DOOR
24 ELECTRICAL ROOM
25 BATTERY ROOM
26 CONTROL ROOM
27 LAVATORY
28 MEETING ROOM
29 STORAGE ROOM
30 MONORAIL
31 VESTIBULE
32 TRIPPER CONVEYOR
33 CHILLER COOLING CIRCULATING PUMP
34 BIN VENT FILTER
35 CO2 CONDENSER FORWARDING PUMP
36 TRANSFORMER

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
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SCALE: 3/32" = 1'

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/TECH. SPEC.	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
C	02/07/13	ISSUED FOR INFORMATION	VJB		VJB				HNG
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PROJECT ENGINEERING MANAGER:
PROJECT MANAGER: HN GOLDSTEIN

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LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365/C18469

GENERAL ARRANGEMENT
LIQ CO2/PRB SLURRY FEED BATCH-PROCESS
PLAN AT GRADE ELEV. 100'-0"

SCALE 3/32"=1'-0"
DRAWING SIZE ARCH D (36" x 24")
WORLEYPARSONS DWG. NO. EPRI-1-SK-156-002-100
REV C

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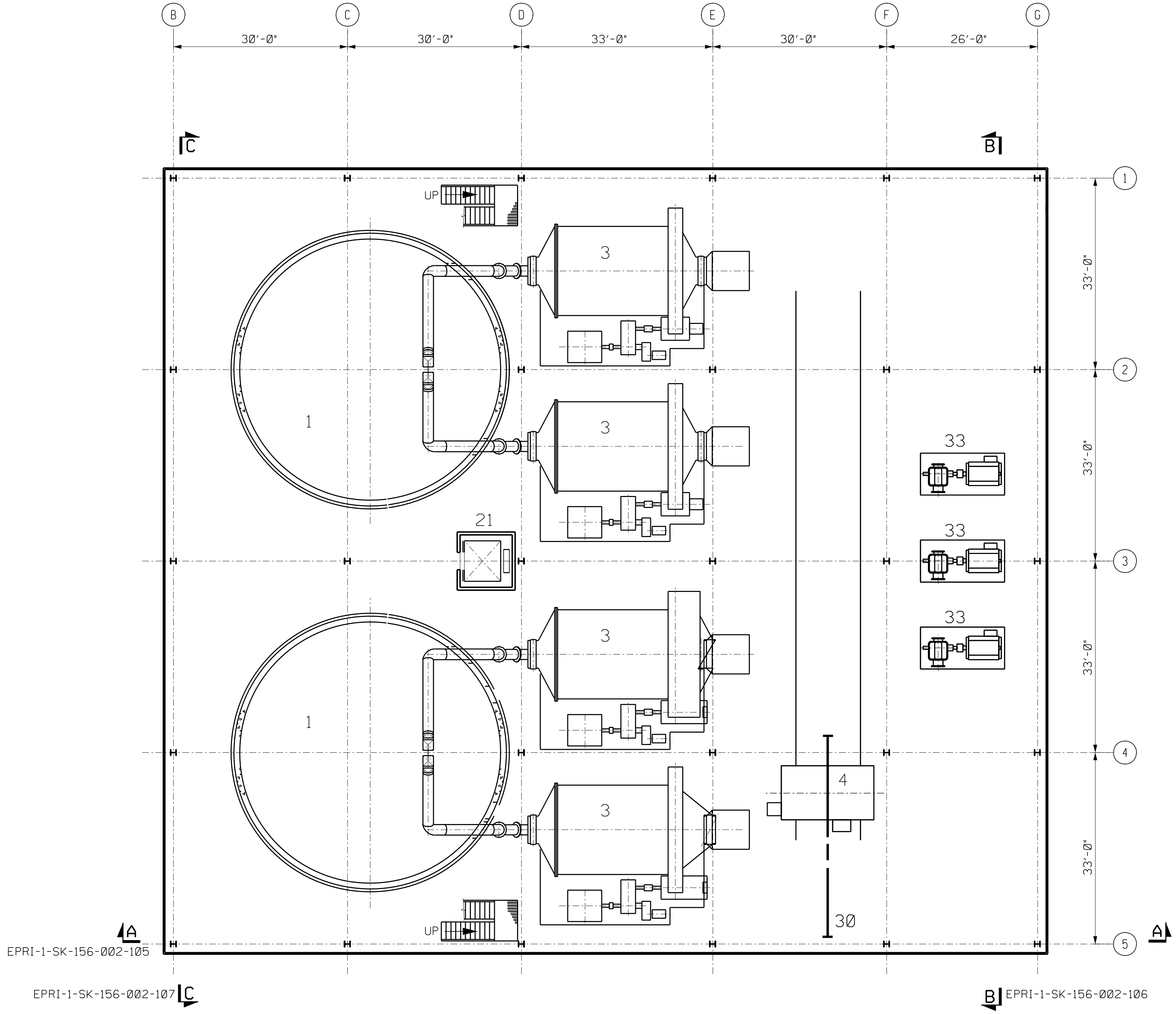

PLAN AT ELEV. 127'-0"

PLANT DESCRIPTION

1. DAY BIN (4100 TONS)
2. WEIGH FEEDER
3. ROD MILL
4. ROD MILL RECHARGING UNIT
5. SCREW PUMP
6. BULK SOLIDS COOLER
7. ROTARY FEEDER
8. FLOP GATE
9. MIXING VESSEL
10. GASIFIER SLURRY FEED PUMP
11. BAG FILTER
12. VENT FAN
13. NOT USED
14. NOT USED
15. REFRIGERATION COMPRESSOR DRIVELINE
16. REFRIGERATION HEAT TRANSFER SKID
17. EXPANSION HEAD TANK
18. DROP ZONE
19. CO2 EXPANSION TURBINE
20. CO2 CONDENSER W/DESUPERHEATER
21. ELEVATOR
22. ROLL UP DOOR
23. SLIDING DOOR
24. ELECTRICAL ROOM
25. BATTERY ROOM
26. CONTROL ROOM
27. LAVATORY
28. MEETING ROOM
29. STORAGE ROOM
30. MONORAIL
31. VESTIBULE
32. TRIPPER CONVEYOR
33. CHILLER COOLING CIRCULATING PUMP
34. BIN VENT FILTER
35. CO2 CONDENSER FORWARDING PUMP
36. TRANSFORMER

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
NOT FOR CONSTRUCTION

SCALE: 3/32" = 1'

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/TECH. SPEC.	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
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B	06 27 12	GENERAL UPDATE	JEV		JEV				HNG
A	04 30 12	ISSUED FOR REVIEW	JEV		JEV				HNG

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CHECKED BY:
LEAD DESIGNER: JE VEEN
ENGINEER/TECH SPECIALIST:
PROJECT ENGINEERING MANAGER:
PROJECT MANAGER: HN GOLDSTEIN

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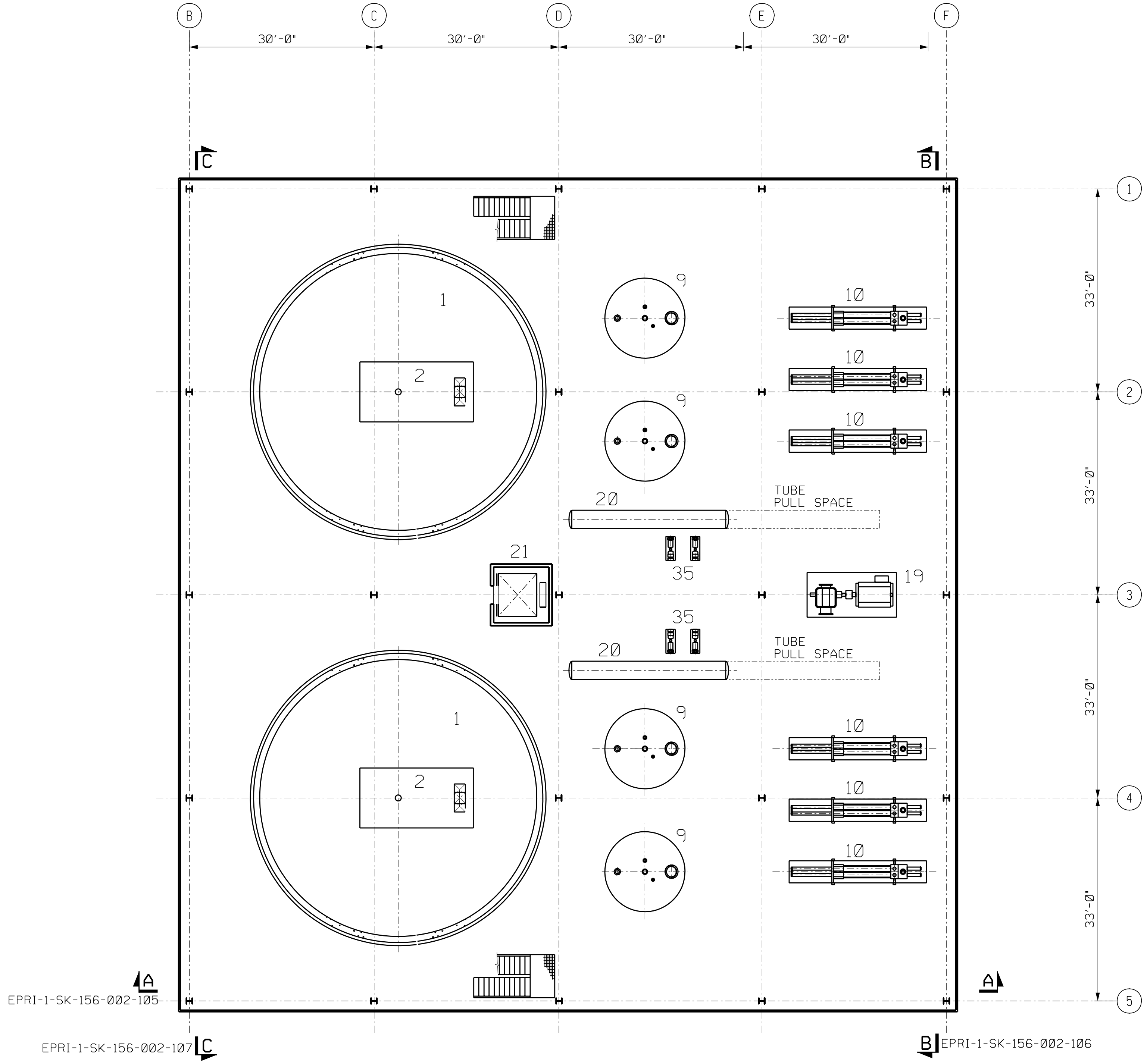
WorleyParsons resources & energy

CLIENT/PROJECT TITLE
US DEPARTMENT OF ENERGY
ELECTRIC POWER RESEARCH INSTITUTE
LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365/C18469

GENERAL ARRANGEMENT
LIQ CO2/PRB SLURRY FEED BATCH-PROCESS
PLAN AT ELEV. 127'-0"

SCALE: 3/32"=1'-0"
DRAWING SIZE: ARCH D (36" x 24")
WORLEYPARSONS DWG. NO.: EPRI-1-SK-156-002-101
REV: C

\epri-1-sk-156-002-101.dgn 2/11/2013 1:56:23 PM



PLAN AT ELEV. 154'-6"

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SCREW PUMP
6 BULK SOLIDS COOLER
7 ROTARY FEEDER
8 FLOP GATE
9 MIXING VESSEL
10 GASIFIER SLURRY FEED PUMP
11 BAG FILTER
12 VENT FAN
13 NOT USED
14 NOT USED
15 REFRIGERATION COMPRESSOR DRIVELINE
16 REFRIGERATION HEAT TRANSFER SKID
17 EXPANSION HEAD TANK
18 DROP ZONE
19 CO2 EXPANSION TURBINE
20 CO2 CONDENSER W/DESUPERHEATER
21 ELEVATOR
22 ROLL UP DOOR
23 SLIDING DOOR
24 ELECTRICAL ROOM
25 BATTERY ROOM
26 CONTROL ROOM
27 LAVATORY
28 MEETING ROOM
29 STORAGE ROOM
30 MONORAIL
31 VESTIBULE
32 TRIPPER CONVEYOR
33 CHILLER COOLING CIRCULATING PUMP
34 BIN VENT FILTER
35 CO2 CONDENSER FORWARDING PUMP
36 TRANSFORMER

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
NOT FOR CONSTRUCTION

10 0 10 20 30
SCALE: 3/32" = 1'

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/ TECH. SPEC.	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
C	02 07 13	ISSUED FOR INFORMATION	VJB		VJB				HNG
B	06 27 12	GENERAL UPDATE	JEV		JEV				HNG
A	04 30 12	ISSUED FOR REVIEW	JEV		JEV				HNG

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LEAD DESIGNER: JE VEEN
ENGINEER/TECH SPECIALIST:
PROJECT ENGINEERING MANAGER:
PROJECT MANAGER: HN GOLDSTEIN

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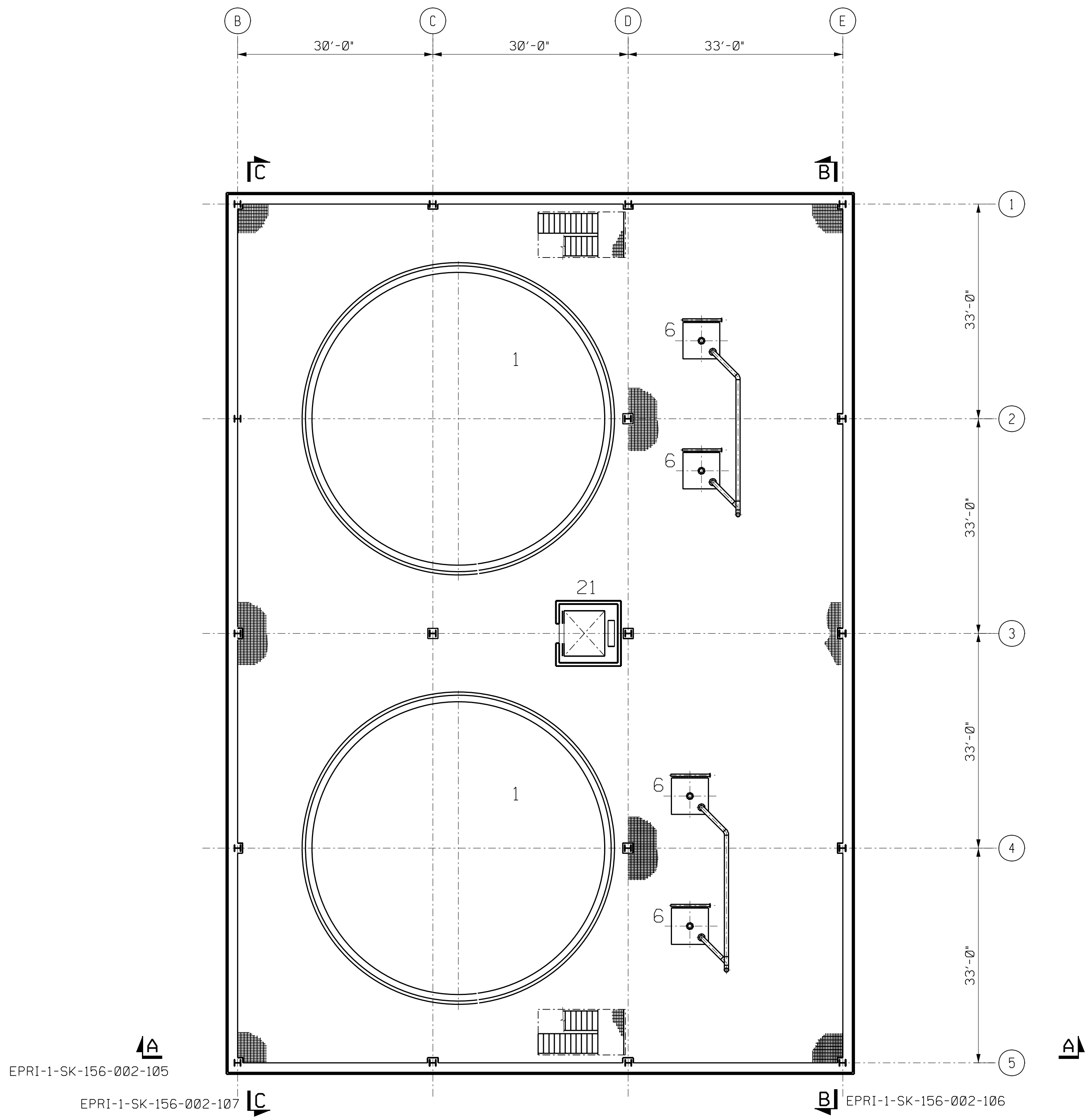
CLIENT/PROJECT TITLE
US DEPARTMENT OF ENERGY
ELECTRIC POWER RESEARCH INSTITUTE
LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365/C18469

GENERAL ARRANGEMENT
LIQ CO2/PRB SLURRY FEED BATCH-PROCESS
PLAN AT ELEV. 154'-6"

SCALE 3/32"=1'-0"
DRAWING SIZE ARCH D (36" x 24")
WORLEYPARSONS DWG. NO. EPRI-1-SK-156-002-102
REV C



PLAN AT ELEV. 218'-6"

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SCREW PUMP
6 BULK SOLIDS COOLER
7 ROTARY FEEDER
8 FLOP GATE
9 MIXING VESSEL
10 GASIFIER SLURRY FEED PUMP
11 BAG FILTER
12 VENT FAN
13 NOT USED
14 NOT USED
15 REFRIGERATION COMPRESSOR DRIVELINE
16 REFRIGERATION HEAT TRANSFER SKID
17 EXPANSION HEAD TANK
18 DROP ZONE
19 CO2 EXPANSION TURBINE
20 CO2 CONDENSER W/DESUPERHEATER
21 ELEVATOR
22 ROLL UP DOOR
23 SLIDING DOOR
24 ELECTRICAL ROOM
25 BATTERY ROOM
26 CONTROL ROOM
27 LAVATORY
28 MEETING ROOM
29 STORAGE ROOM
30 MONORAIL
31 VESTIBULE
32 TRIPPER CONVEYOR
33 CHILLER COOLING CIRCULATING PUMP
34 BIN VENT FILTER
35 CO2 CONDENSER FORWARDING PUMP
36 TRANSFORMER

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
NOT FOR CONSTRUCTION

10 0 10 20 30
SCALE: 3/32" = 1'

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/ TECH. SPEC.	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
C	02 07 13	ISSUED FOR INFORMATION	VJB		VJB				HNG
B	06 27 12	GENERAL UPDATE	JEV		JEV				HNG
A	04 30 12	ISSUED FOR REVIEW	JEV		JEV				HNG

PRELIMINARY STATUS DATE
LDE HN GOLDSTEIN 02/07/13
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LDE / /
REPRESENTS REVIEWED AND APPROVED DESIGN. ANY PORTION MARKED "HOLD" RETAINS PRELIMINARY STATUS.

