NATIONAL ENERGY TECHNOLOGY LABORATORY

Advancing Oxycombustion Technology for Bituminous Coal Power Plants: An R&D Guide

April 2012

FINAL REPORT

DOE/NETL-2010/1405

U.S. DEPARTMENT OF ENERGY

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LIST OF ACRONYMS AND ABBREVIATIONS

AACE	American Association of Cost Engineering
acfm	Actual cubic feet per minute
ASU	Air separation unit
Ar	Argon
BFD	Block flow diagram
BFW	Boiler feed water
Bhp	Break horse power
Btu	British thermal unit
Btu/hr	British thermal unit per hour
Btu/kWh	British thermal unit per kilowatt hour
Btu/lb	British thermal unit per pound
Btu/lb_m	British thermal unit per pound-mass
B&W	Babcock and Wilcox
CAR	Ceramic auto-thermal recovery
CCF	Capital charge factor
CCFp	Capital charge factor for a levelization period of P years
CCS	Carbon capture and storage
CF	Capacity factor
CO_2	Carbon dioxide
COE	Cost of electricity
CPU	CO_2 compression and purification unit
CWT	Cold water temperature
DCC	Direct contact cooler
DCS	Distributed control system
DOE	Department of Energy
ft	Foot, feet
ft^3	Cubic foot
EPRI	Electric Power Research Institute
ESPA	Energy Sector Planning and Analysis
FGD	Flue gas desulfurization
FGR	Flue gas recirculation
FWH	Feedwater heater
Gal	Gallon
GHG	Greenhouse gas
gpm	Gallons per minute
GJ	Gigajoule
h, hr	Hour
H_2	Hydrogen
HHV	Higher heating value
hp	Horsepower

HP	High pressure
HVAC	Heating, ventilating, and air conditioning
HWT	Hot water temperature
ICFM	Inlet cubic feet per minute
IEA	International Energy Agency
IEP	Innovations for existing plants
ID	Induced draft
ISO	International Standards Organization
IOU	Investor-owned utility
kg	Kilogram
kg/hr	Kilogram per hour
kg_{mol}/hr	Kilogram mole per hour
kJ	Kilojoul
kV	Kilovolts
kW	Kilowatt
kWh	Kilowatt-hour
kW_{th}	Kilowatt-thermal
lb	Pound
lbm/hr	Pound per hour
lb_{mol}/hr	Pound-mole per hour
LCOE	Levelized cost of electricity
LF	Levelization factor
LHV	Lower heating value
LP	Low pressure
lpm	Liter per minute
m	Meter
MAC	Main air compressor
md	millidarcy (a measure of permeability)
MMBtu	Million British thermal units (also shown as 10^6 Btu)
MMBtu/hr	Million British thermal units per hour (also shown as 10^6 Btu/hr)
MPa	Megapascals
MVA	Megavolt-amps
MW	Megawatt
MWe	Megawatt electric
MWh	Megawatt-hour
MW_{th}	Megawatt-thermal
NETL	National Energy Technology Laboratory
N_2	Nitrogen
NG	Natural gas
NO_x	Oxides of nitrogen
O&M	Operations and maintenance
OC	Operating cost

OF	Oxyfuel
PC	Pulverized coal
p.f.	Power Factor
PM	Particulate matter
ppm	Parts per million
psi	Pounds per square inch
psia	Pounds per square inch absolute
psig	Pounds per square inch gage
RDS	Research and Development Solutions, LLC
rpm	Revolutions per minute
SC	Supercritical
scfm	Standard cubic feet per minute
SO_2	Sulfur dioxide
SOx	Sulfur oxides
TOC	Total overnight cost
TPC	Total plant cost
TPD	Tons per day
tph	Ton per hour
ton	2,000 pounds
tonne	1,000 kg
TS&M	Transport, storage, and monitoring
USC	Ultra-supercritical
V	Volts
V-L	Vapor and liquid portion of stream (excluding solids)
vol%	Percent by volume
VPSA	Vacuum pressure swing adsorption
WG	Water Gauge

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EXECUTIVE SUMMARY

The National Energy Technology Laboratory (NETL) is funding research aimed at improving the performance and reducing the cost of oxycombustion. The objective of this study is to guide oxycombustion research in areas that can provide the largest benefits in electricity cost and plant performance. The advanced oxycombustion technologies evaluated in this study can be categorized into four major areas: advanced boiler design, advanced oxygen production, advanced flue gas treatment, and innovative CO_2 compression concepts. This report contains the results of a techno-economic study of eight advanced oxycombustion systems that were anticipated to improve oxycombustion performance. In all, the report covers nine cases: eight cases employing advanced oxycombustion technologies and a base case employing what is considered to be current oxycombustion technology. These cases are summarized in Exhibit ES-1.

Exhibit ES-1 Case Descriptions

Case	Boiler Technology psig/°F/°F	Advanced PC Concept	Coal Type	Oxidant	Sulfur Removal	CO_2 Storage
Base	Supercritical PC 3500/1110/1150	Current Oxycombustion	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
1	Supercritical PC 3500/1110/1150	Advanced O_2 Membrane with Boiler Integration	Illinois No. 6	~100% Advanced O_2 Membrane	Wet FGD	Remote Geologic
1a	Supercritical PC 3500/1110/1150	Advanced O_2 Membrane with Natural Gas Preheater	Illinois No. 6	~100% Advanced O_2 Membrane	Wet FGD	Remote Geologic
2	*Chemical Looping*	*Covered in a separate study*	---	---	---	---
3	Ultra-supercritical PC 4000/1350/1400	Advanced Materials for Ultra-supercritical Conditions	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
4	Supercritical PC 3500/1110/1150	Co-sequestration	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Co-capture	Remote Geologic
5	Supercritical PC 3500/1110/1150	Advanced Recycle	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
6	Supercritical PC 3500/1110/1150	Advanced CO_2 Compression	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
7	Supercritical PC 3500/1110/1150	Oxycombustion Boiler	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
Cumulative	Ultra-supercritical PC 4000/1350/1400	Cumulative Case	Illinois No. 6	~100% Advanced O_2 Membrane	Co-capture	Remote Geologic

Each of the advanced oxycombustion cases are modeled as new, commercial-scale plants projected to be designed and built in the 2030 timeframe. These advances are compared to what is considered to be current technology: a supercritical pulverized coal plant operated with flue gas recycle and equipped with a state of the art cryogenic distillation ASU, a wet FGD sulfur removal unit, and a conventional CO_2 purification/compression system.

In order to meet the challenges of reducing greenhouse gas emissions, DOE/NETL has established carbon capture, utilization and storage (CCUS) goals for the Existing Plants, Emissions & Capture (EPEC) program. By 2020, advanced technologies will be demonstrated and best practices will be implemented to achieve the following goals:

- 90 percent CO_2 capture
- 99+ percent storage permanence
- For post- and oxy-combustion carbon capture, the increase in the cost of electricity (COE) should be less than 35 percent above that of an equivalent plant without carbon capture, excluding the cost of CO_2 transport, storage and monitoring.

The advanced oxycombustion technologies studied were evaluated to determine if they could meet the DOE goal. The first year electricity costs of the advanced technology cases were compared to the cost of electricity (COE) of an air-fired, supercritical boiler with no carbon capture. The results are shown in Exhibit ES-2 and Exhibit ES-3. None of the advanced technologies currently meet the DOE goal on their own, however the combined effect of including all advanced technologies in the same plant is shown here to exceed the DOE goal.

Exhibit ES-2 Cost of Electricity

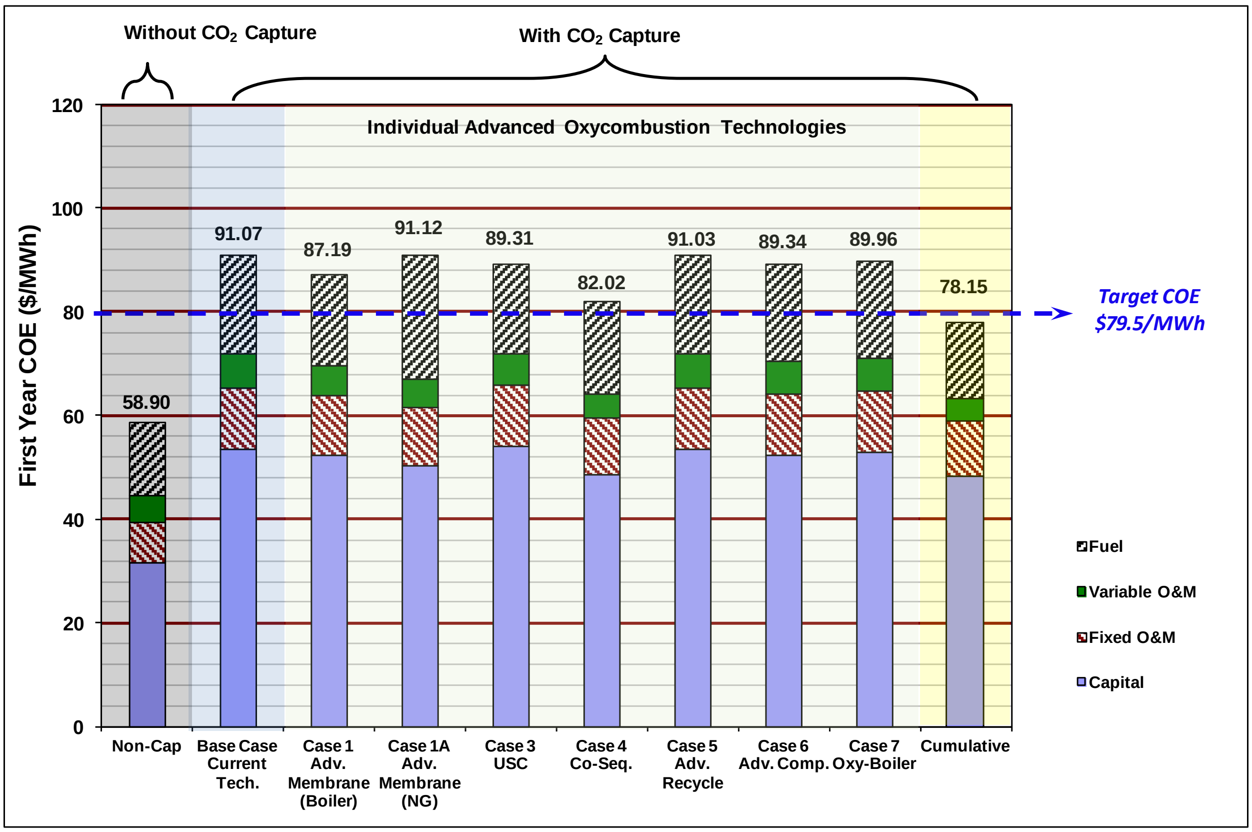


Exhibit ES-3 Percent Increase in Cost of Electricity with CCS

Study Case	First Year Cost of Electricity ($/MWh)						Increase in COE (%)[a]
	Capital	Fixed O&M	Variable O&M	Fuel	TS&M	Total (Less TS&M)	
Non-Capture Reference, Air-fired SC w/o CCS	31.68	7.97	5.03	14.22	0.00	58.90	-
Current OF Technology, O_2-fired SC w/ASU & CCS	53.72	11.81	6.47	19.08	5.83	91.07	54.6
Case 1, O_2-fired SC w/Boiler Adv. Membrane & CCS	52.35	11.53	5.99	17.32	5.60	87.19	48.0
Case 1A, O_2-fired SC w/NG Adv. Membrane & CCS	50.45	11.23	5.63	23.81	5.25	91.12	54.7
Case 3, O_2-fired USC w/ASU & CCS	54.15	11.81	6.10	17.25	5.58	89.31	51.6
Case 4, O_2-fired SC w/ASU & Co-Sequestration	48.85	10.79	4.78	17.60	5.67	82.02	39.3
Case 5, O_2-fired SC w/ASU, Wet Recycle & CCS	53.66	11.80	6.47	19.11	5.91	91.03	54.5
Case 6 O_2-fired SC w/ASU & Shock Compression	52.59	11.60	6.34	18.81	5.87	89.34	51.7
Case 7, O_2-fired SC w/ASU, Adv. Boiler & CCS	53.13	11.65	6.32	18.87	5.89	89.96	52.7
Cumulative Technology Case	**48.52**	**10.66**	**4.30**	**14.68**	**5.28**	**78.15**	**32.7**

While the Cumulative Case has been shown to meet the DOE carbon capture goal, none of the advanced technologies are yet ready for commercial implementation and require substantial research, development and demonstration before they can be considered viable solutions for carbon capture.

The results of this report suggest that both cost and performance improvements need to be made in multiple technologies applicable to the oxycombustion pathway for CO_2 capture in order to meet DOE's CO_2 capture goals.