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DRAWN BY: JEV
CHECKED BY:
LEAD DESIGNER: JE VEEN
ENGINEER/TECH SPECIALIST:
PROJECT ENGINEERING MANAGER:
PROJECT MANAGER: HN GOLDSTEIN

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CLIENT/PROJECT TITLE
US DEPARTMENT OF ENERGY
ELECTRIC POWER RESEARCH INSTITUTE
LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365/C18469

GENERAL ARRANGEMENT
LIQ CO2/PRB SLURRY FEED BATCH-PROCESS
PLAN AT ELEV. 218'-6"

SCALE: 3/32"=1'-0"
DRAWING SIZE: ARCH D (36" x 24")
WORLEYPARSONS DWG. NO.: EPRI-1-SK-156-002-103
REV: C

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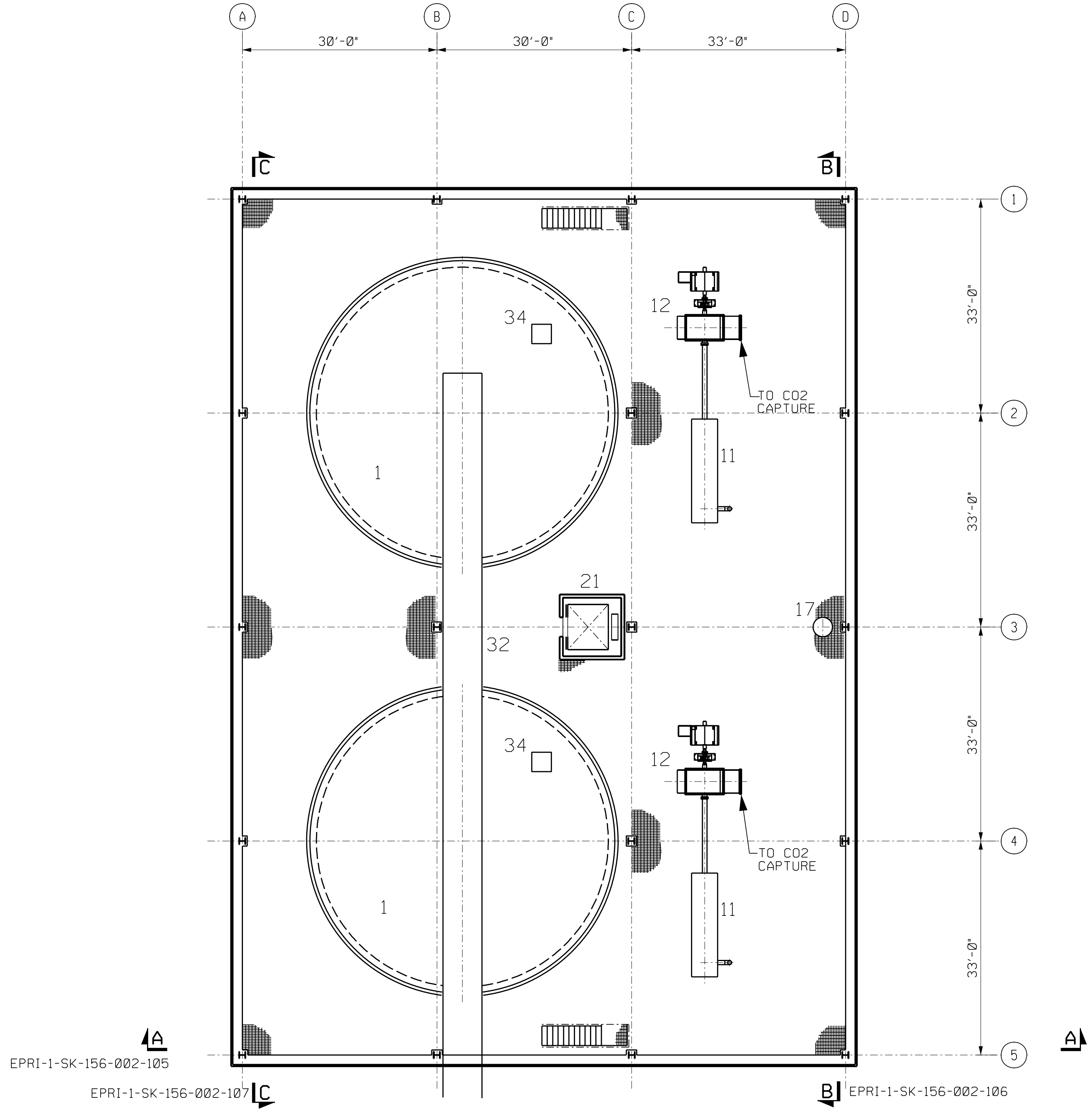

PLAN AT ELEV. 288'-0"

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SCREW PUMP
6 BULK SOLIDS COOLER
7 ROTARY FEEDER
8 FLOP GATE
9 MIXING VESSEL
10 GASIFIER SLURRY FEED PUMP
11 BAG FILTER
12 VENT FAN
13 NOT USED
14 NOT USED
15 REFRIGERATION COMPRESSOR DRIVELINE
16 REFRIGERATION HEAT TRANSFER SKID
17 EXPANSION HEAD TANK
18 DROP ZONE
19 CO2 EXPANSION TURBINE
20 CO2 CONDENSER W/DESUPERHEATER
21 ELEVATOR
22 ROLL UP DOOR
23 SLIDING DOOR
24 ELECTRICAL ROOM
25 BATTERY ROOM
26 CONTROL ROOM
27 LAVATORY
28 MEETING ROOM
29 STORAGE ROOM
30 MONORAIL
31 VESTIBULE
32 TRIPPER CONVEYOR
33 CHILLER COOLING CIRCULATING PUMP
34 BIN VENT FILTER
35 CO2 CONDENSER FORWARDING PUMP
36 TRANSFORMER

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
NOT FOR CONSTRUCTION

10 0 10 20 30
SCALE: 3/32" = 1'

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/ TECH. SPEC.	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
C	02 07 13	ISSUED FOR INFORMATION	VJB		VJB				HNG
B	06 27 12	GENERAL UPDATE	JEV		JEV				HNG
A	04 30 12	ISSUED FOR REVIEW	JEV		JEV				HNG

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DRAWN BY JEV
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LEAD DESIGNER JE VEEN
ENGINEER/TECH SPECIALIST
PROJECT ENGINEERING MANAGER
PROJECT MANAGER HN GOLDSTEIN

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US DEPARTMENT OF ENERGY
ELECTRIC POWER RESEARCH INSTITUTE
LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365/C18469

GENERAL ARRANGEMENT
LIQ CO2/PRB SLURRY FEED BATCH-PROCESS
PLAN AT ELEV. 293'-6"

SCALE 3/32"=1'-0"
DRAWING SIZE ARCH D (36" x 24")
WORLEYPARSONS DWG. NO. EPRI-1-SK-156-002-104
REV C

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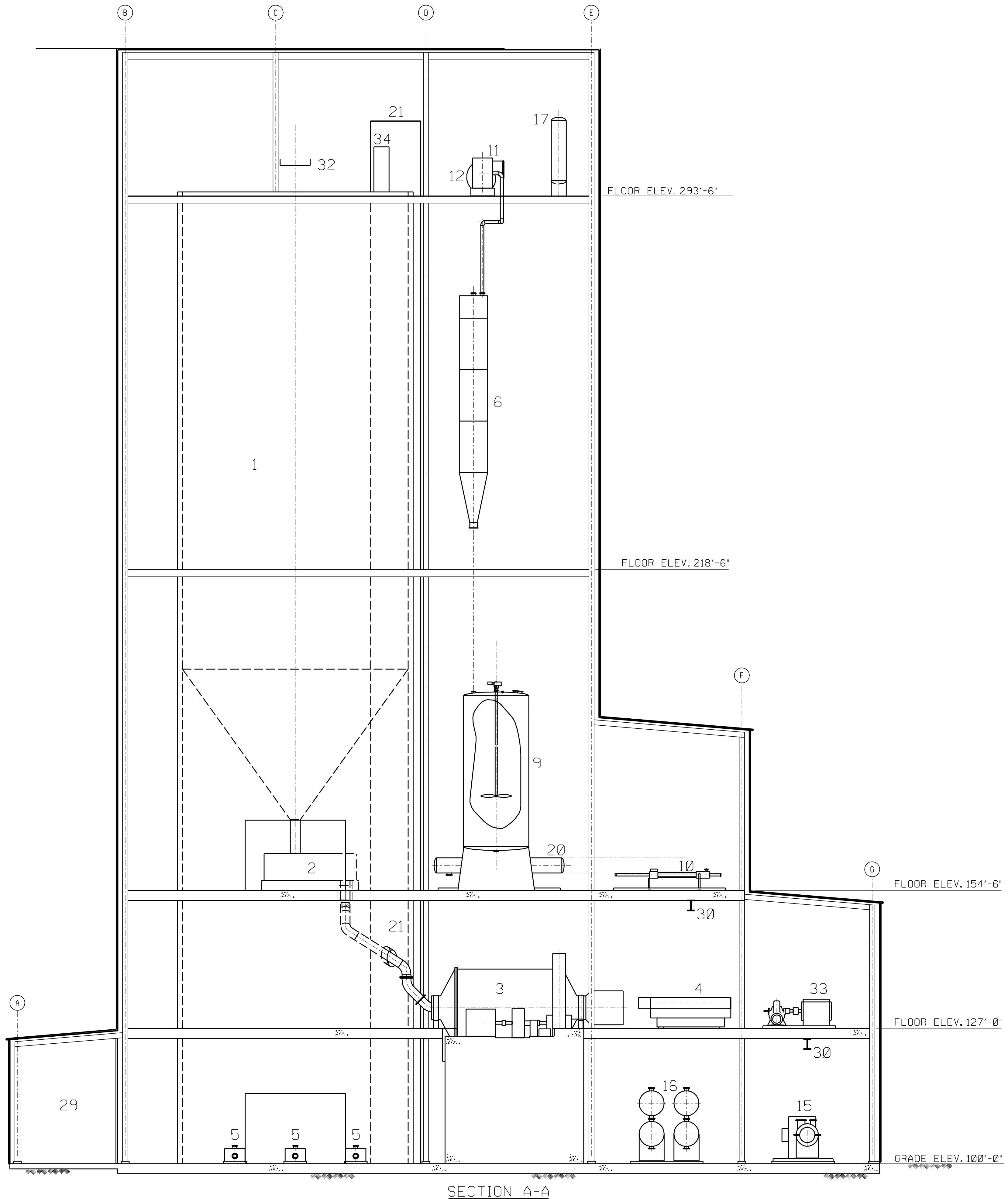

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SCREW PUMP
6 BULK SOLIDS COOLER
7 ROTARY FEEDER
8 FLOP GATE
9 MIXING VESSEL
10 GASIFIER SLURRY FEED PUMP
11 BAG FILTER
12 VENT FAN
13 NOT USED
14 NOT USED
15 REFRIGERATION COMPRESSOR DRIVELINE
16 REFRIGERATION HEAT TRANSFER SKID
17 EXPANSION HEAD TANK
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29 STORAGE ROOM
30 MONORAIL
31 VESTIBULE
32 TRIPPER CONVEYOR
33 CHILLER COOLING CIRCULATING PUMP
34 BIN VENT FILTER
35 CO2 CONDENSER FORWARDING PUMP
36 TRANSFORMER

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
NOT FOR CONSTRUCTION

10 0 10 20 30
SCALE: 3/32" = 1'

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/ TECH. SPEC.	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
C	02 07 13	ISSUED FOR INFORMATION	VJB		VJB				HNG
B	06 27 12	GENERAL ISSUE	JEV		JEV				HNG
A	04 30 12	ISSUE FOR REVIEW	JEV		JEV				HNG

PRELIMINARY STATUS DATE
LDE HN GOLDSTEIN 02/07/13
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LEAD DESIGNER JE VEEN
ENGINEER/TECH SPECIALIST
PROJECT ENGINEERING MANAGER
PROJECT MANAGER HN GOLDSTEIN

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PE: STATE:
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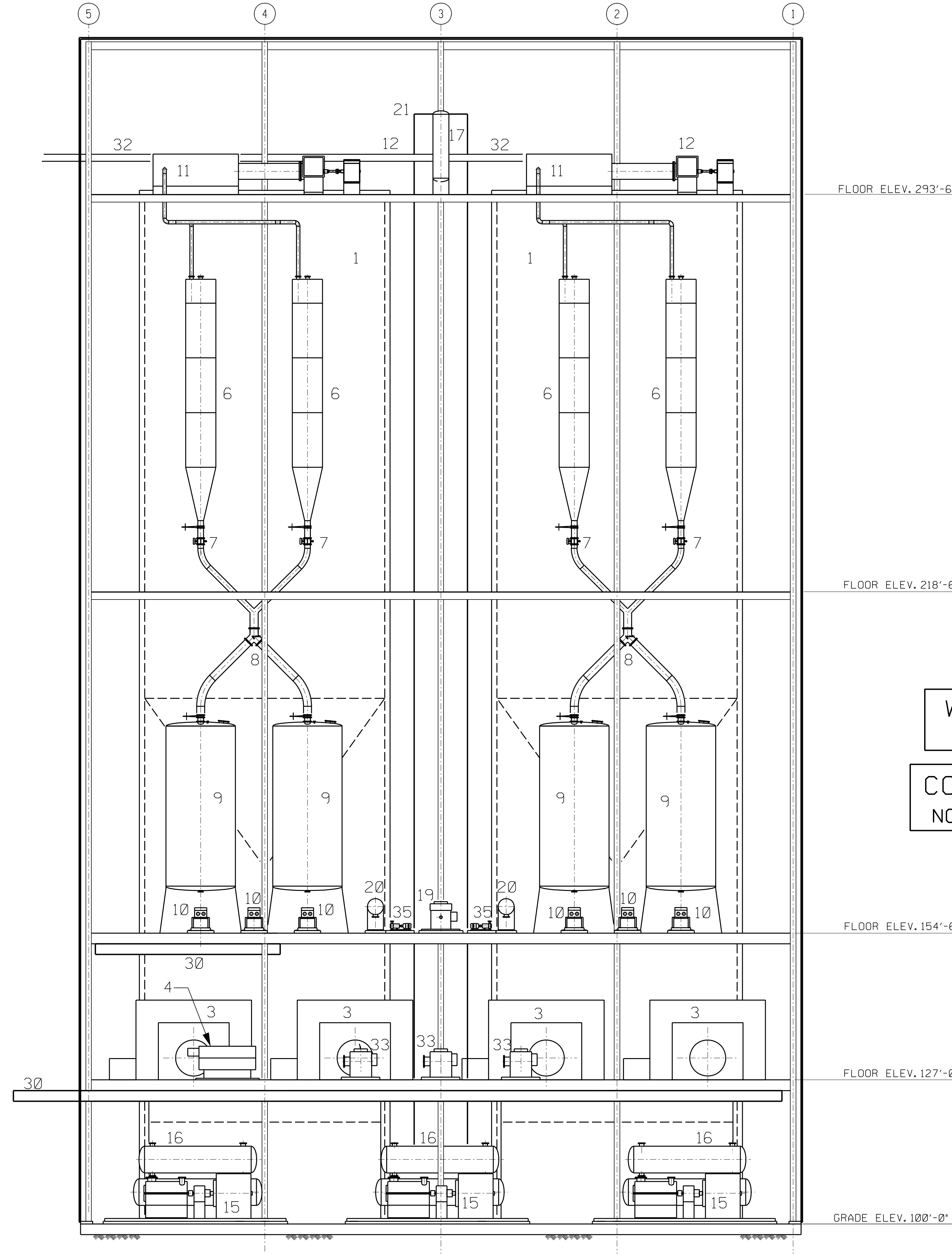
resources & energy

CLIENT/PROJECT TITLE
US DEPARTMENT OF ENERGY
ELECTRIC POWER RESEARCH INSTITUTE
LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365/C18469

GENERAL ARRANGEMENT
LIQ CO2/PRB SLURRY FEED BATCH-PROCESS
SECTION A-A

SCALE 3/32"=1'-0"
DRAWING SIZE ARCH D (36" x 24")
WORLEYPARSONS DWG. NO. EPRI-1-SK-111-002-105
REV C



SECTION B-B

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
NOT FOR CONSTRUCTION

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SCREW PUMP
6 BULK SOLIDS COOLER
7 ROTARY FEEDER
8 FLOP GATE
9 MIXING VESSEL
10 GASIFIER SLURRY FEED PUMP
11 BAG FILTER
12 VENT FAN
13 NOT USED
14 NOT USED
15 REFRIGERATION COMPRESSOR DRIVELINE
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26 CONTROL ROOM
27 LAVATORY
28 MEETING ROOM
29 STORAGE ROOM
30 MONORAIL
31 VESTIBULE
32 TRIPPER CONVEYOR
33 CHILLER COOLING CIRCULATING PUMP
34 BIN VENT FILTER
35 CO2 CONDENSER FOERWARDING PUMP
36 TRANSFORMER

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/ TECH.SPEC	LEAD DISC. ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
C	02 07	ISSUED FOR INFORMATION	VJB		VJB				HNG
B	06 27 12	GENERAL UPDATE	JEV		JEV				HNG
A	04 30 12	ISSUE FOR REVIEW	JEV		JEV				HNG

PRELIMINARY STATUS — DATE — INFORMATION ONLY - NOT TO BE USED FOR CONSTRUCTION.
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ORIGINATING PERSONNEL — PROFESSIONAL ENGINEER'S SEAL

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LEAD DESIGNER: JE VEEN
ENGINEER/TECH SPECIALIST:
PROJECT ENGINEERING MANAGER:
PROJECT MANAGER: HN GOLDSTEIN