The major conclusions of this study uncover how future research and development should focus on developing oxycombustion-specific technologies for the most beneficial improvements in performance and cost. Based on the results of this study, improvements in the following technologies should have the largest positive impact on oxycombustion:

- **Oxygen Supply**: Advanced membrane-based air separation technology shows promise due to its high temperature and high pressure operation, which allows for a relatively high amount of heat and power recovery. Membrane system integration, membrane performance enhancements, and capital cost reduction should be the main areas of focus for this technology area based on the results of this study.
- **Sulfur-Tolerant Materials**: Research should be conducted to develop sulfur-tolerant materials to handle the recycled flue gas in systems with reduced flue gas desulfurization. It is understood that completely eliminating the FGD may not be possible in the near-term because of materials constraints and potential restrictions on sequestration, however if continual progress is made in these areas, system efficiency will continue to increase in proportion.
- **Oxycombustion Boilers**: As sulfur-tolerant materials are developed, smaller oxycombustion-based boiler designs with enhanced heat transfer may become more effective. Sulfur-tolerant materials will allow less recycle, less flue gas desulfurization requirements, and therefore higher efficiencies all while decreasing the boiler size, and potentially cost depending on the premium for exotic material.
- **Advanced Steam Conditions**: While not specific to oxycombustion, raising steam conditions in the Rankine cycle also has a beneficial effect on oxycombustion systems. Advancing steam conditions in the Rankine cycle can maximize the benefit of the potentially high temperatures of the oxycombustion process and should be taken into consideration when designing oxycombustion-specific boiler designs.

The objective of this study was not to review the degree to which research and development in these areas is already progressing, nor was it to uncover any thermodynamic, physical or economic limitations on improvements in these areas. Instead, the main objective was to identify major performance bottlenecks and the effect of eliminating them. Therefore, it is possible that room for improvement in one or more of the targeted research areas is limited, which would limit the potential performance of oxycombustion as predicted by this study. Nevertheless, this study suggests that a diverse portfolio of oxycombustion-based technologies should be included in RD&D plans for government, industrial and academic entities as a means to drive down costs and improve the performance of carbon capture and sequestration.

The overall performance summary comparison is shown in Exhibit ES-4. This study was designed to incorporate advanced oxycombustion technologies anticipated to improve cost and/or performance over an oxycombustion system composed of currently available technologies. The Cumulative Case incorporates all concepts under the assumption that all advanced technologies will enhance performance in an integrated system as well. A decision was made to use the indirect fired, coal-integrated advanced membrane ASU system (represented in Case 1) in the cumulative case because it was the lower cost (COE) of the two advanced membrane systems analyzed. In addition, this case does not vent the CO_2 generated from the air preheat like the natural gas-integrated advanced membrane configuration (Case 1A) does. The amount of natural gas required to completely preheat the air feed would result in an excessive amount of vented CO_2, decreasing overall CO_2 capture below 90%. Therefore, a regenerative heat exchanger immediately prior to the N_2 vent gas expander was used to perform a portion of the preheat.

Exhibit ES-4 Performance Summary Comparison

Case	Base Case	Case 1	Case 1A	Case 3	Case 4	Case 5	Case 6	Case 7	Case 10	
Description	Current Technology	Advanced Membrane/Boiler Integration	Advanced Membrane/NG Integration	USC w/Advanced Material	Co-Sequestration	Advanced Recycle	Advanced CO_2 Compression	Oxyfuel Boiler	Cumulative	
Plant Output										
Steam Turbine Power	790,800	620,500	662,300	765,900	765,500	790,600	814,000	785,900	624,700	kW_e
Advanced Membrane Expander Power	N/A	345,200	272,400	N/A	N/A	N/A	N/A	N/A	295,500	kW_e
Gross Power	**790,800**	**965,700**	**934,700**	**765,900**	**765,500**	**790,600**	**814,000**	**785,900**	**920,200**	kWe
Auxiliary Load										
Coal Handling and Conveying	500	480	440	480	480	500	500	500	440	kW_e
Limestone Handling & Reagent Preparation	1,210	1,100	930	1,090	0	1,210	1,190	1,200	0	kW_e
Pulverizers	3,740	3,390	2,860	3,380	3,450	3,740	3,680	3,690	2,880	kW_e
Ash Handling	720	650	550	650	660	720	710	710	550	kW_e
Primary Air Fans	1,010	910	770	910	1,410	980	1,010	790	860	kW_e
Forced Draft Fans	1,280	1,150	990	1,150	1,800	1,240	1,270	1,010	1,080	kW_e
Induced Draft Fans	7,080	6,330	5,390	6,380	3,610	6,610	7,010	6,030	2,380	kW_e
Air Separation Unit Main Air Compressor	125,720	315,240	296,100	113,350	115,970	125,880	123,950	124,190	269,910	kW_e
ASU Auxiliaries	1,000	0	0	1,000	1,000	1,000	1,000	1,000	0	kW_e
Baghouse	90	90	70	80	90	90	90	90	70	kW_e
FGD Pumps and Agitators	4,050	3,680	3,230	3,650	0	4,050	3,990	4,000	0	kWe
CO_2 Compression	73,410	64,170	55,550	65,070	67,770	73,620	98,700	72,520	76,250	kW_e
Condensate Pumps	1,040	810	880	960	1,020	1,040	1,070	1,050	890	kW_e
Boiler Feedwater Booster Pumps	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	kW_e
Miscellaneous Balance of Plant[2,3]	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	kW_e
Steam Turbine Auxiliaries	400	400	400	400	400	400	400	400	400	kW_e
Circulating Water Pumps	9,160	7,730	7,310	7,990	8,170	9,180	8,930	9,010	6,030	kW_e
Cooling Tower Fans	5,340	4,510	4,270	4,670	4,770	5,360	5,220	5,260	3,520	kW_e
Transformer Losses	3,030	3,000	3,040	2,880	2,880	3,030	3,160	3,000	2,880	kW_e
Total	240,780	415,640	384,780	216,090	215,480	240,650	263,880	236,450	370,140	kW_e
Plant Performance										
Net Auxiliary Load	240,780	415,640	384,780	216,090	215,480	240,650	263,880	236,450	370,140	kW_e
Net Plant Power	550,020	550,060	549,920	549,810	550,020	549,950	550,120	549,450	550,060	kW_e
Net Plant Efficiency (HHV)	29.3%	32.2%	33.0%	32.4%	31.7%	29.2%	29.7%	29.6%	38.1%	
Net Plant Heat Rate (HHV)	12,300 (11,658)	11,167 (10,584)	10,904 (10,335)	11,120 (10,540)	11,347 (10,754)	12,317 (11,675)	12,124 (11,492)	12,163 (11,528)	9,461 (8,968)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	249,312 (549,638)	226,371 (499,062)	190,935 (420,941)	225,320 (496,745)	229,991 (507,043)	249,640 (550,361)	245,804 (541,905)	246,282 (542,960)	191,790 (422,825)	kg/hr (lb/hr)
Natural Gas	N/A	N/A	15,544 (34,268)	N/A	N/A	N/A	N/A	N/A	N/A	kg/hr (lb/hr)
Coal Thermal Input[1]	1,879,193	1,706,276	1,439,182	1,698,356	1,733,562	1,881,666	1,852,755	1,856,362	1,445,623	kW_{th}
Natural Gas Thermal Input[4]	N/A	N/A	226,458	N/A	N/A	N/A	N/A	N/A	N/A	kW_{th}
Thermal Input (Coal + Natural Gas)	1,879,193	1,706,276	1,665,640	1,698,356	1,733,562	1,881,666	1,852,755	1,856,362	1,445,623	kW_{th}
Condenser Duty	3,079 (2,918)	2,831 (2,683)	2,821 (2,674)	2,648 (2,510)	3,160 (2,995)	3,088 (2,927)	3,398 (3,221)	3,062 (2,902)	2,618 (2,482)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	33.0 (8,729)	27.6 (7,304)	27.2 (7,186)	29.6 (7,822)	30.2 (7,976)	33.2 (8,777)	32.2 (8,499)	32.5 (8,587)	21.8 (5,771)	m^3/min (gpm)

1 - HHV of as-received Illinois No. 6 coal is 27,135 kJ/kg(11,666 Btu/lb)

2 - Boiler feed pumps are turbine driven

3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

4 - HHV of natural gas is 22,549 Btu/lb

1. INTRODUCTION

The rising concentration of carbon dioxide (CO_2) in the environment has been widely documented. Levels of CO_2 in the atmosphere have shown a steady rise from approximately 300 parts per million (ppm) in 1940 to more than 370 ppm today [1]. At the same time, various studies have documented noticeable changes in climate during recent years, and model predictions suggest that CO_2 levels play a role in these climate variations [2]. Given the potential implications surrounding global climate change and increasing concentrations of CO_2 in the atmosphere, technology and policy options are being investigated for mitigating CO_2 emissions.

Electric power generation represents one of the largest CO_2 contributors in the United States. Electricity consumption is expected to grow and fossil fuels are expected to continue to be the dominant fuel source. Therefore, fossil-fuel-based power generation can be expected to provide an even greater CO_2 contribution in the future. Coal fuels nearly half of this electric power generation capacity and typically produces the cheapest electricity among all fuel sources, however coal is generally more CO_2-intensive. This creates a need for more aggressive and more cost effective CO_2 mitigation for coal-based power generation.

The U.S. Department of Energy (DOE) has adopted a goal of developing technology capable of capturing and sequestering 90 percent of the CO_2 produced in a pulverized coal (PC)-fired power plant with an increase in the cost of electricity (COE) of no more than 35 percent over that for a non-capture base plant. Systems studies have shown that this is an appropriate stretch goal that will encourage aggressive technology advances in CO_2 capture and compression as a means to stabilize atmospheric CO_2 concentrations.

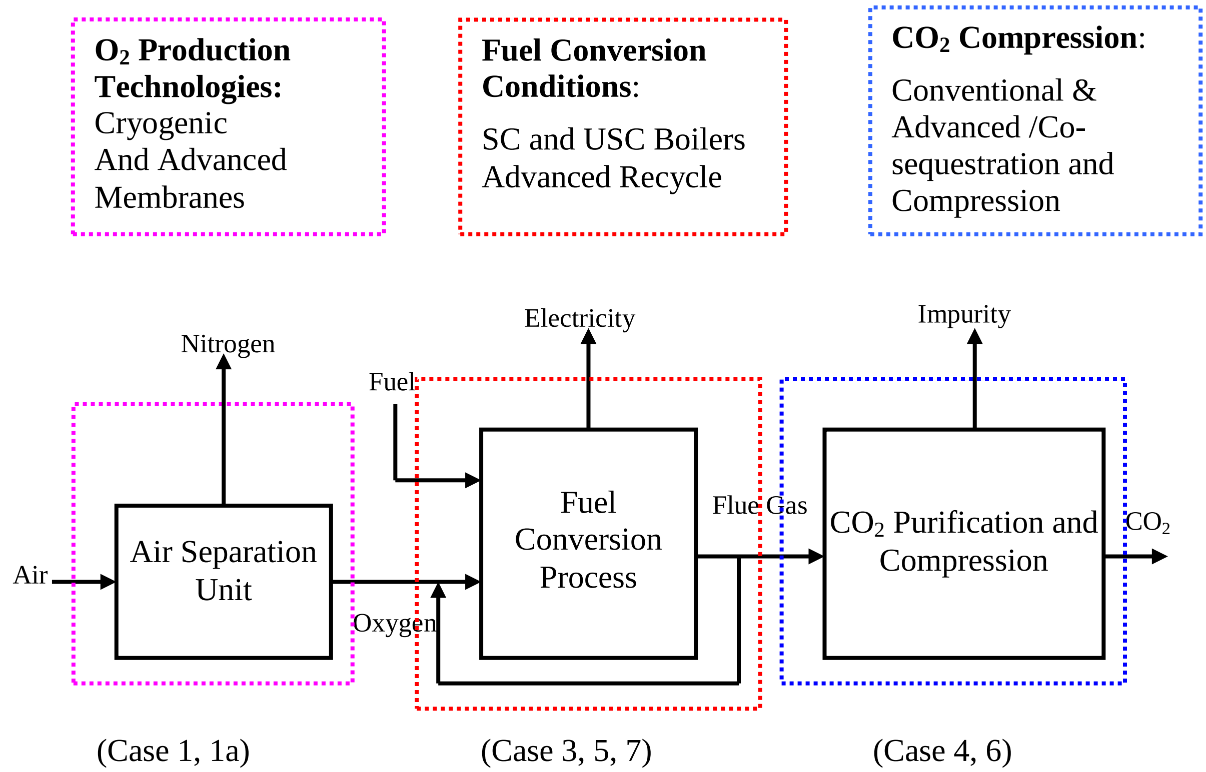
Recent analyses carried out by ALSTOM Power [3], Air Liquide [4], IEA GHG [5] and the National Energy Technology Laboratory's (NETL's) Office of Systems, Analyses and Planning [7] have shown that oxycombustion with CO_2 capture is competitive with conventional air-based combustion utilizing amine scrubbing for CO_2 control. In addition, these studies identified potential areas for oxycombustion process improvements that have the potential to significantly decrease CO_2 mitigation costs and to approach the DOE carbon capture goal.