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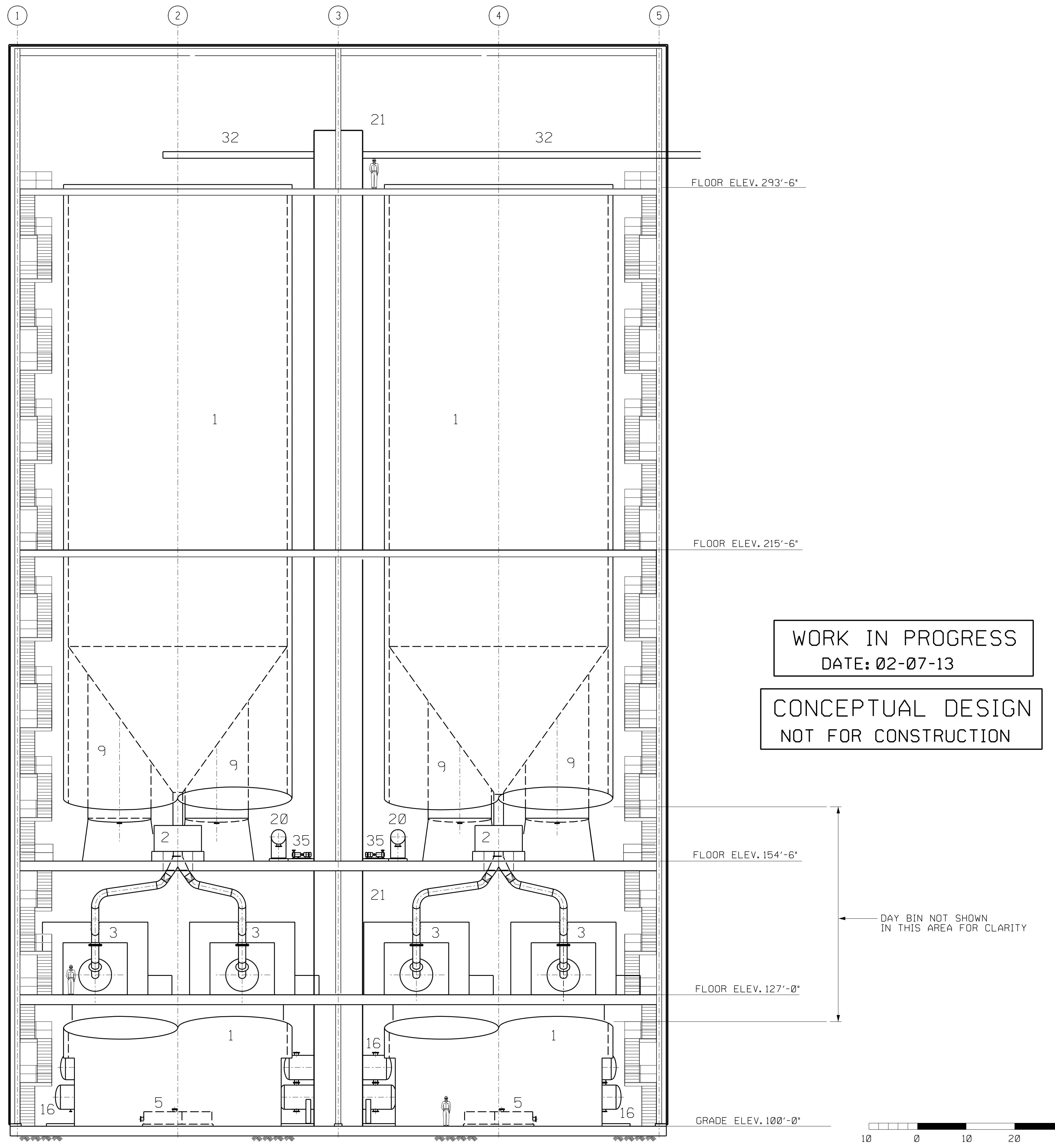
US DEPARTMENT OF ENERGY
ELECTRIC POWER RESEARCH INSTITUTE
LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365/C18469

GENERAL ARRANGEMENT
LIQ CO2/PRB SLURRY FEED BATCH-PROCESS
SECTION B-B

SCALE: 3/32"=1'-0"
DRAWING SIZE: ARCH D (36" x 24")
SCALE: 3/32" = 1'
WORLEYPARSONS DWG. NO.: EPRI-1-SK-156-002-106
REV: C



SECTION C-C

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
NOT FOR CONSTRUCTION

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SCREW PUMP
6 BULK SOLIDS COOLER
7 ROTARY FEEDER
8 FLOP GATE
9 MIXING VESSEL
10 GASIFIER SLURRY FEED PUMP
11 BAG FILTER
12 VENT FAN
13 NOT USED
14 NOT USED
15 REFRIGERATION COMPRESSOR DRIVELINE
16 REFRIGERATION HEAT TRANSFER SKID
17 EXPANSION HEAD TANK
18 DROP ZONE
19 CO2 EXPANSION TURBINE
20 CO2 CONDENSER W/DESUPERHEATER
21 ELEVATOR
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26 CONTROL ROOM
27 LAVATORY
28 MEETING ROOM
29 STORAGE ROOM
30 MONORAIL
31 VESTIBULE
32 TRIPPER CONVEYOR
33 CHILLER COOLING CIRCULATING PUMP
34 BIN VENT FILTER
35 CO2 CONDENSER FORWARDING PUMP
36 TRANSFORMER

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/ TECH. SPEC.	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
C	02 07 13	ISSUED FOR INFORMATION	VJB		VJB				HNG
B	10 24 12	GENERAL UPDATE	JEV		JEV				HNG
A	04 30 12	ISSUE FOR REVIEW	JEV		JEV				HNG

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LEAD DESIGNER: JE VEEN
ENGINEER/TECH SPECIALIST:
PROJECT ENGINEERING MANAGER:
PROJECT MANAGER: HN GOLDSTEIN

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LIC. NO.: __________ DATE: ______

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US DEPARTMENT OF ENERGY
ELECTRIC POWER RESEARCH INSTITUTE
LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P4236S/C18469

GENERAL ARRANGEMENT
LIQ CO2/PRB SLURRY FEED BATCH-PROCESS
SECTION C-C

SCALE: 3/32"=1'-0"
DRAWING SIZE: ARCH D (36" x 24")
WORLEYPARSONS DWG. NO.: EPRI-1-SK-156-002-107
REV: C

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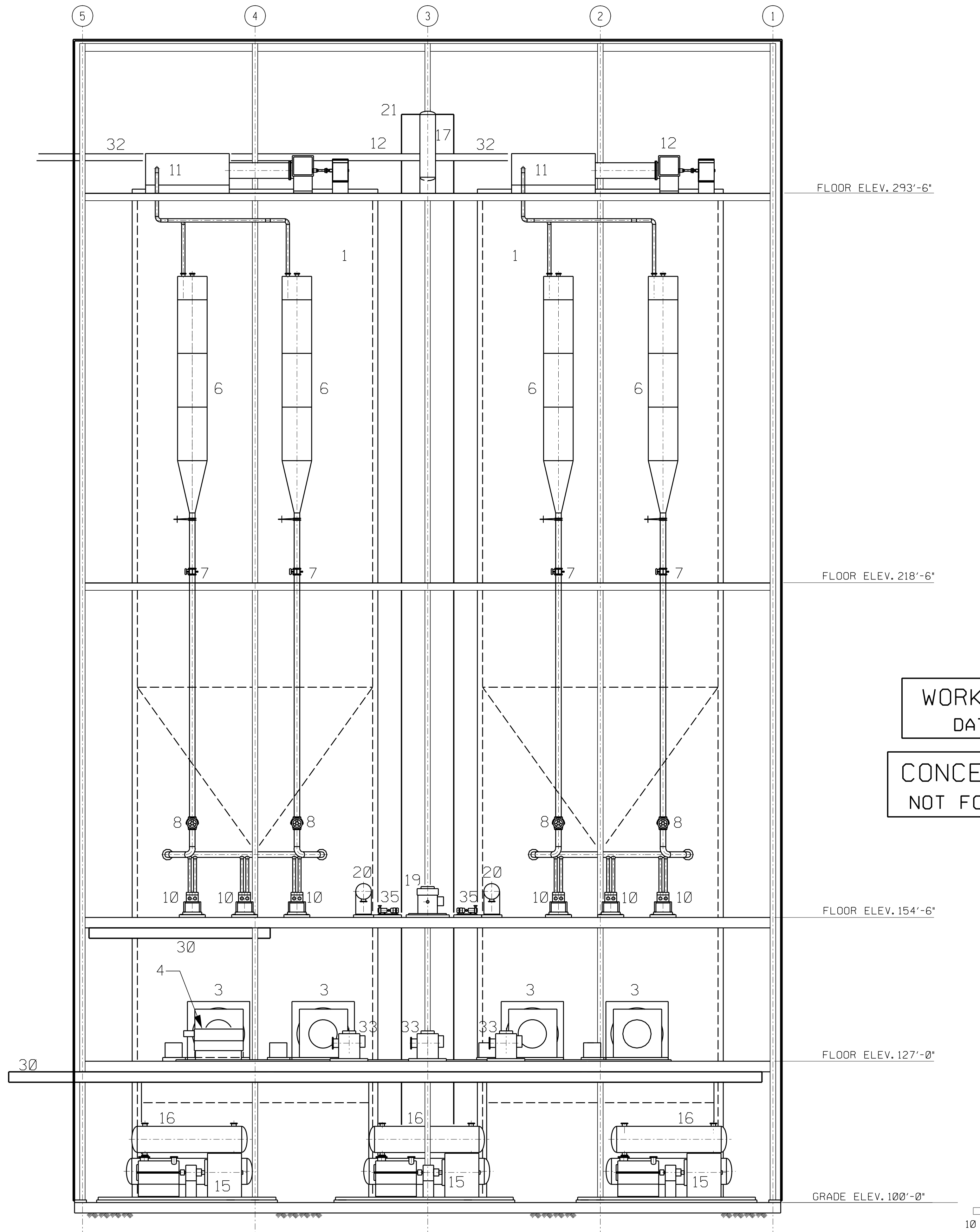

SECTION B-B

SCALE: 3/32" = 1'

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SCREW PUMP
6 BULK SOLIDS COOLER
7 ROTARY FEEDER COAL METERING
8 ROTARY FEEDER HIGH PRESSURE DISCHARGE
9 IN-LINE MIXER
10 GASIFIER SLURRY FEED PUMP
11 BAG FILTER
12 VENT FAN
13 NOT USED
14 NOT USED
15 REFRIGERATION COMPRESSOR DRIVELINE
16 REFRIGERATION HEAT TRANSFER SKID
17 EXPANSION HEAD TANK
18 DROP ZONE
19 CO2 EXPANSION TURBINE
20 CO2 CONDENSER W/DESUPERHEATER
21 ELEVATOR
22 ROLL UP DOOR
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32 TRIPPER CONVEYOR
33 CHILLER COOLING CIRCULATING PUMP
34 BIN VENT FILTER
35 CO2 CONDENSER FORWARDING PUMP
36 TRANSFORMER

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
NOT FOR CONSTRUCTION

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER
B	02/07/13	ISSUED FOR INFORMATION	VJB		VJB
A	06/20/12	ISSUE FOR REVIEW	JEV		JEV

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CHECKED BY:
LEAD DESIGNER: JE VEEN
ENGINEER/TECH SPECIALIST:
PROJECT ENGINEERING MANAGER:
PROJECT MANAGER: HN GOLDSTEIN

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WorleyParsons resources & energy

CLIENT/PROJECT TITLE
US DEPARTMENT OF ENERGY
ELECTRIC POWER RESEARCH INSTITUTE
LIQUID CO2/COAL SLURRY CONCEPTUAL DESIGN
EP-P42365/C18469

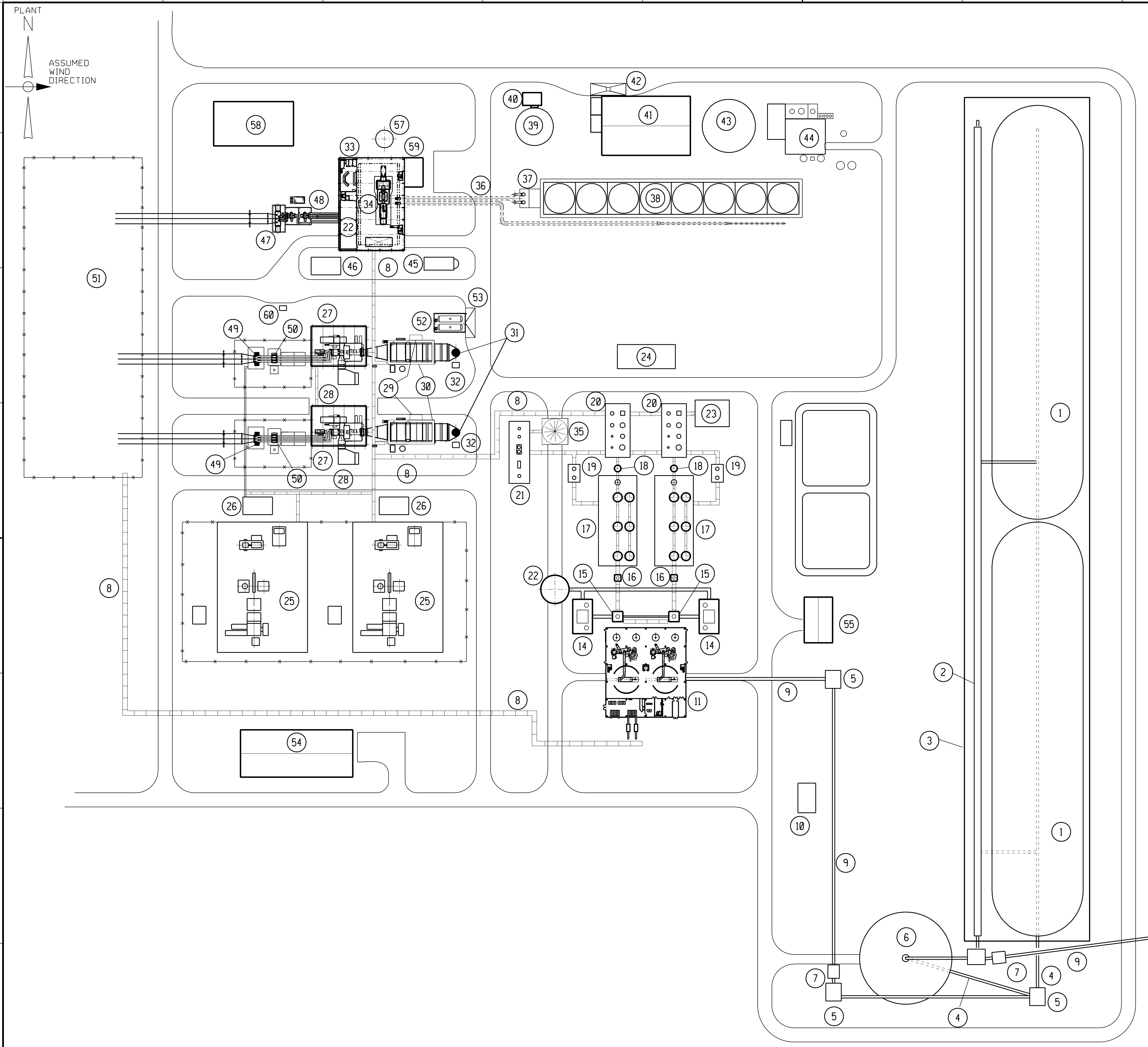
GENERAL ARRANGEMENT
LIQ CO2/PRB SLURRY CONTINUOUS FEED-PROCESS
SECTION B-B

SCALE 3/32"=1'-0" — DRAWING SIZE ARCH D (36" x 24")

WORLEYPARSONS DWG. NO. EPRI-1-SK-156-002-206 — REV B

3. Appendix A-3 Dry Coal Feed Drawings

1. **IGCC Plant with Dry Coal Feed Site Plan (EPRI-1-SK-111-002-500)**
2. **Dry Coal Feed Process Plan at Grade Elevation 100 ft (EPRI-1-SK-156-002-501)**
3. **Dry Coal Feed Process Plan at Grade Elevation 154 ft 6 in (EPRI-1-SK-156-002-502)**
4. **Dry Coal Feed Process Vertical Section (EPRI-1-SK-156-002-503)**



PLAN VIEW

PLANT SITE DESCRIPTION

1 COAL STORAGE
2 COAL TRAVELING STACKER
3 COAL STORAGE BUILDING
4 COAL RECLAIM CONVEYOR
5 COAL TRANSFER STRUCTURE
6 EMERGENCY COAL PILE
7 COAL SAMPLE SYSTEM
8 UTILITY BRIDGE (TYPICAL)
9 BELT CONVEYOR (TYPICAL)
10 COAL ELECTRICAL BUILDING
11 COAL DRY LOCK-HOPPER PROCESS BUILDING
12 NOT USED
13 NOT USED
14 SLAG PROCESSING AREA AND WATER HANDLING
15 GASIFIER
16 GAS SCRUBBER
17 SHIFT REACTION SECTION
18 MERCURY REMOVAL
19 SOUR WATER STRIPPERS
20 ACID GAS REMOVAL
21 CLAUS PLANT
22 SLAG SILO
23 CO2 COMPRESSION
24 ELECTRICAL ROOM/ELECTRICAL BUILDING
25 AIR SEPARATION UNIT (ASU)
26 ASU ELECTRICAL BUILDING
27 COMBUSTION TURBINE (CT)
28 AIR INLET FILTER
29 SCR SKID
30 HEAT RECOVERY STEAM GENERATOR (HRSG)
31 STACK
32 CEMS ENCLOSURE
33 CONTROL ROOM
34 STEAM TURBINE GENERATOR
35 SULFUR STORAGE
36 CIRCULATING WATER PIPING
37 CIRCULATING WATER PUMPS
38 COOLING TOWER
39 FIRE/SERVICE WATER TANK
40 FIRE/SERVICE WATER PUMP HOUSE
41 WATER TREATMENT FACILITY
42 CHEMICAL TRUCK UNLOADING
43 RAW WATER STORAGE TANK
44 ZERO LIQUID DISCHARGE
45 AUXILIARY BOILER
46 EMERGENCY DIESEL GENERATOR
47 STG STEP-UP TRANSFORMER
48 GENERATOR CIRCUIT BREAKER
49 CTG STEP-UP TRANSFORMER
50 AUXILIARY TRANSFORMER
51 SWITCHYARD
52 AMMONIA STORAGE TANKS & PUMPS
53 AMMONIA TRUCK UNLOADING AREA
54 WAREHOUSE
55 VEHICLE MAINTENANCE GARAGE
56 STORM WATER POND
57 DEMINERALIZED WATER TANK
58 ADMINISTRATION/VISITORS BUILDING
59 WORKSHOP & STORES
60 OILY WATER SEPARATOR

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80 0 80 160 240
SCALE: 1" = 80'

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2x1 COP GASIFIER IGCC
SITE PLAN
DRY PRB COAL LOCK HOPPER CASE

SCALE: 1"=80'
DRAWING SIZE: ARCH D (36" x 24")