The main objectives of this study are to (1) identify performance bottlenecks in oxycombustion technology (2) assess how removing these barriers may contribute to achieving the DOE goal of no more than a 35 percent increase in COE for 90 percent CO_2 capture (excluding CO_2 transport, storage and monitoring [TS&M]).

1.1 OXYCOMBUSTION TECHNOLOGY

Oxycombustion is one of the pathways to implement CO_2 capture on coal-fired power plants. In an oxycombustion process, a pure or enriched oxygen gas stream is used instead of air as the oxidant for combustion. In this process, almost all of the nitrogen is removed from the air yielding a concentrated stream of oxygen (typically ~95 percent O_2). Oxycombustion technology involves three components: an oxygen production unit, a combustion (fuel conversion) unit, and a CO_2 purification and compression unit. Exhibit 1-1 shows these three components, along with different options for each.

Exhibit 1-1 Components of an Oxycombustion System



Compared to traditional air-fired plants, oxycombustion has many potential advantages. The main benefits of oxycombustion technology as a CO_2 capture and sequestration solution are:

1. Due to the removal of nitrogen in air, oxycombustion produces approximately 75 percent or less flue gas than air-fired combustion, and produces exhaust consisting of typically over 70 vol% CO_2 [6]. Due to lower flue gas volumes, plant equipment sizes, and thus the capital cost, have the potential to be significantly reduced.
2. Oxycombustion produces high purity, near-sequestration-ready CO_2, which requires minimal purification.
3. As a result of the lower nitrogen levels in the oxidant, 60–70 percent reduction of NO_x versus air-fired combustion is possible. Some nitrogen is still available from the coal and from air infiltration, however, which may still contribute to NO_x formation.
4. Increased mercury ionization. With oxycombustion, there is potential for enhancement of Hg removal in the baghouse and flue gas desulfurization (FGD) unit based on Babcock & Wilcox (B&W) data during Small Boiler Simulator (~5 MMBtu/hr) tests, which showed an increase in the oxidized Hg/elemental Hg ratio during oxycombustion with bituminous coal. Oxidized Hg is more efficiently captured in the baghouse and FGD unit.
5. Oxycombustion technology can readily be applied to new and existing coal-fired power plants. Current oxycombustion technology uses conventional equipment already proven in the power generation industry; however it has not yet been demonstrated as a fully integrated system at commercial scale.

The above benefits position oxycombustion as a viable alternative to post-combustion CO_2 removal technology for conventional air-fired boilers. Like post-combustion technologies however, the appeal of oxycombustion is tempered by some challenges, as described below:

1. Since pure or enriched oxygen is used, oxygen separation is required, which is an energy- and capital-intensive process.
2. Air infiltration into the boiler is an issue, as it dilutes the resulting flue gases. Various options are being investigated to minimize infiltration.
3. Single-pass combustion of coal in pure oxygen would occur at temperatures too high for existing burner designs and would have lower mass flows that would reduce convective heat transfer and create heat transfer problems in existing boiler designs. This issue is mitigated by diluting the oxygen with a cooled Flue Gas Recycle (FGR) stream; however this results in an increase of the parasitic power load.
4. Because of the oxygen separation, flue gas recycle, and CO_2 compression, an oxycombustion power plant is much less efficient than a traditional air-fired power plant without CO_2 removal.

The intent of this study is to examine how some or all of these challenges may be alleviated to improve the performance of an oxycombustion power plant. In the following sections, the current status and detail of conventional oxycombustion technology is briefly summarized, and the innovative technology concepts for advanced oxycombustion systems are evaluated.

2. DESIGN BASIS

Eight advanced oxycombustion cases were evaluated and are compared to a supercritical current technology case, which represents the current technology. The eight oxycombustion cases include two cases with supercritical configurations using advanced membrane-derived oxygen, one case with an ultra-supercritical configuration using cryogenic oxygen, and several cases with advanced technologies involving alternative flue gas cleaning/recycle configurations, advanced CO_2 compression, and advanced boiler configurations. The case descriptions are summarized in Exhibit 2-1 followed by more detailed explanations below. The general design basis used for the systems analyses is described in the following subsections.

Exhibit 2-1 Case Descriptions

Case	Boiler Technology psig/°F/°F	Advanced PC Concept	Coal Type	Oxidant	Sulfur Removal	CO_2 Storage
Base	Supercritical PC 3500/1110/1150	Current Oxycombustion	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
1	Supercritical PC 3500/1110/1150	Advanced O_2 Membrane with Boiler Integration	Illinois No. 6	~100% Oxygen/ Advanced Membrane	Wet FGD	Remote Geologic
1a	Supercritical PC 3500/1110/1150	Advanced O_2 Membrane with Natural Gas Preheater	Illinois No. 6	~100% Oxygen/ Advanced Membrane	Wet FGD	Remote Geologic
2	*Chemical Looping*	*Covered in a separate study*	---	---	---	---
3	Ultra-supercritical PC 4000/1350/1400	Advanced Materials for Ultra-supercritical Conditions	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
4	Supercritical PC 3500/1110/1150	Co-sequestration	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Co-capture	Remote Geologic
5	Supercritical PC 3500/1110/1150	Advanced Recycle	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
6	Supercritical PC 3500/1110/1150	Advanced CO_2 Compression	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
7	Supercritical PC 3500/1110/1150	Oxycombustion Boiler	Illinois No. 6	95% Oxygen/ Cryogenic ASU	Wet FGD	Remote Geologic
Cumulative	Ultra-supercritical PC 4000/1350/1400	Cumulative Case	Illinois No. 6	~100% Oxygen/ Advanced Membrane	Co-capture	Remote Geologic

Current Technology Case – This case includes a supercritical pulverized coal (SC PC) oxycombustion plant with a wet FGD unit. The boiler design is based on bituminous coal air-fired units. Consistent with current air-fired boiler designs, the theoretical adiabatic flame temperature of the boiler is controlled to 2,031°C (3,687°F) by varying the amount of flue gas recycled to the boiler. This adiabatic flame temperature is based on that of an air-fired bituminous PC plant as represented in a previous NETL report [7]. The oxidant is supplied by conventional cryogenic ASU technology that produces 95 vol% O_2. The recycled flue gas stream is superheated to 9°C (15°F) before entering the primary and induced draft fans. The CO_2 compression is accomplished by eight stages of centrifugal compression (86 percent polytropic efficiency) with intercooling between each stage. This base plant is the “current” approach to oxycombustion. Illinois No. 6 coal is the fuel and the plant is located at a generic non-minemouth site in the Midwestern United States.

Case 1 – This case includes a SC PC oxycombustion plant with a wet FGD unit. This plant employs an advanced membrane air separation unit (ASU) to produce nearly 100 vol% purity O_2 for combustion. The high temperatures are generated through integration of the membrane feed stream with the PC boiler system. Due to the high temperatures generated in the process, the oxidant cooling scheme is integrated with both high- and low-pressure boiler feedwater. This reduces the amount of steam to be extracted from the steam cycle, which can increase the power output of the steam cycle.

Case 1a – This case also uses an advanced membrane ASU system to produce the oxygen necessary for combustion. Instead of pre-heating the air inlet stream by integration with the boiler, a natural gas-fired direct contact heater is used. An oxidant cooling scheme similar to that in Case 1 is employed.

Case 3 – This case is the same as the current technology case, except the oxycombustion boiler drives a USC steam cycle. The USC steam cycle conditions are 27.6 MPa/732°C/760°C (4,000 psig/1,350°F/1,400°F).

Case 4 – This case is the same as the current technology case, except the FGD unit is not employed. Co-sequestration of all sulfur constituents is assumed to be possible.

Case 5 – This case is the same as the current technology case, except the recycled flue gas is not superheated and enters the forced- and induced-draft fans at saturated conditions. This reduces the amount of steam to be extracted from the steam cycle, which can increase the power output of the steam cycle.

Case 6 – This case is the same as the current technology case, except the CO_2 compression system utilizes advanced shock wave compression technology with higher stage compression efficiency (90 percent polytropic). The interstage compression heat is recovered in the boiler feedwater system, which reduces the amount of steam to be extracted from the steam cycle and can increase the power output of the steam cycle.

Case 7 – This case is the same as the current technology case, except the adiabatic flame temperature is controlled to 2,310°C (4,190°F) based on an oxycombustion boiler by reducing the recycle rate relative to the Current Technology Case. This enables a reduction in the amount of flue gas recycled to the boiler, which leads to lower parasitic load and improved system efficiency.

Cumulative Case – This case is intended to model the cumulative effect and any synergies of the proposed PC oxycombustion concepts.

2.1 SITE DESCRIPTION

All plants in this study are assumed to be located at a generic Midwestern U.S. plant site, with ambient conditions and site characteristics as presented in Exhibit 2-2 and Exhibit 2-3. The ambient conditions are the same as International Standards Organization (ISO) conditions [8].

Exhibit 2-2 Site Ambient Conditions

Elevation, ft	0
Barometric Pressure, psia	14.696
Design Ambient Temperature, Dry Bulb, °F	59
Design Ambient Temperature, Wet Bulb, °F	51.5
Design Ambient Relative Humidity, %	60

Exhibit 2-3 Site Characteristics

Location	A Greenfield site in the Midwestern United States[a]
Topography	Level
Size, acres	300
Transportation	Rail
Ash Disposal	Off Site
Water	Municipal (50%) / Groundwater (50%)
Access	Land locked, having access by rail and highway
CO_2	Compressed to 15.3 MPa (2,215 psia), transported 50 miles, and sequestered in a saline formation at a depth of 4,055 feet
[a]Champaign County, Illinois, is assumed for assessment of construction costs.	

The following design parameters are considered site-specific, and are not quantified for this study. Allowances for normal conditions and construction are included in the cost estimates:

- Flood plain considerations
- Existing soil/site conditions
- Water discharges and reuse
- Rainfall/snowfall criteria
- Seismic design
- Buildings/enclosures
- Fire protection
- Local code height requirements
- Noise regulations (impact on site and surrounding area)

2.2 COAL CHARACTERISTICS

The design coal characteristics are presented in Exhibit 2-4. All cases in this study were modeled using Illinois No. 6 bituminous coal.

Exhibit 2-4 Design Coal

Coal seam nomenclature	*Herrin (No. 6)*	
Coal name	*Illinois No. 6*	
Mine	*Old Ben No. 26*	
ASTM D388 Rank	*High Volatile A Bituminous*	
Proximate Analysis	**As-Received**	**Dry**
Moisture	11.12%	0.00%
Volatile Matter	34.99%	39.37%
Ash	9.70%	10.91%
Fixed Carbon	44.19%	49.72%
Total	100.00%	100.00%
Ultimate Analysis	**As-Received**	**Dry**
Carbon	63.75%	71.73%
Hydrogen	4.50%	5.06%
Nitrogen	1.25%	1.41%
Sulfur	2.51%	2.82%
Chlorine	0.29%	0.33%
Ash	9.70%	10.91%
Moisture	11.12%	0.00%
Oxygen	6.88%	7.74%
Total	100.00%	100.00%
Reported Heating Value	**As-Received**	**Dry**
HHV* (Btu/lb)	11,666	13,126
LHV**(Btu/lb)	11,252	12,660
HHV (kJ/kg)	27,135	30,531
LHV (kJ/kg)	26,171	29,447

* HHV = higher heating value

**LHV = lower heating value

Exhibit 2-4 Design Coal (continued)

Typical Ash Mineral Analysis		
Silica	SiO_2	45.0%
Aluminum Oxide	Al_2O_3	18.0%
Titanium Dioxide	TiO_2	1.0%
Iron Oxide	Fe_2O_3	20.0%
Calcium Oxide	CaO	7.0%
Magnesium Oxide	MgO	1.0%
Sodium Oxide	Na_2O	0.6%
Potassium Oxide	K_2O	1.9%
Phosphorus Pentoxide	P_2O_5	0.2%
Sulfur Trioxide	SO_3	3.5%
Undetermined		1.8%
Total		100.0%
Typical Ash Fusion Temperatures (°F)		
Reducing		
Initial – Limited deformation		1,950 ºF
Softening	H=W	2,030 ºF
Hemispherical	H=1/2W	2,140 ºF
Fluid		2,150 ºF
Oxidizing		
Initial – Limited deformation		2,250 ºF
Softening	H=W	2,300 ºF
Hemispherical	H=1/2W	2,430 ºF
Fluid		2,450 ºF
Hardgrove Grindability Index		60 HGI