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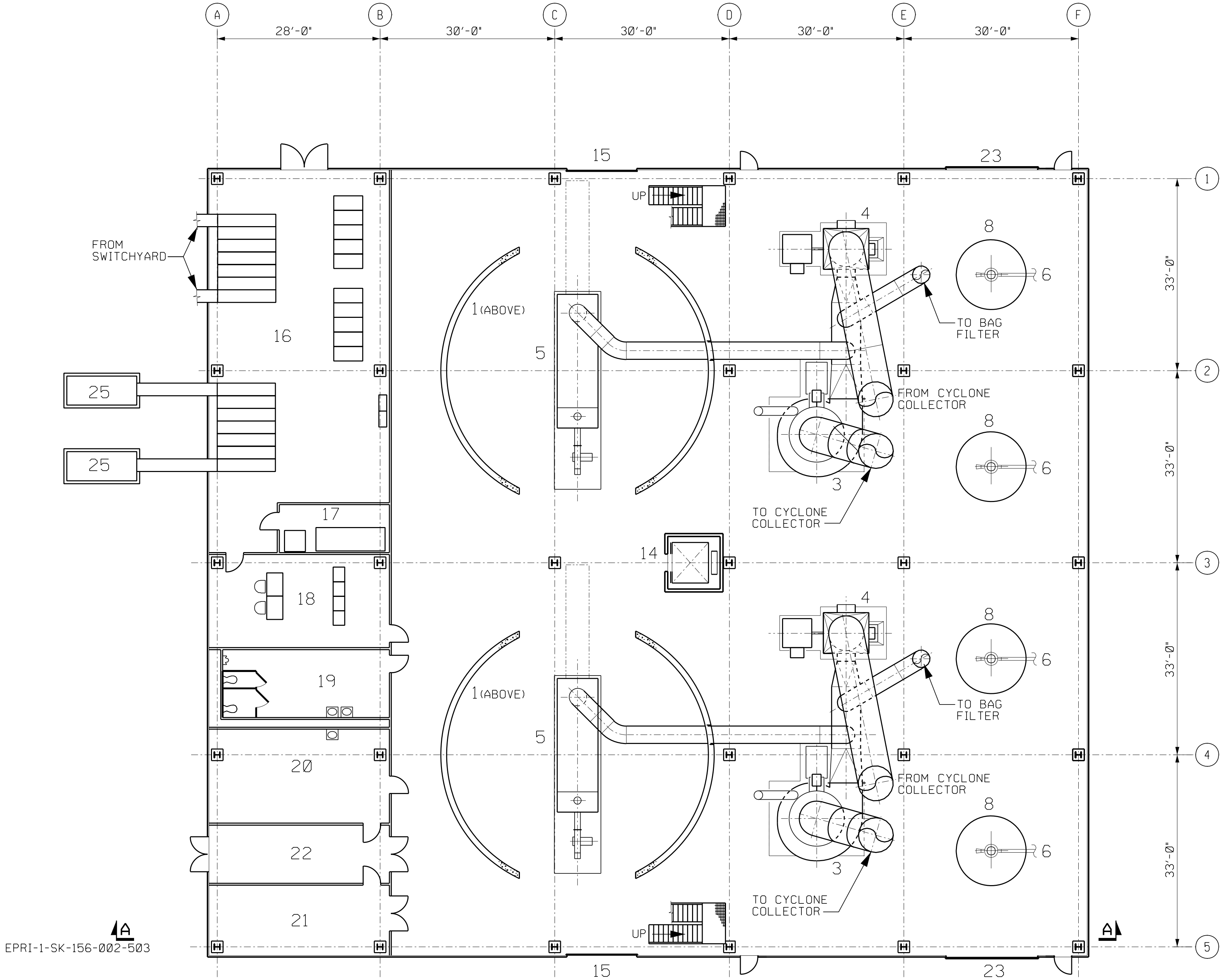

PLAN AT ELEV. 100'-0"

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 COAL/LIMESTONE ROLLER MILL
4 MAIN ROLLER MILL FAN
5 MILL AIR HEATER
6 FUEL (COAL/LIMESTONE) TRANSPORT PIPE
7 FUEL STORAGE INJECTOR
8 FUEL PRIMARY INJECTOR
9 PREPARED COAL/LIMESTONE SURGE BIN
10 FUEL (COAL/LIMESTONE) CYCLONE COLLECTOR
11 FUEL PREP DUST BAG FILTER
12 BAG FILTER EXHAUST FAN
13 FUEL SCREEN
14 ELEVATOR
15 ROLL UP DOOR
16 ELECTRICAL ROOM
17 BATTERY ROOM
18 CONTROL ROOM
19 LAVATORY
20 MEETING ROOM
21 STORAGE ROOM
22 VESTIBULE
23 TRIPPER CONVEYOR
24 BIN VENT FILTER
25 TRANSFORMER

WORK IN PROGRESS
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SCALE: 3/32" = 1'

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GENERAL ARRANGEMENT
DRY PRB COAL - LOCK HOPPER PROCESS
PLAN AT GRADE ELEV. 100'-0"

SCALE 3/32"=1'-0" — DRAWING SIZE ARCH D (36" x 24")

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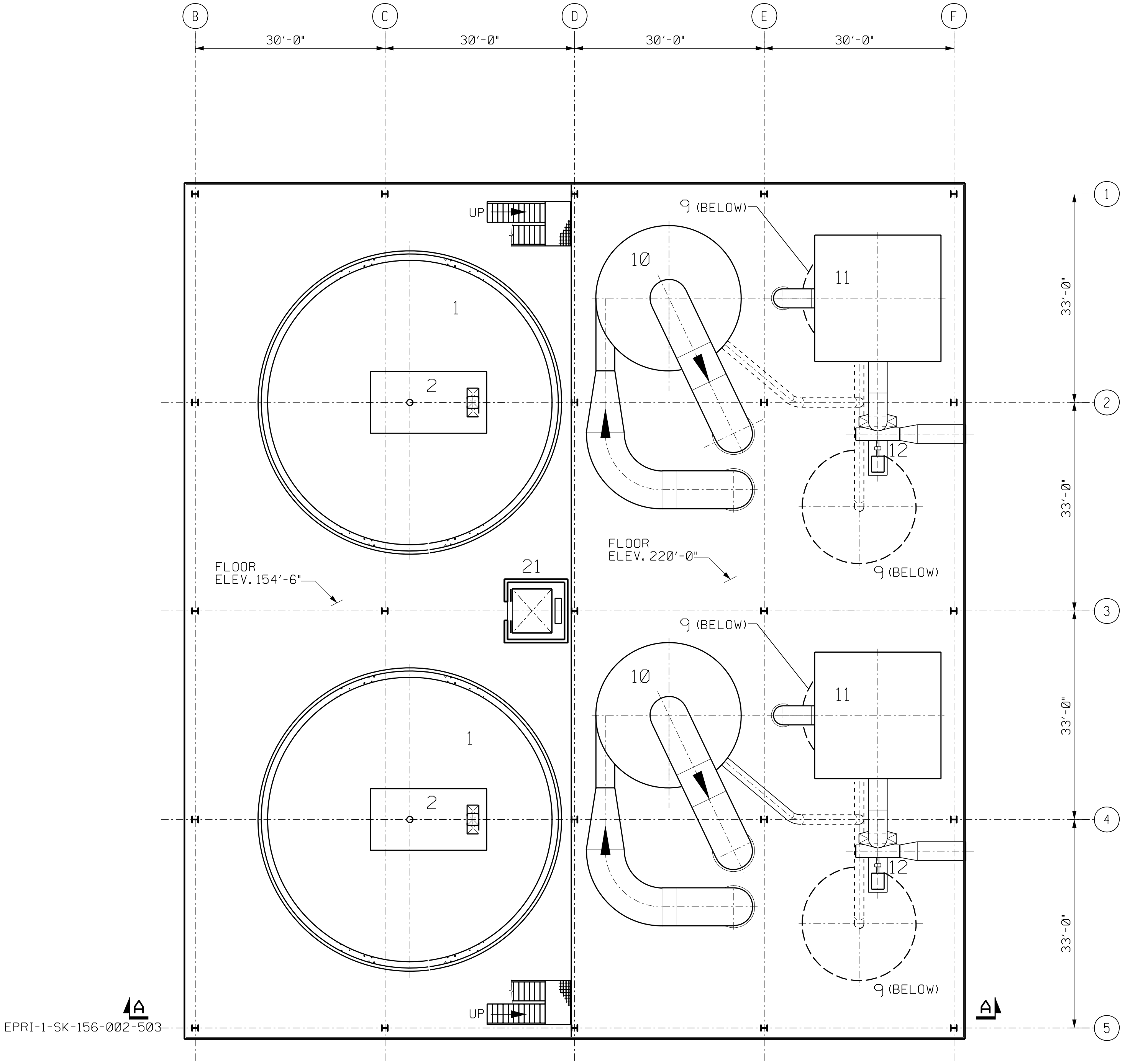

PLAN AT ELEV. 154'-6" & 220'-0"

PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 COAL/LIMESTONE ROLLER MILL
4 MAIN ROLLER MILL FAN
5 MILL AIR HEATER
6 FUEL (COAL/LIMESTONE) TRANSPORT PIPE
7 FUEL STORAGE INJECTOR
8 FUEL PRIMARY INJECTOR
9 PREPARED COAL/LIMESTONE SURGE BIN
10 FUEL (COAL/LIMESTONE) CYCLONE COLLECTOR
11 FUEL PREP DUST BAG FILTER
12 BAG FILTER EXHAUST FAN
13 FUEL SCREEN
14 ELEVATOR
15 ROLL UP DOOR
16 ELECTRICAL ROOM
17 BATTERY ROOM
18 CONTROL ROOM
19 LAVATORY
20 MEETING ROOM
21 STORAGE ROOM
22 VESTIBULE
23 TRIPPER CONVEYOR
24 BIN VENT FILTER
25 TRANSFORMER

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
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10 0 10 20 30
SCALE: 3/32" = 1'

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/TECH SPEC	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
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GENERAL ARRANGEMENT
DRY PRB COAL - LOCK HOPPER PROCESS
PLAN AT ELEV. 154'-6" & 220'-0"

SCALE: 3/32"=1'-0"
DRAWING SIZE: ARCH D (36" x 24")
WORLEYPARSONS DWG. NO.: EPRI-1-SK-156-002-502
REV: B

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PLANT DESCRIPTION

1 DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 COAL/LIMESTONE ROLLER MILL
4 MAIN ROLLER MILL FAN
5 MILL AIR HEATER
6 FUEL (COAL/LIMESTONE) TRANSPORT PIPE
7 FUEL STORAGE INJECTOR
8 FUEL PRIMARY INJECTOR
9 PREPARED COAL/LIMESTONE SURGE BIN
10 FUEL (COAL/LIMESTONE) CYCLONE COLLECTOR
11 FUEL PREP DUST BAG FILTER
12 BAG FILTER EXHAUST FAN
13 FUEL SCREEN
14 ELEVATOR
15 ROLL UP DOOR
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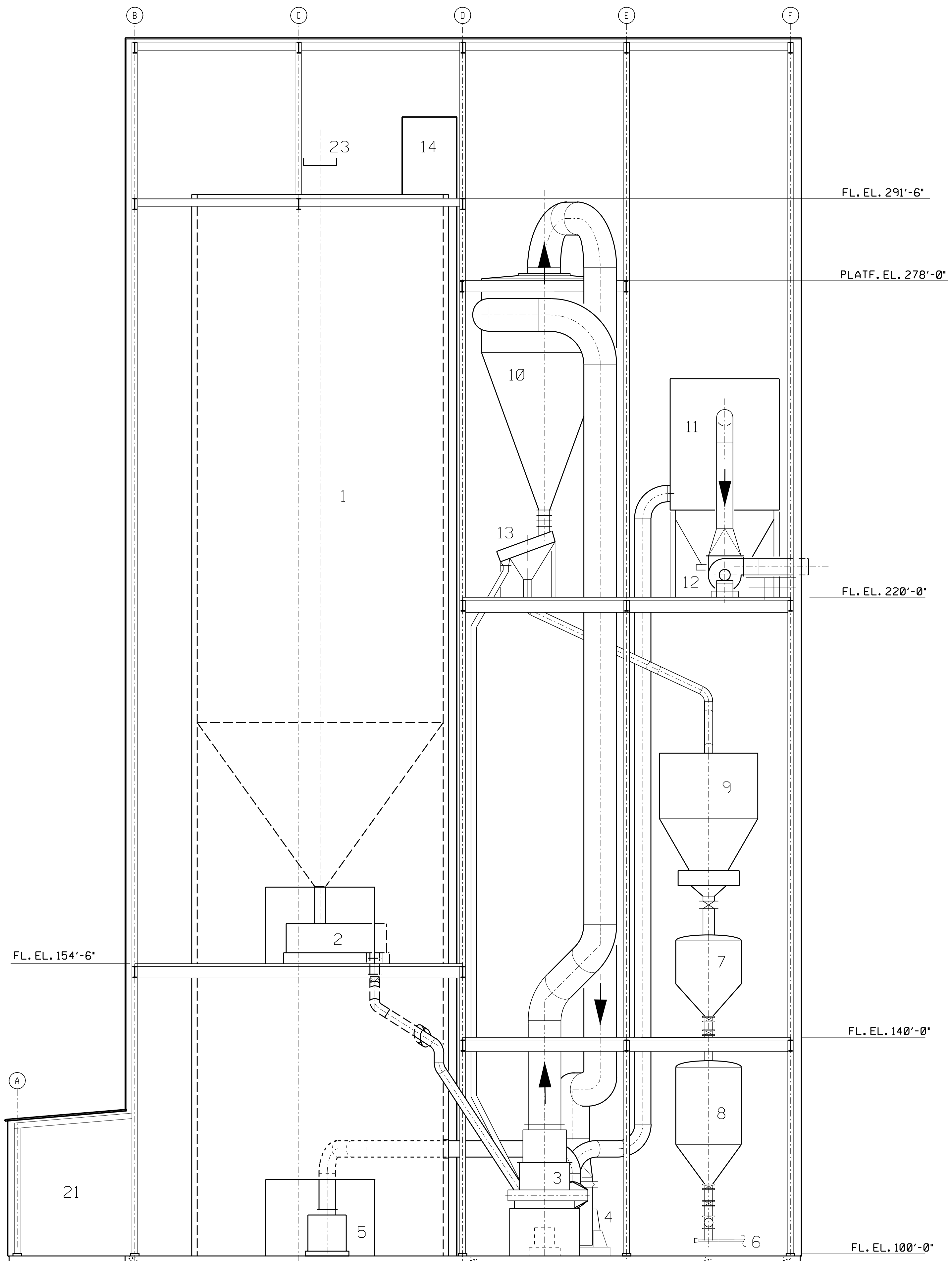
17 BATTERY ROOM
18 CONTROL ROOM
19 LAVATORY
20 MEETING ROOM
21 STORAGE ROOM
22 VESTIBULE
23 TRIPPER CONVEYOR
24 BIN VENT FILTER
25 TRANSFORMER



SECTION A-A

WORK IN PROGRESS
DATE: 02-07-13

CONCEPTUAL DESIGN
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10 0 10 20 30
SCALE: 3/32" = 1'

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/TECH SPEC	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
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GENERAL ARRANGEMENT
DRY PRB COAL - LOCK HOPPER PROCESS
SECTION

SCALE: 3/32"=1'-0"
DRAWING SIZE: ARCH D (36" x 24")
WORLEYPARSONS DWG. NO.: EPRI-1-SK-156-002-503
REV: B

4. Appendix A-4 Process Comparison

1. **General Arrangement Process Comparison PRB Coal Section A-A (EPRI-1-SK-156-002-111)**
2. **General Arrangement Process Coal / Water Slurry Fuel Comparison Section A-A (EPRI-1-SK-156-002-112)**

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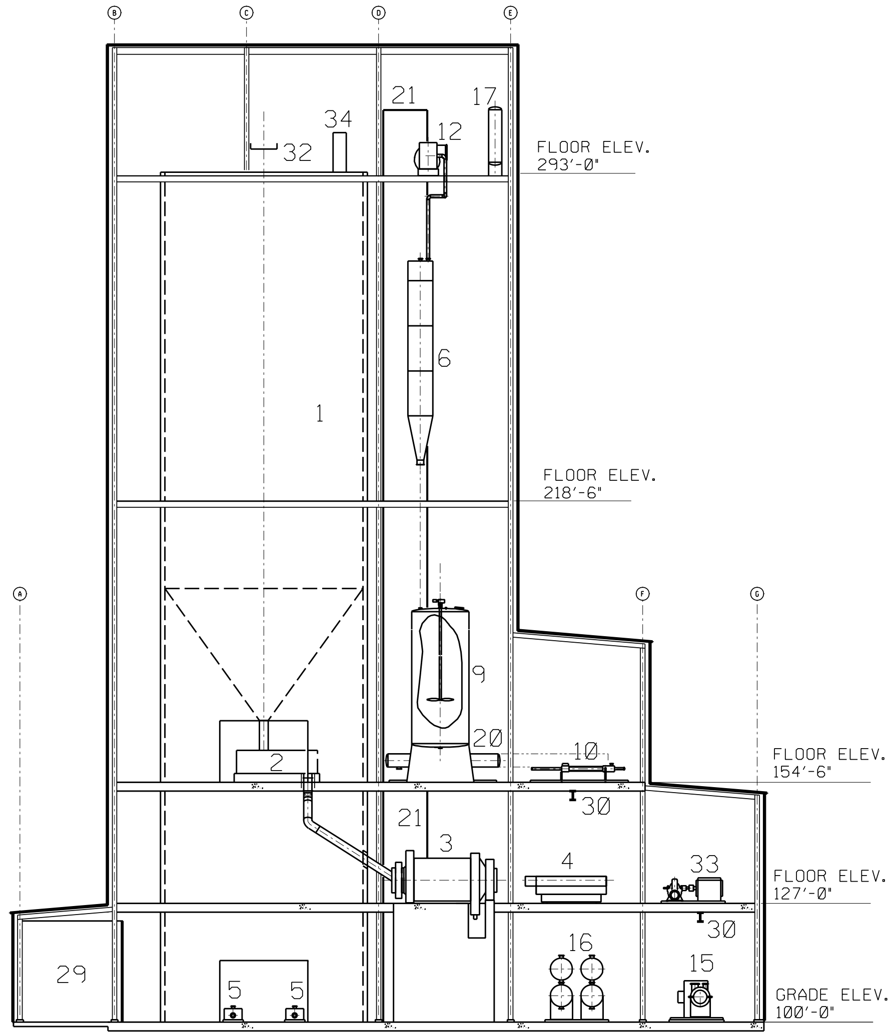
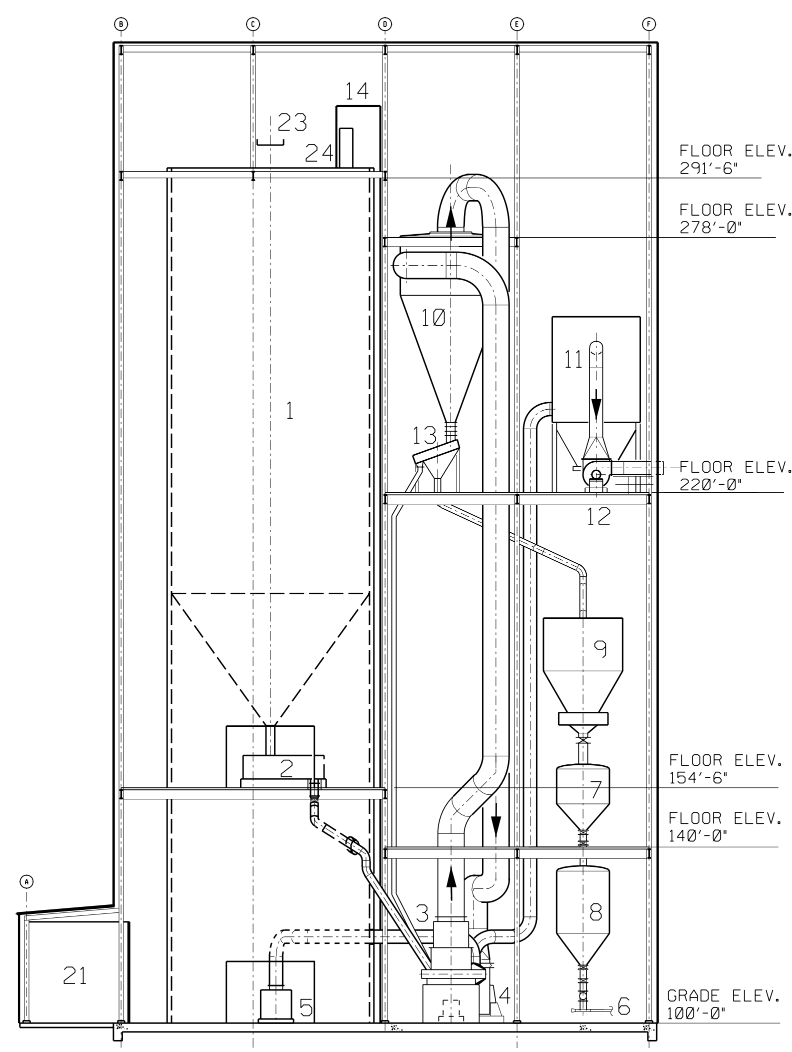