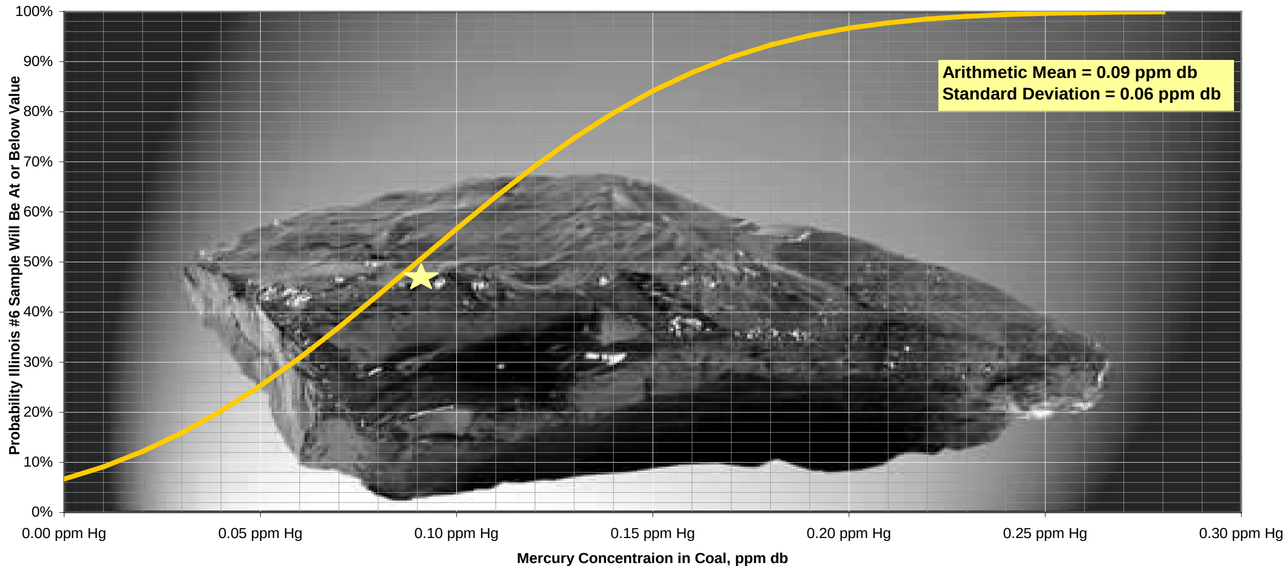
Exhibit 2-4 Design Coal (continued)

Average Trace Element Composition of Coal Shipped by Illinois Mines, Dry basis, ppm			
Trace Element		**Arithmetic Mean**	**Standard Deviation**
Arsenic	As	7.5	8.1
Boron	B	90	45
Beryllium	Be	1.2	0.7
Cadmium	Cd	0.5	0.9
Chlorine	Cl	1671	1189
Cobalt	Co	3.5	1.3
Chromium	Cr	14	6
Copper	Cu	9.2	2.5
Fluorine	F	93	36
Mercury	Hg	0.09	0.06
Lithium	Li	9.4	7.1
Manganese	Mn	38	32
Molybdenum	Mo	8.4	5.7
Nickel	Ni	14	5
Phosphorus	Ph	87	83
Lead	Pb	24	21
Tin	Sb	0.9	0.7
Selenium	Se	1.9	0.9
Thorium	Th	1.5	0.4
Uranium	Ur	2.2	1.9
Vanadium	V	31	16
Zinc	Zn	84.4	84.2

Note: Average trace element composition of coal shipped by Illinois mines is based on 34 samples [9]

The mercury content in the Illinois No. 6 coal is reported as an arithmetic mean value of 0.09 ppm (dry basis), with a standard deviation of 0.06. Hence, as illustrated in Exhibit 2-5, there is a 50 percent probability that the mercury content in the Illinois No. 6 coal would not exceed 0.09 ppm (dry basis), and 99.9 percent probability that the mercury content in the Illinois No. 6 coal would not exceed 0.28 ppm (dry basis).

Exhibit 2-5 Probability Distribution of Mercury Concentration in the Illinois No. 6 Coal



For the cases in this study, coal mercury content was assumed to be equal to the arithmetic mean mercury concentration plus one standard deviation, or 0.15 ppmd. About 84 percent of the coal samples represented in Exhibit 2-5 have a mercury concentration equal to or less than 0.15 ppmd.

2.3 NATURAL GAS CHARACTERISTICS

Natural gas is utilized as the main fuel in Case 1a (NG-fired advanced membrane ASU), and its composition is presented in Exhibit 2-6.

Exhibit 2-6 Natural Gas Composition

Component		**Volume Percentage**
Methane	CH_4	93.1
Ethane	C_2H_6	3.2
Propane	C_3H_8	0.7
n-Butane	C_4H_{10}	0.4
Carbon Dioxide	CO_2	1.0
Nitrogen	N_2	1.6
	Total	1000
	LHV	**HHV**
kJ/kg	47,889	53,028
MJ/scm	35.03	38.79
Btu/lb	20,583	22,792
Btu/scf	940	1,041

Note: Fuel composition is normalized and heating values are calculated

2.4 STEAM CONDITIONS

Steam conditions for the Rankine cycle were selected based on the NETL Advanced Materials for Supercritical Boilers program. The program is a collaborative effort of NETL, EPRI, and Industry Partners (Babcock & Wilcox, Foster Wheeler, Alstom, and Babcock Borsig). The goals of the program dictated the steam conditions selected for the study:

- For supercritical cycle cases – 24.1MPa/599°C/621°C (3,500 psig/1,110°F/1,150°F)
- For ultra-supercritical cases – 27.6 MPa/732°C/760°C (4,000 psig/1,350°F/1,400°F)

2.5 TECHNOLOGY REVIEW AND SIMULATION ASSUMPTIONS

This section will provide a brief overview of the current status of conventional oxycombustion technology. This section will also present the merit behind the innovative technology concepts identified here as advanced oxycombustion systems and how they are implemented in the system studies.

2.5.1 Current Status of Oxycombustion Technology

NETL has conducted several comprehensive studies on oxycombustion technology for state of the art SC PC power plants. Extensive details on the design basis and process configuration of state of the art oxycombustion plants were covered in the earlier report and so will not be reiterated here [10]. Of interest to this study however, is the cost breakdown for a SC PC plant with and without oxycombustion technology listed in Exhibit 2-7. Both the air-based reference plant (without CO_2 capture) and the oxycombustion plant (with CO_2 capture) have a net output of 550 MWe.