SECTION A-A

PRB CO2/COAL SLURRY
EPRI-1-SK-156-002-101, 102, 103 & 104
BUILDING VOLUME: 3,422,255 CUBIC FEET

PLANT DESCRIPTION

1 24 HOUR DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SCREW PUMP
6 BULK SOLIDS COOLER
9 MIXING VESSEL
10 GASIFIER SLURRY FEED PUMP
12 VENT FAN
15 REFRIGERATION COMPRESSOR DRIVELINE
16 REFRIGERATION HEAT TRANSFER SKID
17 EXPANSION HEAD TANK
20 CO2 CONDENSER W/DESUPERHEATER
21 ELEVATOR
29 STORAGE ROOM
30 MONORAIL
32 TRIPPER CONVEYOR
33 CHILLER COOLING CIRCULATING PUMP
34 BIN VENT FILTER

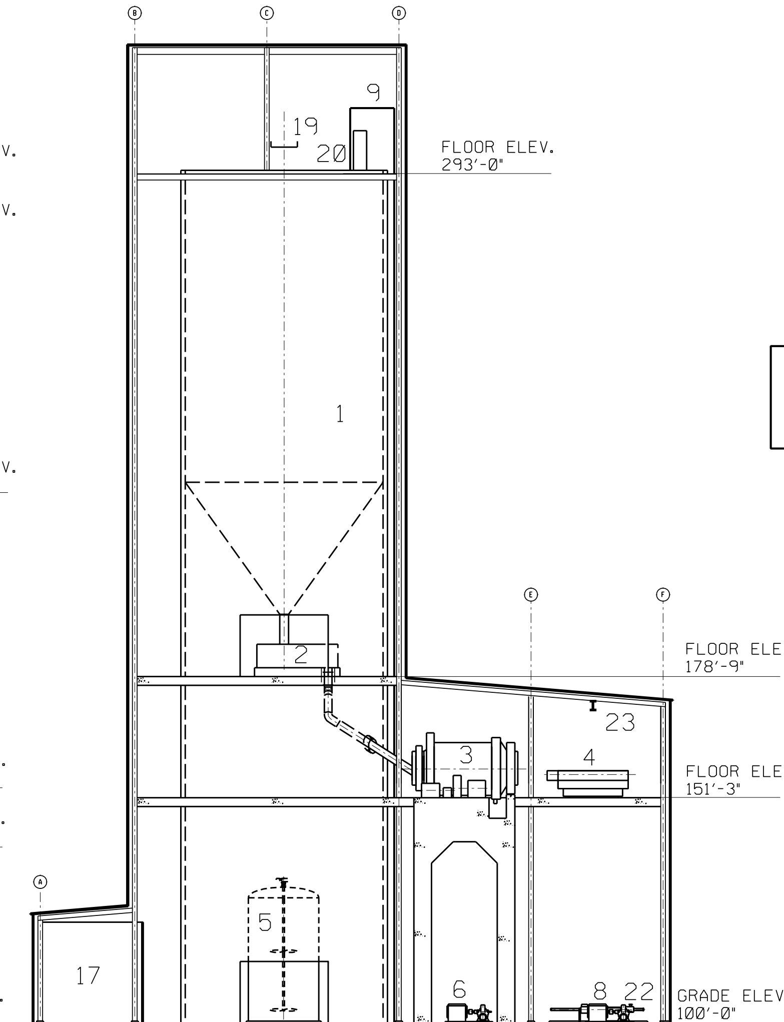


SECTION A-A

PRB DRY FEED
EPRI-1-SK-156-002-501 & 502
BUILDING VOLUME: 3,803,440 CUBIC FEET

PLANT DESCRIPTION

1 24 HOUR DAY BIN (4100 TONS)
2 WEIGH FEEDER
3 COAL/LIMESTONE ROLLER MILL
4 MAIN ROLLER MILL FAN
5 MILL AIR HEATER
6 FUEL (COAL/LIMESTONE) TRANSPORT PIPE
7 FUEL STORAGE INJECTOR
8 FUEL PRIMARY INJECTOR
9 PREPARED COAL/LIMESTONE SURGE BIN
10 FUEL (COAL/LIMESTONE) CYCLONE COLLECTOR
11 FUEL PREP DUST BAG FILTER
12 BAG FILTER EXHAUST FAN
13 FUEL SCREEN
14 ELEVATOR
21 STORAGE ROOM
23 TRIPPER CONVEYOR
24 BIN VENT FILTER



SECTION A-A

PRB COAL/WATER SLURRY
EPRI-1-SK-156-002-601 & 602
BUILDING VOLUME: 2,595,118 CUBIC FEET

PLANT DESCRIPTION

1 18 HOUR DAY BIN (3100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SLURRY BATCH TANK
6 SLURRY RECYCLE PUMP
8 SLURRY FORWARDING PUMP
9 ELEVATOR
17 STORAGE ROOM
19 TRIPPER CONVEYOR
20 BIN VENT FILTER
22 SLURRY FEED PUMP
23 MONORAIL

REV	DATE	DESCRIPTION	DRAWN	CHECKED	LEAD DESIGNER	ENGINEER/TECH SPEC	LEAD DISC ENGINEER	PROJ ENGR MANAGER	PROJECT MANAGER
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A	10 22 12	ISSUE FOR REVIEW	JEV		JEV				HNG

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GENERAL ARRANGEMENT
PROCESS COMPARISON - PRB COAL
SECTION A-A

SCALE 1"=20'
DRAWING SIZE ARCH D (36" x 24")

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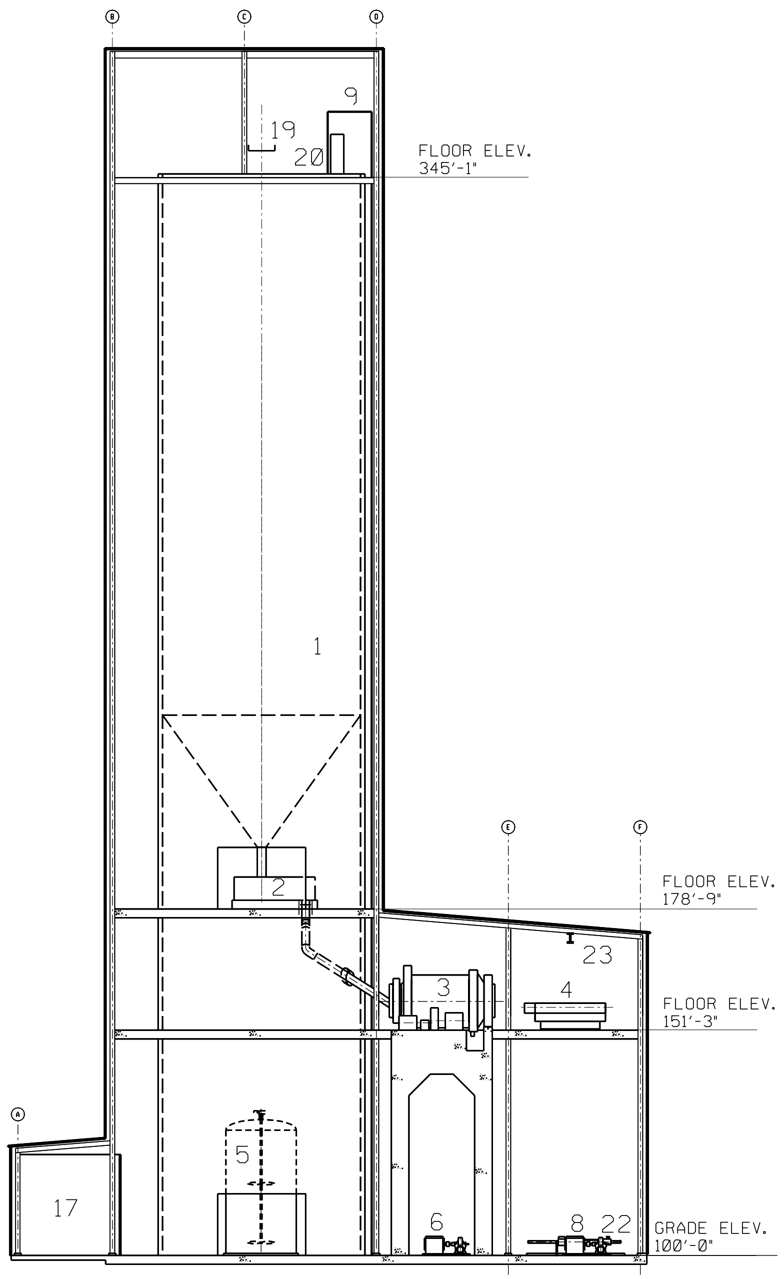
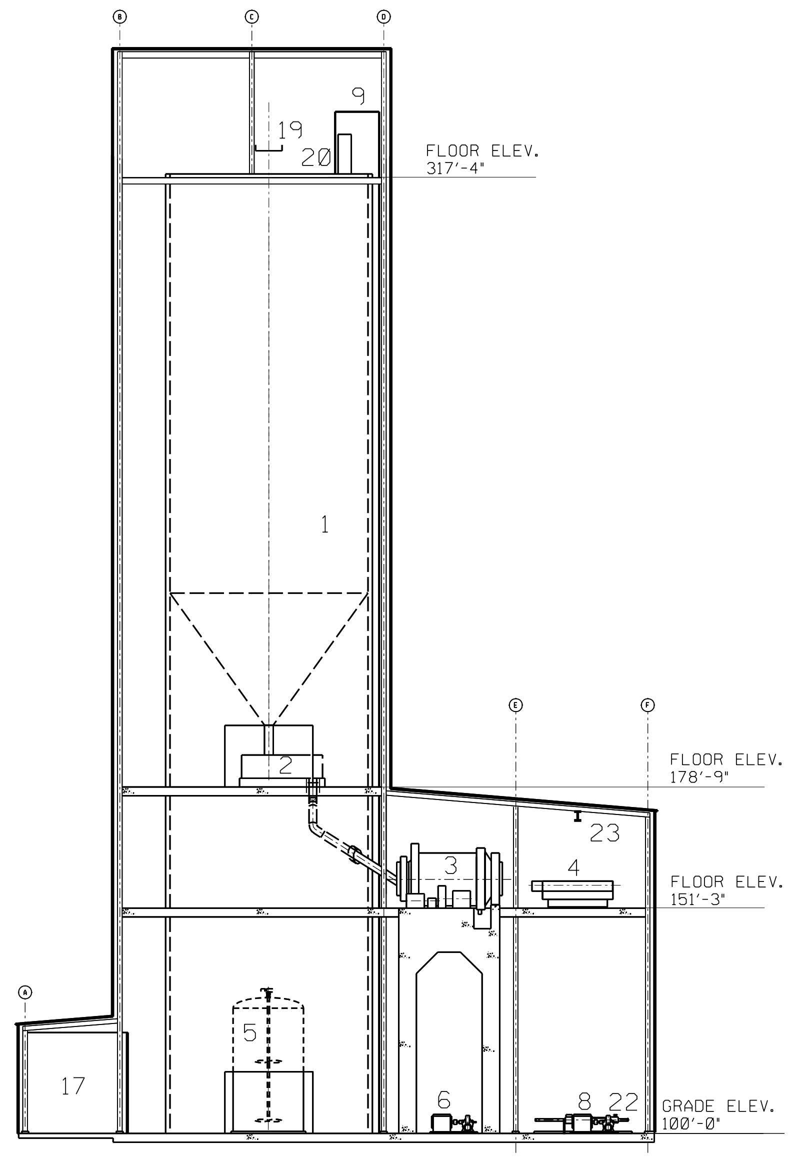
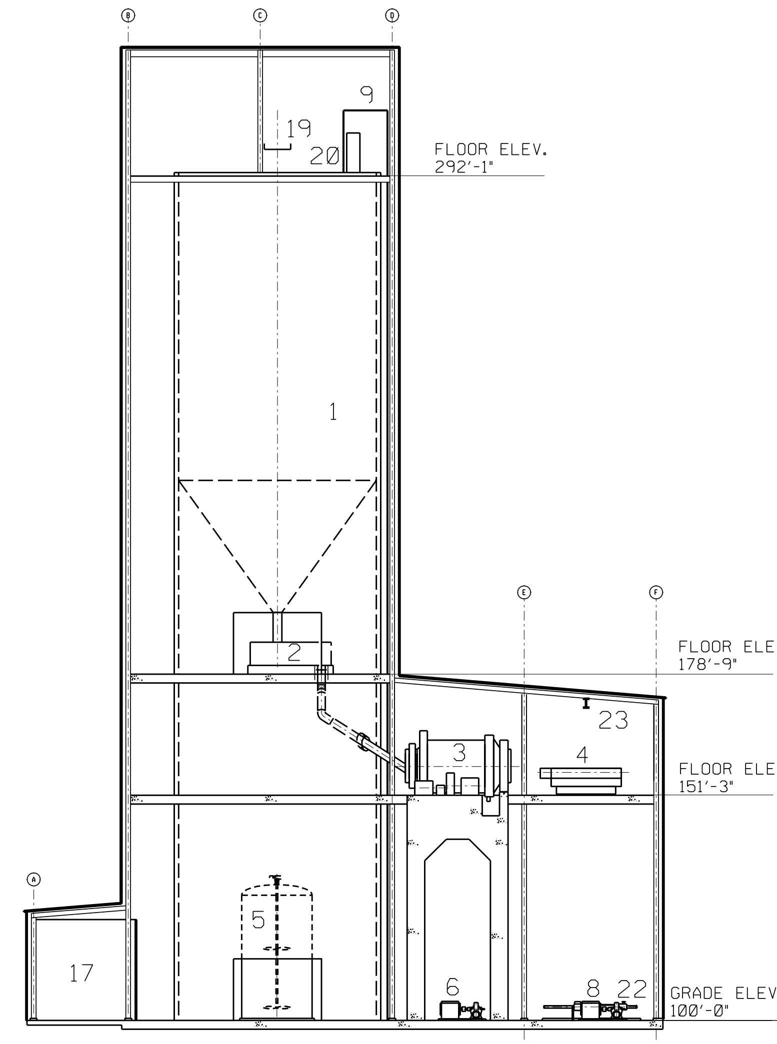


SECTION A-A
ND LIGNITE COAL/WATER SLURRY
BUILDING VOLUME: 2,929,883 CUBIC FEET



SECTION A-A
PRB COAL/WATER SLURRY
BUILDING VOLUME: 2,700,957 CUBIC FEET



SECTION A-A
ILL NO. 6 COAL/WATER SLURRY
BUILDING VOLUME: 2,497,466 CUBIC FEET

PLANT DESCRIPTION

1 18 HOUR DAY BIN (3100 TONS)
2 WEIGH FEEDER
3 ROD MILL
4 ROD MILL RECHARGING UNIT
5 SLURRY BATCH TANK
6 SLURRY RECYCLE PUMP
8 SLURRY FORWARDING PUMP
9 ELEVATOR
17 STORAGE ROOM
19 TRIPPER CONVEYOR
20 BIN VENT FILTER
22 SLURRY FEED PUMP
23 MONORAIL

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A	01 02 13	ISSUE FOR REVIEW	JEV		JEV				HNG

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GENERAL ARRANGEMENT
COAL/WATER SLURRY FUEL COMPARISON
SECTION A-A

SCALE: 1"=20'
DRAWING SIZE: ARCH D (36" x 24")
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Appendix B

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1. Water/Coal Slurry PRB Case Equipment List

Taken from the Low Rank Coal Baseline Report Case S4B

Major equipment items for the Phillips 66 gasifier IGCC plant with CO_2 capture are shown in the following tables. The accounts used in the equipment list correspond to the account numbers used in the cost estimates in Section 12. In general, the design conditions include a 10 percent contingency for flows and heat duties and a 21 percent contingency for heads on pumps and fans.

ACCOUNT 1 COAL HANDLING

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Bottom Trestle Dumper and Receiving Hoppers	N/A	181 tonne (200 ton)	2	0
2	Feeder	Belt	572 tonne/hr (630 tph)	2	0
3	Conveyor No. 1	Belt	1,134 tonne/hr (1,250 tph)	1	0
4	Transfer Tower No. 1	Enclosed	N/A	1	0
5	Conveyor No. 2	Belt	1,134 tonne/hr (1,250 tph)	1	0
6	As-Received Coal Sampling System	Two-stage	N/A	1	0
7	Stacker/Reclaimer	Traveling, linear	1,134 tonne/hr (1,250 tph)	1	0
8	Reclaim Hopper	N/A	64 tonne (70 ton)	2	1
9	Feeder	Vibratory	254 tonne/hr (280 tph)	2	1
10	Conveyor No. 3	Belt w/ tripper	508 tonne/hr (560 tph)	1	0
11	Crusher Tower	N/A	N/A	1	0
12	Coal Surge Bin w/ Vent Filter	Dual outlet	254 tonne (280 ton)	2	0
13	Crusher	Impactor reduction	8 cm x 0 - 3 cm x 0 (3" x 0 - 1-1/4" x 0)	2	0
14	As-Fired Coal Sampling System	Swing hammer	N/A	1	1
15	Conveyor No. 4	Belt w/tripper	508 tonne/hr (560 tph)	1	0
16	Transfer Tower No. 2	Enclosed	N/A	1	0
17	Conveyor No. 5	Belt w/ tripper	508 tonne/hr (560 tph)	1	0
18	Coal Silo w/ Vent Filter and Slide Gates	Field erected	545 tonne (600 ton)	6	0

ACCOUNT 2 COAL PREPARATION and FEED

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Feeder	Vibratory	109 tonne/hr (120 tph)	3	0
2	Conveyor No. 6	Belt w/tripper	336 tonne/hr (370 tph)	1	0
3	Rod Mill Feed Hopper	Dual Outlet	671 tonne (740 ton)	1	0
4	Weigh Feeder	Belt	172 tonne/hr (190 tph)	2	0
5	Rod Mill	Rotary	172 tonne/hr (190 tph)	2	0
6	Slurry Water Storage Tank with Agitator	Field erected	530,530 liters (140,150 gal)	2	0
7	Slurry Water Pumps	Centrifugal	2,953 lpm (780 gpm)	1	0
8	Trommel Screen	Coarse	263 tonne/hr (290 tph)	2	0
9	Rod Mill Discharge Tank with Agitator	Field erected	483,250 liters (127,660 gal)	2	0
10	Rod Mill Product Pumps	Centrifugal	4,164 lpm (1100 gpm)	2	0
11	Slurry Storage Tank with Agitator	Field erected	2,899,649 liters (766,000 gal)	1	0
12	Slurry Recycle Pumps	Centrifugal	7,949 lpm (2,100 gpm)	2	2
13	Slurry Product Pumps	Positive displacement	4,164 lpm (1,100 gpm)	2	2

ACCOUNT 3 FEEDWATER and MISCELLANEOUS SYSTEMS/ EQUIPMENT

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	560,241 liters (148,000 gal)	2	0
2	Condensate Pumps	Vertical canned	8,290 lpm @ 91 m H_2O (2,190 gpm @ 300 ft H_2O)	2	1
3	Deaerator (integral w/ HRSG)	Horizontal spray type	573,341 kg/hr (1,264,000 lb/hr)	2	0
4	Intermediate Pressure Feedwater Pump	Horizontal centrifugal, single stage	2,158 lpm @ 27 m H_2O (570 gpm @ 90 ft H_2O)	2	1

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
5	High Pressure Feedwater Pump No. 1	Barrel type, multi-stage, centrifugal	HP water: 5,754 lpm @ 1,890 m H_2O (1,520 gpm @ 6,200 ft H_2O)	2	1
6	High Pressure Feedwater Pump No. 2	Barrel type, multi-stage, centrifugal	IP water: 189 lpm @ 223 m H_2O (50 gpm @ 730 ft H_2O)	2	1
7	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	1	0
8	Service Air Compressors	Flooded Screw	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	2	1
9	Instrument Air Dryers	Duplex, regenerative	28 m^3/min (1,000 scfm)	2	1
10	Closed Cycle Cooling Heat Exchangers	Plate and frame	372 GJ/hr (353 MMBtu/hr) each	2	0
11	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	133,625 lpm @ 21 m H_2O (35,300 gpm @ 70 ft H_2O)	2	1
12	Engine-Driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1	1
13	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1	1
14	Raw Water Pumps	Stainless steel, single suction	3,785 lpm @ 18 m H_2O (1,000 gpm @ 60 ft H_2O)	2	1
15	Ground Water Pumps	Stainless steel, single suction	2,536 lpm @ 268 m H_2O (670 gpm @ 880 ft H_2O)	2	1
16	Filtered Water Pumps	Stainless steel, single suction	1,931 lpm @ 49 m H_2O (510 gpm @ 160 ft H_2O)	2	1
17	Filtered Water Tank	Vertical, cylindrical	927,426 liter (245,000 gal)	2	0
18	Makeup Water Demineralizer	Anion, cation, and mixed bed	908 lpm (240 gpm)	2	0
19	Liquid Waste Treatment System		10 years, 24-hour storm	1	0

ACCOUNT 4 GASIFIER, ASU, and ACCESSORIES INCLUDING LOW TEMPERATURE HEAT RECOVERY

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Gasifier	Pressurized two-stage, slurry-feed entrained bed	4,082 tonne/day, 4.2 MPa (4,500 tpd, 615 psia)	2	0
2	Synthesis Gas Cooler	Fire-tube boiler	391,450 kg/hr (863,000 lb/hr)	2	0
3	Synthesis Gas Cyclone	High efficiency	391,450 kg/hr (863,000 lb/hr) Design efficiency 90%	2	0
4	Candle Filter	Pressurized filter with pulse-jet cleaning	metallic filters	2	0
5	Syngas Scrubber Including Sour Water Stripper	Vertical up flow	391,450 kg/hr (863,000 lb/hr)	2	0
6	Raw Gas Coolers	Shell and tube with condensate drain	417,759 kg/hr (921,000 lb/hr)	8	0
7	Raw Gas Knockout Drum	Vertical with mist eliminator	327,494 kg/hr, 35°C, 3.9 MPa (722,000 lb/hr, 95°F, 560 psia)	2	0
8	Synthesis Gas Reheater	Shell and tube	50,349 kg/hr (111,000 lb/hr)	2	0
9	Flare Stack	Self-supporting, carbon steel, stainless steel top, pilot ignition	391,450 kg/hr (863,000 lb/hr) syngas	2	0
10	ASU Main Air Compressor	Centrifugal, multi-stage	7,277 m^3/min @ 1.3 MPa (257,000 scfm @ 190 psia)	2	0
11	Cold Box	Vendor design	2,903 tonne/day (3,200 tpd) of 95% purity oxygen	2	0
12	Oxygen Compressor	Centrifugal, multi-stage	1,501 m^3/min (53,000 scfm) Suction - 0.9 MPa (130 psia) Discharge - 5.1 MPa (740 psia)	2	0
13	Primary Nitrogen Compressor	Centrifugal, multi-stage	3,115 m^3/min (110,000 scfm) Suction - 0.4 MPa (60 psia) Discharge - 2.7 MPa (390 psia)	2	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
14	Secondary Nitrogen Compressor	Centrifugal, single-stage	680 m^3/min (24,000 scfm) Suction - 1.2 MPa (180 psia) Discharge - 2.7 MPa (390 psia)	2	0
15	Syngas Dilution Nitrogen Boost Compressor	Centrifugal, single-stage	1,750 m^3/min (61,800 scfm) Suction - 2.6 MPa (384 psia) Discharge - 3.2 MPa (469 psia)	2	0

ACCOUNT 5 SYNGAS CLEANUP

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Mercury Adsorber	Sulfated carbon bed	327,494 kg/hr (722,000 lb/hr) 35°C (95°F) 3.6 MPa (525 psia)	2	0
2	Sulfur Plant	Claus type	59 tonne/day (65 tpd)	1	0
3	Water Gas Shift Reactors	Fixed bed, catalytic	417,759 kg/hr (921,000 lb/hr) 232°C (450°F) 4.0 MPa (580 psia)	4	0
4	Shift Reactor Heat Recovery Exchangers	Shell and Tube	Exchanger 1: 133 GJ/hr (126 MMBtu/hr)	4	0
5	Acid Gas Removal Plant	Two-stage Selexol	327,494 kg/hr (722,000 lb/hr) 35°C (95°F) 3.5 MPa (515 psia)	2	0
6	Hydrogenation Reactor	Fixed bed, catalytic	17,274 kg/hr (38,083 lb/hr) 232°C (450°F) 0.1 MPa (12.3 psia)	1	0
7	Tail Gas Recycle Compressor	Centrifugal	14,644 kg/hr (32,284 lb/hr)	1	0

ACCOUNT 5B CO_2 COMPRESSION

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	CO_2 Compressor	Integrally geared, multi-stage centrifugal	1,240 m^3/min @ 15.3 MPa (43,800 scfm @ 2,215 psia)	4	0

ACCOUNT 6 COMBUSTION TURBINE and AUXILIARIES

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Gas Turbine	Advanced F class	215 MW	2	0
2	Gas Turbine Generator	TEWAC	240 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2	0

ACCOUNT 7 HRSG, DUCTING and STACK

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Stack	CS plate, type 409SS liner	76 m (250 ft) high x 8.7 m (19 ft) diameter	2	0
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 326,042 kg/hr, 12.4 MPa/533°C (718,800 lb/hr, 1,800 psig/992°F) Reheat steam - 384,422 kg/hr, 3.1 MPa/533°C (847,506 lb/hr, 452 psig/992°F)	2	0

ACCOUNT 8 STEAM TURBINE GENERATOR and AUXILIARIES

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Steam Turbine	Commercially available	314 MW 12.4 MPa/533°C/533°C (1,800 psig/ 992°F/992°F)	1	0
2	Steam Turbine Generator	Hydrogen cooled, static excitation	350 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1	0
3	Surface Condenser	Single pass, divided waterbox including vacuum pumps	950 GJ/hr (900 MMBtu/hr), Condensing temperature 32°C (90°F), Inlet water temperature 9°C (48°F), Water temperature rise 11°C (20°F)	1	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
4	Air-cooled Condenser	---	950 GJ/hr (900 MMBtu/hr), Condensing temperature 32°C (90°F), Ambient temperature 6°C (42°F)	1	0

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Circulating Water Pumps	Vertical, wet pit	340,687 lpm @ 30 m (90,000 gpm @ 100 ft)	2	1
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	3°C (37°F) WB / 9°C (48°F) CWT / 20°C (68°F) HWT / 1,899 GJ/hr (1,800 MMBtu/hr) heat duty	1	0

ACCOUNT 10 SLAG RECOVERY and HANDLING

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Slag Quench Tank	Water bath	276,335 liters (73,000 gal)	2	0
2	Slag Crusher	Roll	15 tonne/hr (16 tph)	2	0
3	Slag Depressurizer	Proprietary	15 tonne/hr (16 tph)	2	0
4	Slag Receiving Tank	Horizontal, weir	166,558 liters (44,000 gal)	2	0
5	Black Water Overflow Tank	Shop fabricated	75,708 liters (20,000 gal)	2	0
6	Slag Conveyor	Drag chain	15 tonne/hr (16 tph)	2	0
7	Slag Separation Screen	Vibrating	15 tonne/hr (16 tph)	2	0
8	Coarse Slag Conveyor	Belt/bucket	15 tonne/hr (16 tph)	2	0
9	Fine Ash Settling Tank	Vertical, gravity	238,481 liters (63,000 gal)	2	0
10	Fine Ash Recycle Pumps	Horizontal centrifugal	76 lpm @ 14 m H_2O (20 gpm @ 46 ft H_2O)	2	2

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
11	Grey Water Storage Tank	Field erected	75,708 liters (20,000 gal)	2	0
12	Grey Water Pumps	Centrifugal	265 lpm @ 433 m H_2O (70 gpm @ 1,420 ft H_2O)	2	2
13	Slag Storage Bin	Vertical, field erected	1,089 tonne (1,200 tons)	2	0
14	Unloading Equipment	Telescoping chute	118 tonne/hr (130 tph)	1	0

ACCOUNT 11 ACCESSORY ELECTRIC PLANT

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	CTG Step-up Transformer	Oil-filled	24 kV/345 kV, 240 MVA, 3-ph, 60 Hz	2	0
2	STG Step-up Transformer	Oil-filled	24 kV/345 kV, 340 MVA, 3-ph, 60 Hz	1	0
3	High Voltage Auxiliary Transformer	Oil-filled	345 kV/13.8 kV, 70 MVA, 3-ph, 60 Hz	2	0
4	Medium Voltage Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 94 MVA, 3-ph, 60 Hz	1	1
5	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 14 MVA, 3-ph, 60 Hz	1	1
6	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2	0
7	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1	0
8	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1	1
9	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1	1
10	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1	0

ACCOUNT 12 INSTRUMENTATION and CONTROLS

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	DCS - Main Control	Monitor/keyboard; Operator printer (laser color); Engineering printer (laser B&W)	Operator stations/printers and engineering stations/printers	1	0
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1	0
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1	0

2. Liquid CO_2/Coal Slurry PRB Case Equipment List

Adapted from the Low Rank Coal Baseline Report Case S4B

Major equipment items for the Phillips 66 gasifier IGCC plant with CO_2 capture are shown in the following tables. The accounts used in the equipment list correspond to the account numbers used in the cost estimates in Section 12 of the report. In general, the design conditions include a 10 percent contingency for flows and heat duties and a 21 percent contingency for heads on pumps and fans.

ACCOUNT 1 COAL HANDLING

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Bottom Trestle Dumper and Receiving Hoppers	N/A	181 tonne (200 ton)	2	0
2	Feeder	Belt	572 tonne/hr (630 tph)	2	0
3	Conveyor No. 1	Belt	1,134 tonne/hr (1,250 tph)	1	0
4	Transfer Tower No. 1	Enclosed	N/A	1	0
5	Conveyor No. 2	Belt	1,134 tonne/hr (1,250 tph)	1	0
6	As-Received Coal Sampling System	Two-stage	N/A	1	0
7	Stacker/Reclaimer	Traveling, linear	1,134 tonne/hr (1,250 tph)	1	0
8	Reclaim Hopper	N/A	64 tonne (70 ton)	2	1
9	Feeder	Vibratory	250 tonne/hr (275 tph)	2	1
10	Conveyor No. 3	Belt w/ tripper	500 tonne/hr (550 tph)	1	0
11	Crusher Tower	N/A	N/A	1	0
12	Coal Surge Bin w/ Vent Filter	Dual outlet	250 tonne (275 ton)	2	0
13	Crusher	Impactor reduction	8 cm x 0 - 3 cm x 0 (3" x 0 - 1-1/4" x 0)	2	0
14	As-Fired Coal Sampling System	Swing hammer	N/A	1	1
15	Conveyor No. 4	Belt w/tripper	500 tonne/hr (550 tph)	1	0
16	Transfer Tower No. 2	Enclosed	N/A	1	0
17	Conveyor No. 5	Belt w/ tripper	500 tonne/hr (550 tph)	1	0
18	Coal Silo w/ Vent Filter and Slide Gates	Field erected	510 tonne (565 ton)	6	0

ACCOUNT 2 COAL/SLURRY PREPARATION and FEED

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Conveyor BC-7A/B Day Bin Tripper	Moveable Tripper	600 tons/hr	1	0
2	Day Silo	Concrete Silo	4100 tons PRB	2	0
3	Weigh Feeder	Belt Type	170 tons/hr	2	0
4	Rod Mill	Rotary Rod Mill	170 tons/hr	4	2
5	Rod Mil Charger	Drum, Hydraulic Ram	40 tons rod material storage	1	0
6	Screw Pump	Pneumatic	170 tons/hr solids	6	0
7	Bulk Solids Cooler	Indirect Plate Type	175,000 lb/hr each, PRB coal, 70F to -10F	4	0
8	Bag Filter	Pulse-jet Fabric Filter	30,000 acfm	2	0
9	Vent Fan	Centrifugal	30,000 acfm, YY in H2O	2	0
10	Rotary Feeder	Star-type	170 tons/hr	4	0
11	Flop Gate			2	0
12	Mixing Vessel	ASME Sect VIII Div 2 Pressure Vessel	260 psig, -10F	4	0
13	Mixer	Tank-mounted	35 hp	4	0
14	Gasifier Feed Pump	Piston type	120,000 lb/hr slurry @ 850 psig discharge	6	0
15	Refrigeration Driveline	Mechanical Vapor Compression	2500 tons refrigeration per package, R-507	3	0
16	Heat Transfer Skid	Shell/Tube	Matched to R-Driveline, above	3	0
17	Coolant Circulating Pump	Horizontal Centrifugal	10,000 gpm/60 ft TDH	3	0
18	Expansion/Head Tank	Atmos. Press Tank	1,000 gal	1	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
19	CO2 Gas Expander Skid	Vertical dry pit centrifugal pump, 100% capacity	63 lb/sec,475 psig to 275 psig, 533 kWe	1	0
20	CO2 Condenser	Shell and Tube, with desuperheat, condensing, and subcooling surfaces	670 gpm, 510 TDH, 150 bhp	2	0
21	Liquid CO2 Forwarding Pumps	Horizontal, centrifugal type, ANSI, end suction, 100% capacity	650 gpm, 60 TDH, 25 bhp	4	2

ACCOUNT 3 FEEDWATER and MISCELLANEOUS SYSTEMS/EQUIPMENT

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	1,444,300 liters (381,500 gal)	2	0
2	Condensate Pumps	Vertical canned	8,290 lpm @ 91 m H_2O (2,190 gpm @ 300 ft H_2O)	2	1
3	Deaerator (integral w/ HRSG)	Horizontal spray type	573,341 kg/hr (1,264,000 lb/hr)	2	0
4	Intermediate Pressure Feedwater Pump	Horizontal centrifugal, single stage	2,158 lpm @ 27 m H_2O (570 gpm @ 90 ft H_2O)	2	1
5	High Pressure Feedwater Pump No. 1	Barrel type, multi-stage, centrifugal	HP water: 5,754 lpm @ 1,890 m H_2O (1,520 gpm @ 6,200 ft H_2O)	2	1
6	High Pressure Feedwater Pump No. 2	Barrel type, multi-stage, centrifugal	IP water: 189 lpm @ 223 m H_2O (50 gpm @ 730 ft H_2O)	2	1
7	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	1	0
8	Service Air Compressors	Flooded Screw	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	2	1
9	Instrument Air Dryers	Duplex, regenerative	28 m^3/min (1,000 scfm)	2	1
10	Closed Cycle Cooling Heat Exchangers	Plate and frame	372 GJ/hr (353 MMBtu/hr) each	2	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
11	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	133,625 lpm @ 21 m H_2O (35,300 gpm @ 70 ft H_2O)	2	1
12	Engine-Driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1	1
13	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1	1
14	Raw Water Pumps	Stainless steel, single suction	9,760 lpm @ 18 m H_2O (2,580 gpm @ 60 ft H_2O)	2	1
15	Ground Water Pumps	Stainless steel, single suction	6,540 lpm @ 268 m H_2O (1,730 gpm @ 880 ft H_2O)	2	1
16	Filtered Water Pumps	Stainless steel, single suction	4,980 lpm @ 49 m H_2O (1,315 gpm @ 160 ft H_2O)	2	1
17	Filtered Water Tank	Vertical, cylindrical	2,390,000 liter (632,000 gal)	2	0
18	Makeup Water Demineralizer	Anion, cation, and mixed bed	2,340 lpm (620 gpm)	2	0
19	Liquid Waste Treatment System		10 years, 24-hour storm	1	0

ACCOUNT 4 GASIFIER, ASU, and ACCESSORIES INCLUDING LOW TEMPERATURE HEAT RECOVERY

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Gasifier	Pressurized two-stage, slurry-feed entrained bed	3,750 tonne/day, 4.2 MPa (4,120 tpd, 615 psia)	2	0
2	Synthesis Gas Cooler	Fire-tube boiler	357,000 kg/hr (786,000 lb/hr)	2	0
3	Synthesis Gas Cyclone	High efficiency	357,000 kg/hr (786,000 lb/hr) Design efficiency 90%	2	0
4	Candle Filter	Pressurized filter with pulse-jet cleaning	metallic filters	2	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
5	Syngas Scrubber Including Sour Water Stripper	Vertical up flow	357,000 kg/hr (786,000 lb/hr)	2	0
6	Raw Gas Coolers	Shell and tube with condensate drain	357,000 kg/hr (786,000 lb/hr)	8	0
7	Raw Gas Knockout Drum	Vertical with mist eliminator	298,430 kg/hr, 35°C, 3.9 MPa (657,910 lb/hr, 95°F, 560 psia)	2	0
8	Synthesis Gas Reheater	Shell and tube	50,349 kg/hr (111,000 lb/hr)	2	0
9	Flare Stack	Self-supporting, carbon steel, stainless steel top, pilot ignition	357,000 kg/hr (786,000 lb/hr) syngas	2	0
10	ASU Main Air Compressor	Centrifugal, multi-stage	6,294 m^3/min @ 1.3 MPa (222,000 scfm @ 190 psia)	2	0
11	Cold Box	Vendor design	2,510 tonne/day (2,770 tpd) of 95% purity oxygen	2	0
12	Oxygen Compressor	Centrifugal, multi-stage	1,300 m^3/min (45,840 scfm) Suction - 0.9 MPa (130 psia) Discharge - 5.1 MPa (740 psia)	2	0
13	Primary Nitrogen Compressor	Centrifugal, multi-stage	2,694 m^3/min (95,150 scfm) Suction - 0.4 MPa (60 psia) Discharge - 2.7 MPa (390 psia)	2	0
14	Secondary Nitrogen Compressor	Centrifugal, single-stage	750 m^3/min (26,400 scfm) Suction - 1.2 MPa (180 psia) Discharge - 2.7 MPa (390 psia)	2	0
15	Syngas Dilution Nitrogen Boost Compressor	Centrifugal, single-stage	1,925 m^3/min (67,980 scfm) Suction - 2.6 MPa (384 psia) Discharge - 3.2 MPa (469 psia)	2	0

ACCOUNT 5 SYNGAS CLEANUP

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Mercury Adsorber	Sulfated carbon bed	298,430 kg/hr (657,910 lb/hr) 35°C (95°F) 3.6 MPa (525 psia)	2	0
2	Sulfur Plant	Claus type	155 tonne/day (170 tpd)	1	0
3	Water Gas Shift Reactors	Fixed bed, catalytic	357,000 kg/hr (780,000 lb/hr) 232°C (450°F) 4.0 MPa (580 psia)	4	0
4	Shift Reactor Heat Recovery Exchangers	Shell and Tube	Exchanger 1: 112 GJ/hr (107 MMBtu/hr)	4	0
5	Acid Gas Removal Plant	Two-stage Selexol	298,430 kg/hr (657,910 lb/hr) 35°C (95°F) 3.5 MPa (515 psia)	2	0
6	Hydrogenation Reactor	Fixed bed, catalytic	44,625 kg/hr (98,381 lb/hr) 232°C (450°F) 0.1 MPa (12.3 psia)	1	0
7	Tail Gas Recycle Compressor	Centrifugal	37,830 kg/hr (83,400 lb/hr)	1	0

ACCOUNT 5B CO_2 COMPRESSION

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	CO_2 Compressor	Integrally geared, multi-stage centrifugal	1,150 m^3/min @ 15.3 MPa (40,660 scfm @ 2,215 psia)	4	0

ACCOUNT 6 COMBUSTION TURBINE and AUXILIARIES

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Gas Turbine	Advanced F class	232 MW	2	0
2	Gas Turbine Generator	TEWAC	260 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2	0

ACCOUNT 7 HRSG, DUCTING and STACK

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Stack	CS plate, type 409SS liner	76 m (250 ft) high x 8.7 m (19 ft) diameter	2	0
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 372,000 kg/hr, 12.4 MPa/533°C (820,000 lb/hr, 1,800 psig/992°F) Reheat steam - 437,900 kg/hr, 3.1 MPa/533°C (965,900 lb/hr, 452 psig/992°F)	2	0

ACCOUNT 8 STEAM TURBINE GENERATOR and AUXILIARIES

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Steam Turbine	Commercially available	260 MW 12.4 MPa/533°C/533°C (1,800 psig/ 992°F/992°F)	1	0
2	Steam Turbine Generator	Hydrogen cooled, static excitation	300 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1	0
3	Surface Condenser	Single pass, divided waterbox including vacuum pumps	950 GJ/hr (900 MMBtu/hr), Condensing temperature 32°C (90°F), Inlet water temperature 9°C (48°F), Water temperature rise 11°C (20°F)	1	0
4	Air-cooled Condenser	---	950 GJ/hr (900 MMBtu/hr), Condensing temperature 32°C (90°F), Ambient temperature 6°C (42°F)	1	0

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Circulating Water Pumps	Vertical, wet pit	340,687 lpm @ 30 m (90,000 gpm @ 100 ft)	2	1

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	3°C (37°F) WB / 9°C (48°F) CWT / 20°C (68°F) HWT / 1,899 GJ/hr (1,800 MMBtu/hr) heat duty	1	0

ACCOUNT 10 SLAG RECOVERY and HANDLING

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Slag Quench Tank	Water bath	276,335 liters (73,000 gal)	2	0
2	Slag Crusher	Roll	15 tonne/hr (16 tph)	2	0
3	Slag Depressurizer	Proprietary	15 tonne/hr (16 tph)	2	0
4	Slag Receiving Tank	Horizontal, weir	166,558 liters (44,000 gal)	2	0
5	Black Water Overflow Tank	Shop fabricated	75,708 liters (20,000 gal)	2	0
6	Slag Conveyor	Drag chain	15 tonne/hr (16 tph)	2	0
7	Slag Separation Screen	Vibrating	15 tonne/hr (16 tph)	2	0
8	Coarse Slag Conveyor	Belt/bucket	15 tonne/hr (16 tph)	2	0
9	Fine Ash Settling Tank	Vertical, gravity	238,481 liters (63,000 gal)	2	0
10	Fine Ash Recycle Pumps	Horizontal centrifugal	76 lpm @ 14 m H_2O (20 gpm @ 46 ft H_2O)	2	2
11	Grey Water Storage Tank	Field erected	75,708 liters (20,000 gal)	2	0
12	Grey Water Pumps	Centrifugal	265 lpm @ 433 m H_2O (70 gpm @ 1,420 ft H_2O)	2	2
13	Slag Storage Bin	Vertical, field erected	1,089 tonne (1,200 tons)	2	0
14	Unloading Equipment	Telescoping chute	118 tonne/hr (130 tph)	1	0

ACCOUNT 11 ACCESSORY ELECTRIC PLANT

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	CTG Step-up Transformer	Oil-filled	24 kV/345 kV, 240 MVA, 3-ph, 60 Hz	2	0
2	STG Step-up Transformer	Oil-filled	24 kV/345 kV, 340 MVA, 3-ph, 60 Hz	1	0
3	High Voltage Auxiliary Transformer	Oil-filled	345 kV/13.8 kV, 70 MVA, 3-ph, 60 Hz	2	0
4	Medium Voltage Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 94 MVA, 3-ph, 60 Hz	1	1
5	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 14 MVA, 3-ph, 60 Hz	1	1
6	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2	0
7	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1	0
8	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1	1
9	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1	1
10	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1	0

ACCOUNT 12 INSTRUMENTATION and CONTROLS

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	DCS - Main Control	Monitor/keyboard; Operator printer (laser color); Engineering printer (laser B&W)	Operator stations/printers and engineering stations/printers	1	0
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1	0
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1	0

3. Water/Coal Slurry ND Lignite Case Equipment List

Adapted from the Low Rank Coal Baseline Report Case S4B

Major equipment items for the Phillips 66 gasifier IGCC plant with CO_2 capture are shown in the following tables. The accounts used in the equipment list correspond to the account numbers used in the cost estimates in Section 12. In general, the design conditions include a 10 percent contingency for flows and heat duties and a 21 percent contingency for heads on pumps and fans.

ACCOUNT 1 COAL HANDLING

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Bottom Trestle Dumper and Receiving Hoppers	N/A	181 tonne (200 ton)	2	0
2	Feeder	Belt	572 tonne/hr (630 tph)	2	0
3	Conveyor No. 1	Belt	1,134 tonne/hr (1,250 tph)	1	0
4	Transfer Tower No. 1	Enclosed	N/A	1	0
5	Conveyor No. 2	Belt	1,134 tonne/hr (1,250 tph)	1	0
6	As-Received Coal Sampling System	Two-stage	N/A	1	0
7	Stacker/Reclaimer	Traveling, linear	1,134 tonne/hr (1,250 tph)	1	0
8	Reclaim Hopper	N/A	64 tonne (70 ton)	2	1
9	Feeder	Vibratory	254 tonne/hr (280 tph)	2	1
10	Conveyor No. 3	Belt w/ tripper	508 tonne/hr (560 tph)	1	0
11	Crusher Tower	N/A	N/A	1	0
12	Coal Surge Bin w/ Vent Filter	Dual outlet	254 tonne (280 ton)	2	0
13	Crusher	Impactor reduction	8 cm x 0 - 3 cm x 0 (3" x 0 - 1-1/4" x 0)	2	0
14	As-Fired Coal Sampling System	Swing hammer	N/A	1	1
15	Conveyor No. 4	Belt w/tripper	508 tonne/hr (560 tph)	1	0
16	Transfer Tower No. 2	Enclosed	N/A	1	0
17	Conveyor No. 5	Belt w/ tripper	508 tonne/hr (560 tph)	1	0
18	Coal Silo w/ Vent Filter and Slide Gates	Field erected	726 tonne (800 ton)	6	0

ACCOUNT 2 COAL PREPARATION and FEED

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Feeder	Vibratory	150 tonne/hr (165 tph)	3	0
2	Conveyor No. 6	Belt w/tripper	455 tonne/hr (500 tph)	1	0
3	Rod Mill Feed Hopper	Dual Outlet	910 tonne (1000 ton)	1	0
4	Weigh Feeder	Belt	230 tonne/hr (250 tph)	2	0
5	Rod Mill	Rotary	230 tonne/hr (250 tph)	2	0
6	Slurry Water Storage Tank with Agitator	Field erected	605,000 liters (160,000 gal)	2	0
7	Slurry Water Pumps	Centrifugal	2,953 lpm (780 gpm)	2	0
8	Trommel Screen	Coarse	263 tonne/hr (290 tph)	2	0
9	Rod Mill Discharge Tank with Agitator	Field erected	566,000 liters (150,000 gal)	2	0
10	Rod Mill Product Pumps	Centrifugal	1,640 lpm (1800 gpm)	2	0
11	Slurry Storage Tank with Agitator	Field erected	2,899,649 liters (766,000 gal)	2	0
12	Slurry Recycle Pumps	Centrifugal	7,949 lpm (2,100 gpm)	2	2
13	Slurry Product Pumps	Positive displacement	1,640 lpm (1,800 gpm)	2	2

ACCOUNT 3 FEEDWATER and MISCELLANEOUS SYSTEMS/EQUIPMENT

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	1,541,000 liters (410,000 gal)	2	0
2	Condensate Pumps	Vertical canned	14,160 lpm @ 91 m H_2O (3,740 gpm @ 300 ft H_2O)	2	1
3	Deaerator (integral w/ HRSG)	Horizontal spray type	573,341 kg/hr (1,264,000 lb/hr)	2	0
4	Intermediate Pressure Feedwater Pump	Horizontal centrifugal, single stage	2,158 lpm @ 27 m H_2O (570 gpm @ 90 ft H_2O)	2	1

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
5	High Pressure Feedwater Pump No. 1	Barrel type, multi-stage, centrifugal	HP water: 5,754 lpm @ 1,890 m H_2O (1,520 gpm @ 6,200 ft H_2O)	2	1
6	High Pressure Feedwater Pump No. 2	Barrel type, multi-stage, centrifugal	IP water: 189 lpm @ 223 m H_2O (50 gpm @ 730 ft H_2O)	2	1
7	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	1	0
8	Service Air Compressors	Flooded Screw	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	2	1
9	Instrument Air Dryers	Duplex, regenerative	28 m^3/min (1,000 scfm)	2	1
10	Closed Cycle Cooling Heat Exchangers	Plate and frame	372 GJ/hr (353 MMBtu/hr) each	2	0
11	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	212,200 lpm @ 21 m H_2O (56,070 gpm @ 70 ft H_2O)	2	1
12	Engine-Driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1	1
13	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1	1
14	Raw Water Pumps	Stainless steel, single suction	7,851 lpm @ 18 m H_2O (2,070 gpm @ 60 ft H_2O)	2	1
15	Ground Water Pumps	Stainless steel, single suction	3,930 lpm @ 268 m H_2O (1,040 gpm @ 880 ft H_2O)	2	1
16	Filtered Water Pumps	Stainless steel, single suction	4,300 lpm @ 49 m H_2O (1,135 gpm @ 160 ft H_2O)	2	1
17	Filtered Water Tank	Vertical, cylindrical	2,063,000 liter (545,300 gal)	2	0
18	Makeup Water Demineralizer	Anion, cation, and mixed bed	2,600 lpm (690 gpm)	2	0
19	Liquid Waste Treatment System		10 years, 24-hour storm	1	0

ACCOUNT 4 GASIFIER, ASU, and ACCESSORIES INCLUDING LOW TEMPERATURE HEAT RECOVERY

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Gasifier	Pressurized two-stage, slurry-feed entrained bed	3,540 tonne/day, 4.2 MPa (3,900 tpd, 615 psia)	3	0
2	Synthesis Gas Cooler	Fire-tube boiler	335,400 kg/hr (740,000 lb/hr)	3	0
3	Synthesis Gas Cyclone	High efficiency	335,400 kg/hr (740,000 lb/hr) Design efficiency 90%	3	0
4	Candle Filter	Pressurized filter with pulse-jet cleaning	metallic filters	3	0
5	Syngas Scrubber Including Sour Water Stripper	Vertical up flow	335,400 kg/hr (740,000 lb/hr)	3	0
6	Raw Gas Coolers	Shell and tube with condensate drain	257,000 kg/hr (567,000 lb/hr)	3	0
7	Raw Gas Knockout Drum	Vertical with mist eliminator	335,400 kg/hr, 35°C, 3.9 MPa (740,000 lb/hr, 95°F, 560 psia)	3	0
8	Synthesis Gas Reheater	Shell and tube	335,400 kg/hr (740,000 lb/hr)	3	0
9	Flare Stack	Self-supporting, carbon steel, stainless steel top, pilot ignition	260,000 kg/hr (575,000 lb/hr) syngas	3	0
10	ASU Main Air Compressor	Centrifugal, multi-stage	7,730 m^3/min @ 1.3 MPa (273,100 scfm @ 190 psia)	2	0
11	Cold Box	Vendor design	3,090 tonne/day (3,400 tpd) of 95% purity oxygen	2	0
12	Oxygen Compressor	Centrifugal, multi-stage	1,702 m^3/min (60,100 scfm) Suction - 0.9 MPa (130 psia) Discharge - 5.1 MPa (740 psia)	2	0
13	Primary Nitrogen Compressor	Centrifugal, multi-stage	3,930 m^3/min (139,000 scfm) Suction - 0.4 MPa (60 psia) Discharge - 2.7 MPa (390 psia)	2	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
14	Secondary Nitrogen Compressor	Centrifugal, single-stage	557 m^3/min (19,700 scfm) Suction - 1.2 MPa (180 psia) Discharge - 2.7 MPa (390 psia)	2	0
15	Syngas Dilution Nitrogen Boost Compressor	Centrifugal, single-stage	1,670 m^3/min (59,110 scfm) Suction - 2.6 MPa (384 psia) Discharge - 3.2 MPa (469 psia)	2	0

ACCOUNT 5 SYNGAS CLEANUP

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Mercury Adsorber	Sulfated carbon bed	330,100 kg/hr (729,000 lb/hr) 35°C (95°F) 3.6 MPa (525 psia)	2	0
2	Sulfur Plant	Claus type	67 tonne/day (74 tpd)	1	0
3	Water Gas Shift Reactors	Fixed bed, catalytic	502,330 kg/hr (1,108,000 lb/hr) 232°C (450°F) 4.0 MPa (580 psia)	4	0
4	Shift Reactor Heat Recovery Exchangers	Shell and Tube	Exchanger 1: 123 GJ/hr (110 MMBtu/hr)	4	0
5	Acid Gas Removal Plant	Two-stage Selexol	332,800 kg/hr (735,000 lb/hr) 35°C (95°F) 3.5 MPa (515 psia)	2	0
6	Hydrogenation Reactor	Fixed bed, catalytic	17,274 kg/hr (38,083 lb/hr) 232°C (450°F) 0.1 MPa (12.3 psia)	1	0
7	Tail Gas Recycle Compressor	Centrifugal	14,644 kg/hr (32,284 lb/hr)	1	0

ACCOUNT 5B CO_2 COMPRESSION

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	CO_2 Compressor	Integrally geared, multi-stage centrifugal	1,428 m^3/min @ 15.3 MPa (50,400 scfm @ 2,215 psia)	4	0

ACCOUNT 6 COMBUSTION TURBINE and AUXILIARIES

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Gas Turbine	Advanced F class	232 MW	2	0
2	Gas Turbine Generator	TEWAC	260 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2	0

ACCOUNT 7 HRSG, DUCTING and STACK

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Stack	CS plate, type 409SS liner	76 m (250 ft) high x 8.7 m (19 ft) diameter	2	0
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 391,900 kg/hr, 12.4 MPa/533°C (886,700 lb/hr, 1,800 psig/992°F) Reheat steam - 342,500 kg/hr, 3.1 MPa/533°C (755,200 lb/hr, 452 psig/992°F)	2	0

ACCOUNT 8 STEAM TURBINE GENERATOR and AUXILIARIES

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Steam Turbine	Commercially available	346 MW 12.4 MPa/533°C/533°C (1,800 psig/ 992°F/992°F)	1	0
2	Steam Turbine Generator	Hydrogen cooled, static excitation	380 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1	0
3	Surface Condenser	Single pass, divided waterbox including vacuum pumps	950 GJ/hr (900 MMBtu/hr), Condensing temperature 32°C (90°F), Inlet water temperature 9°C (48°F), Water temperature rise 11°C (20°F)	1	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
4	Air-cooled Condenser	---	950 GJ/hr (900 MMBtu/hr), Condensing temperature 32°C (90°F), Ambient temperature 6°C (42°F)	1	0

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Circulating Water Pumps	Vertical, wet pit	340,687 lpm @ 30 m (90,000 gpm @ 100 ft)	2	1
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	3°C (37°F) WB / 9°C (48°F) CWT / 20°C (68°F) HWT / 1,899 GJ/hr (1,800 MMBtu/hr) heat duty	1	0

ACCOUNT 10 SLAG RECOVERY and HANDLING

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Slag Quench Tank	Water bath	415,000 liters (109,710 gal)	2	0
2	Slag Crusher	Roll	22 tonne/hr (25 tph)	2	0
3	Slag Depressurizer	Proprietary	22 tonne/hr (25 tph)	2	0
4	Slag Receiving Tank	Horizontal, weir	330,000 liters (90,000 gal)	2	0
5	Black Water Overflow Tank	Shop fabricated	150,000 liters (40,000 gal)	2	0
6	Slag Conveyor	Drag chain	22 tonne/hr (25 tph)	2	0
7	Slag Separation Screen	Vibrating	22 tonne/hr (25 tph)	2	0
8	Coarse Slag Conveyor	Belt/bucket	22 tonne/hr (25 tph)	2	0
9	Fine Ash Settling Tank	Vertical, gravity	256,100 liters (127,000 gal)	2	0
10	Fine Ash Recycle Pumps	Horizontal centrifugal	150 lpm @ 14 m H_2O (40 gpm @ 46 ft H_2O)	2	2

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
11	Grey Water Storage Tank	Field erected	150,900 liters (40,000 gal)	2	0
12	Grey Water Pumps	Centrifugal	265 lpm @ 433 m H_2O (70 gpm @ 1,420 ft H_2O)	4	2
13	Slag Storage Bin	Vertical, field erected	1,089 tonne (1,200 tons)	4	0
14	Unloading Equipment	Telescoping chute	118 tonne/hr (130 tph)	2	0

ACCOUNT 11 ACCESSORY ELECTRIC PLANT

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	CTG Step-up Transformer	Oil-filled	24 kV/345 kV, 240 MVA, 3-ph, 60 Hz	2	0
2	STG Step-up Transformer	Oil-filled	24 kV/345 kV, 340 MVA, 3-ph, 60 Hz	1	0
3	High Voltage Auxiliary Transformer	Oil-filled	345 kV/13.8 kV, 70 MVA, 3-ph, 60 Hz	2	0
4	Medium Voltage Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 94 MVA, 3-ph, 60 Hz	1	1
5	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 14 MVA, 3-ph, 60 Hz	1	1
6	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2	0
7	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1	0
8	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1	1
9	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1	1
10	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1	0

ACCOUNT 12 INSTRUMENTATION and CONTROLS

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	DCS - Main Control	Monitor/keyboard; Operator printer (laser color); Engineering printer (laser B&W)	Operator stations/printers and engineering stations/printers	1	0
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1	0
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1	0

4. Liquid CO2/Coal Slurry ND Lignite Case Equipment List

Adapted from the Low Rank Coal Baseline Report Case S4B

Major equipment items for the Phillips 66 gasifier IGCC plant with CO_2 capture are shown in the following tables. The accounts used in the equipment list correspond to the account numbers used in the cost estimates in Section 12. In general, the design conditions include a 10 percent contingency for flows and heat duties and a 21 percent contingency for heads on pumps and fans.

ACCOUNT 1 COAL HANDLING

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Bottom Trestle Dumper and Receiving Hoppers	N/A	181 tonne (200 ton)	2	0
2	Feeder	Belt	572 tonne/hr (630 tph)	2	0
3	Conveyor No. 1	Belt	1,134 tonne/hr (1,250 tph)	1	0
4	Transfer Tower No. 1	Enclosed	N/A	1	0
5	Conveyor No. 2	Belt	1,134 tonne/hr (1,250 tph)	1	0
6	As-Received Coal Sampling System	Two-stage	N/A	1	0
7	Stacker/Reclaimer	Traveling, linear	1,134 tonne/hr (1,250 tph)	1	0
8	Reclaim Hopper	N/A	64 tonne (70 ton)	2	1
9	Feeder	Vibratory	254 tonne/hr (280 tph)	2	1
10	Conveyor No. 3	Belt w/ tripper	508 tonne/hr (560 tph)	1	0
11	Crusher Tower	N/A	N/A	1	0
12	Coal Surge Bin w/ Vent Filter	Dual outlet	254 tonne (280 ton)	2	0
13	Crusher	Impactor reduction	8 cm x 0 - 3 cm x 0 (3" x 0 - 1-1/4" x 0)	2	0
14	As-Fired Coal Sampling System	Swing hammer	N/A	1	1
15	Conveyor No. 4	Belt w/tripper	508 tonne/hr (560 tph)	1	0
16	Transfer Tower No. 2	Enclosed	N/A	1	0
17	Conveyor No. 5	Belt w/ tripper	480 tonne/hr (530 tph)	1	0
18	Coal Silo w/ Vent Filter and Slide Gates	Field erected	906 tonne (750 ton)	6	0

ACCOUNT 2 COAL/SLURRY PREPARATION and FEED

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Conveyor BC-7A/B Day Bin Tripper	Moveable Tripper	850 tons/hr	1	0
2	Day Silo	Concrete Silo	5,810 tons ND Lig	2	0
3	Weigh Feeder	Belt Type	240 tons/hr	2	0
4	Rod Mill	Rotary Rod Mill	240 tons/hr	4	0
5	Rod Mil Charger	Drum, Hydraulic Ram	40 tons rod material storage	1	0
6	Screw Pump	Pneumatic	240 tons/hr solids	4	2
7	Bulk Solids Cooler	Indirect Plate Type	248,100 lb/hr each, ND Lig coal, 70F to -10F	4	0
8	Bag Filter	Pulse-jet Fabric Filter	42,500 acfm	2	0
9	Vent Fan	Centrifugal	42,500 acfm, YY in H2O	2	0
10	Rotary Feeder	Star-type	240 tons/hr	4	0
11	Flop Gate			2	0
12	Mixing Vessel	ASME Sect VIII Div 2 Pressure Vessel	260 psig, -10F	4	0
13	Mixer	Tank-mounted	40 hp	4	0
14	Gasifier Feed Pump	Piston type	166,000 lb/hr slurry @ 850 psig discharge	6	0
15	Refrigeration Driveline	Mechanical Vapor Compression	3540 tons refrigeration per package, R-507	3	0
16	Heat Transfer Skid	Shell/Tube	Matched to R-Driveline, above	3	0
17	Coolant Circulating Pump	Horizontal Centrifugal	14,200 gpm/60 ft TDH	3	0
18	Expansion/Head Tank	Atmos. Press Tank	1,420 gal	1	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
19	CO2 Gas Expander Skid	Vertical dry pit centrifugal pump, 100% capacity	89 lb/sec,475 psig to 275 psig, 756 kWe	1	0
20	CO2 Condenser	Shell and Tube, with desuperheat, condensing, and subcooling surfaces	950 gpm, 510 TDH, 210 bhp	2	0
21	Liquid CO2 Forwarding Pumps	Horizontal, centrifugal type, ANSI, end suction, 100% capacity	920 gpm, 60 TDH, 35 bhp	4	2

ACCOUNT 3 FEEDWATER and MISCELLANEOUS SYSTEMS/EQUIPMENT

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	1,906,000 liters (507,000 gal)	2	0
2	Condensate Pumps	Vertical canned	14,160 lpm @ 91 m H_2O (3,740 gpm @ 300 ft H_2O)	2	1
3	Deaerator (integral w/ HRSG)	Horizontal spray type	573,341 kg/hr (1,264,000 lb/hr)	2	0
4	Intermediate Pressure Feedwater Pump	Horizontal centrifugal, single stage	2,158 lpm @ 27 m H_2O (570 gpm @ 90 ft H_2O)	2	1
5	High Pressure Feedwater Pump No. 1	Barrel type, multi-stage, centrifugal	HP water: 5,754 lpm @ 1,890 m H_2O (1,520 gpm @ 6,200 ft H_2O)	2	1
6	High Pressure Feedwater Pump No. 2	Barrel type, multi-stage, centrifugal	IP water: 189 lpm @ 223 m H_2O (50 gpm @ 730 ft H_2O)	2	1
7	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	1	0
8	Service Air Compressors	Flooded Screw	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	2	1
9	Instrument Air Dryers	Duplex, regenerative	28 m^3/min (1,000 scfm)	2	1
10	Closed Cycle Cooling Heat Exchangers	Plate and frame	372 GJ/hr (353 MMBtu/hr) each	2	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
11	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	212,000 lpm @ 21 m H_2O (56,070 gpm @ 70 ft H_2O)	2	1
12	Engine-Driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1	1
13	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1	1
14	Raw Water Pumps	Stainless steel, single suction	7,851 lpm @ 18 m H_2O (2,070 gpm @ 60 ft H_2O)	2	1
15	Ground Water Pumps	Stainless steel, single suction	3,930 lpm @ 268 m H_2O (1,040 gpm @ 880 ft H_2O)	2	1
16	Filtered Water Pumps	Stainless steel, single suction	4,300 lpm @ 49 m H_2O (1,135 gpm @ 160 ft H_2O)	2	1
17	Filtered Water Tank	Vertical, cylindrical	2,063,000 liter (545,200 gal)	2	0
18	Makeup Water Demineralizer	Anion, cation, and mixed bed	2,600 lpm (690 gpm)	2	0
19	Liquid Waste Treatment System		10 years, 24-hour storm	1	0

ACCOUNT 4 GASIFIER, ASU, and ACCESSORIES INCLUDING LOW TEMPERATURE HEAT RECOVERY

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Gasifier	Pressurized two-stage, slurry-feed entrained bed	3,340 tonne/day, 4.2 MPa (3,670 tpd, 615 psia)	3	0
2	Synthesis Gas Cooler	Fire-tube boiler	446,270 kg/hr (985,400 lb/hr)	3	0
3	Synthesis Gas Cyclone	High efficiency	446,270 kg/hr (985,400 lb/hr) Design efficiency 90%	3	0
4	Candle Filter	Pressurized filter with pulse-jet cleaning	metallic filters	3	0

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
5	Syngas Scrubber Including Sour Water Stripper	Vertical up flow	446,270 kg/hr (985,400 lb/hr)	3	0
6	Raw Gas Coolers	Shell and tube with condensate drain	476,820 kg/hr (1,051,000 lb/hr)	3	0
7	Raw Gas Knockout Drum	Vertical with mist eliminator	373,200 kg/hr, 35°C, 3.9 MPa (824,000 lb/hr, 95°F, 560 psia)	3	0
8	Synthesis Gas Reheater	Shell and tube	57,500 kg/hr (127,000 lb/hr)	3	0
9	Flare Stack	Self-supporting, carbon steel, stainless steel top, pilot ignition	446,270 kg/hr (985,400 lb/hr) syngas	3	0
10	ASU Main Air Compressor	Centrifugal, multi-stage	6,850 m^3/min @ 1.3 MPa (241,740 scfm @ 190 psia)	2	0
11	Cold Box	Vendor design	2,740 tonne/day (3,010 tpd) of 95% purity oxygen	2	0
12	Oxygen Compressor	Centrifugal, multi-stage	1,410 m^3/min (49,850 scfm) Suction - 0.9 MPa (130 psia) Discharge - 5.1 MPa (740 psia)	2	0
13	Primary Nitrogen Compressor	Centrifugal, multi-stage	3,885 m^3/min (137,420 scfm) Suction - 0.4 MPa (60 psia) Discharge - 2.7 MPa (390 psia)	2	0
14	Secondary Nitrogen Compressor	Centrifugal, single-stage	550 m^3/min (19,500 scfm) Suction - 1.2 MPa (180 psia) Discharge - 2.7 MPa (390 psia)	2	0
15	Syngas Dilution Nitrogen Boost Compressor	Centrifugal, single-stage	1,650 m^3/min (58,400 scfm) Suction - 2.6 MPa (384 psia) Discharge - 3.2 MPa (469 psia)	2	0

ACCOUNT 5 SYNGAS CLEANUP

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Mercury Adsorber	Sulfated carbon bed	373,200 kg/hr (824,000 lb/hr) 35°C (95°F) 3.6 MPa (525 psia)	2	0
2	Sulfur Plant	Claus type	63 tonne/day (69 tpd)	1	0
3	Water Gas Shift Reactors	Fixed bed, catalytic	476,820 kg/hr (1,051,000 lb/hr) 232°C (450°F) 4.0 MPa (580 psia)	4	0
4	Shift Reactor Heat Recovery Exchangers	Shell and Tube	Exchanger 1: 117 GJ/hr (110 MMBtu/hr)	4	0
5	Acid Gas Removal Plant	Two-stage Selexol	373,200 kg/hr (824,000 lb/hr) 35°C (95°F) 3.5 MPa (515 psia)	2	0
6	Hydrogenation Reactor	Fixed bed, catalytic	17,274 kg/hr (38,083 lb/hr) 232°C (450°F) 0.1 MPa (12.3 psia)	1	0
7	Tail Gas Recycle Compressor	Centrifugal	14,644 kg/hr (32,284 lb/hr)	1	0

ACCOUNT 5B CO_2 COMPRESSION

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	CO_2 Compressor	Integrally geared, multi-stage centrifugal	1,322 m^3/min @ 15.3 MPa (46,700 scfm @ 2,215 psia)	4	0

ACCOUNT 6 COMBUSTION TURBINE and AUXILIARIES

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Gas Turbine	Advanced F class	232 MW	2	0
2	Gas Turbine Generator	TEWAC	260 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2	0

ACCOUNT 7 HRSG, DUCTING and STACK

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Stack	CS plate, type 409SS liner	76 m (250 ft) high x 8.7 m (19 ft) diameter	2	0
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 394,100 kg/hr, 12.4 MPa/533°C (868,100 lb/hr, 1,800 psig/992°F) Reheat steam - 644,200 kg/hr, 3.1 MPa/533°C (1,024,000 lb/hr, 452 psig/992°F)	2	0

ACCOUNT 8 STEAM TURBINE GENERATOR and AUXILIARIES

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Steam Turbine	Commercially available	307 MW 12.4 MPa/533°C/533°C (1,800 psig/ 992°F/992°F)	1	0
2	Steam Turbine Generator	Hydrogen cooled, static excitation	340 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1	0
3	Surface Condenser	Single pass, divided waterbox including vacuum pumps	950 GJ/hr (900 MMBtu/hr), Condensing temperature 32°C (90°F), Inlet water temperature 9°C (48°F), Water temperature rise 11°C (20°F)	1	0
4	Air-cooled Condenser	---	950 GJ/hr (900 MMBtu/hr), Condensing temperature 32°C (90°F), Ambient temperature 6°C (42°F)	1	0

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Circulating Water Pumps	Vertical, wet pit	340,687 lpm @ 30 m (90,000 gpm @ 100 ft)	2	1

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	3°C (37°F) WB / 9°C (48°F) CWT / 20°C (68°F) HWT / 1,899 GJ/hr (1,800 MMBtu/hr) heat duty	1	0

ACCOUNT 10 SLAG RECOVERY and HANDLING

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	Slag Quench Tank	Water bath	391,100 liters (103,403 gal)	2	0
2	Slag Crusher	Roll	21 tonne/hr (24 tph)	2	0
3	Slag Depressurizer	Proprietary	21 tonne/hr (24 tph)	2	0
4	Slag Receiving Tank	Horizontal, weir	233,200 liters (61,600 gal)	2	0
5	Black Water Overflow Tank	Shop fabricated	105,990 liters (28,000 gal)	2	0
6	Slag Conveyor	Drag chain	21 tonne/hr (24 tph)	2	0
7	Slag Separation Screen	Vibrating	21 tonne/hr (24 tph)	2	0
8	Coarse Slag Conveyor	Belt/bucket	21 tonne/hr (24 tph)	2	0
9	Fine Ash Settling Tank	Vertical, gravity	333,200 liters (88,200 gal)	2	0
10	Fine Ash Recycle Pumps	Horizontal centrifugal	106 lpm @ 14 m H_2O (28 gpm @ 46 ft H_2O)	2	2
11	Grey Water Storage Tank	Field erected	105,990 liters (28,000 gal)	2	0
12	Grey Water Pumps	Centrifugal	265 lpm @ 433 m H_2O (70 gpm @ 1,420 ft H_2O)	4	2
13	Slag Storage Bin	Vertical, field erected	1,089 tonne (1,200 tons)	4	0
14	Unloading Equipment	Telescoping chute	118 tonne/hr (130 tph)	2	0

ACCOUNT 11 ACCESSORY ELECTRIC PLANT

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	CTG Step-up Transformer	Oil-filled	24 kV/345 kV, 240 MVA, 3-ph, 60 Hz	2	0
2	STG Step-up Transformer	Oil-filled	24 kV/345 kV, 340 MVA, 3-ph, 60 Hz	1	0
3	High Voltage Auxiliary Transformer	Oil-filled	345 kV/13.8 kV, 70 MVA, 3-ph, 60 Hz	2	0
4	Medium Voltage Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 94 MVA, 3-ph, 60 Hz	1	1
5	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 14 MVA, 3-ph, 60 Hz	1	1
6	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2	0
7	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1	0
8	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1	1
9	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1	1
10	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1	0

ACCOUNT 12 INSTRUMENTATION and CONTROLS

Equipment No.	Description	Type	Design Condition	Operating Qty	Spares
1	DCS - Main Control	Monitor/keyboard; Operator printer (laser color); Engineering printer (laser B&W)	Operator stations/printers and engineering stations/printers	1	0
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1	0
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1	0