Exhibit 2-7 Cost Breakdown of a SC PC Plant with and without Oxycombustion

Study Case		Ref Case, Air-fired SC w/o CO_2 Capture	O_2-fired SC w/ASU & CO_2 Capture	COE Difference
Cost of Electricity ($/MWh)	Capital	31.68	53.72	22.04
	Fixed O&M	7.97	11.81	3.84
	Variable O&M	5.03	6.47	1.44
	Fuel	14.22	19.08	4.86
	CO_2 TS&M	0.00	5.83	5.83
	Total	58.90	91.07[1]	32.17

[1] Excluding TS&M (NETL goals for carbon capture do not include TS&M costs)

While Exhibit 2-7 does not explicitly list energy consumption, the large auxiliary loads associated with the ASU and CO_2 compression indirectly result in increased costs [11]. The additional auxiliary loads that must be overcome to maintain a target net output (in this case 550 MW) require a larger overall plant size, which raises capital costs considerably. This additional capital cost would not be required otherwise and so can be attributed to the need for a larger plant to meet the same electricity demand without carbon capture; the additional capital costs of the larger plant can be assigned to the ASU and compression systems according to their relative contribution to incremental auxiliary loads. A similar redistribution can be done with the fuel cost; the increased fuel consumption results from the energy consumption of the oxycombustion system and CO_2 compression system and so can be reassigned to those systems accordingly.

As mentioned, nearly 100% of the incremental COE required for carbon capture can be attributed to the installation and operation of the carbon capture equipment, namely the ASU and CO_2 compression/purification systems. To capture the effect that the cost and auxiliary loads of these systems have on the incremental COE, the cost items in Exhibit 2-7 are shown redistributed as the five major categories responsible for increasing COE. Based on the results of a previous oxycombustion study, these categories are listed in Exhibit 2-8 [12].

Exhibit 2-8 Cost Breakdown for Oxycombustion Power Plant

Cost Item	Percentage Contribution to COE [%]
ASU capital	29.5
ASU power	35.8
CO_2 Compressor Capital	8.6
CO_2 Compressor Power	19.1
TS&M	7.0
Total COE Increase	**100%**

Exhibit 2-8 clearly shows that the parasitic loads of the ASU and compression required for oxycombustion are the major contributors to the total incremental COE. Reducing ASU capital costs can also provide large economic benefits to the oxycombustion carbon capture pathway. This type of information is useful because it shows the major impacts of oxycombustion technology and where there is a need for future research and development. For example, provided there is room for improvement, Exhibit 2-8 suggests that providing low cost and efficient oxygen production should be major focus areas for oxycombustion research and development. Comparisons such as this were responsible for inspiring the examinations of the advanced oxycombustion technologies that are detailed in the following sub-sections.

2.5.2 Oxygen Separation (Cases 1 and 1A)

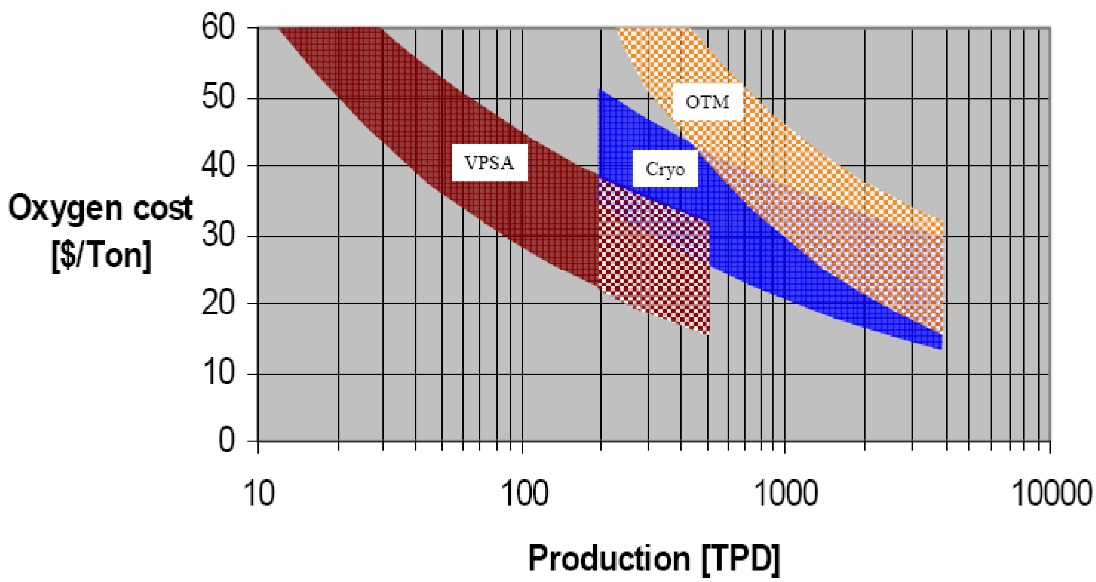
Exhibit 2-9 lists the most common oxygen separation technologies currently available [11]. Adsorption (mostly vacuum pressure swing adsorption, VPSA) and polymeric membrane processes are only suitable for small-scale applications, mainly due to the nature of these two processes. Adsorption processes are more economic when the plant scale is < 200 ton O_2/day. The economic scale for membrane processes is even smaller (< 20 TPD). The cryogenic process is a mature technology and is the only option currently available at production scale that can meet typical power plant demands. Advanced membrane technology, on the other hand, is relatively new. It offers very attractive features, but more research and development is needed before it can be commercialized and before it can perform at the levels required to satisfy DOE carbon capture goals [13].

Exhibit 2-9 Oxygen Separation Technology Comparison Table

Process	Economic Scale (TPD)	Purity Limit (vol%)	Start-up Time
Adsorption	< 200	95	minutes
Cryogenic	> 200	99+	hours
Membrane	< 20	~40	minutes
Advanced Membrane	undetermined	99+	hours

Exhibit 2-10 depicts oxygen production cost for the three selected oxygen separation technologies at different scales [14]. At a larger scale (e.g., over 200 tons/day), the cryogenic process becomes more competitive. For oxycombustion application, oxygen consumption is around 12,000 tons/day for a 500 MWe PC power plant. This scale is actually beyond the largest scale in Exhibit 2-10. At the scale in this study, only cryogenic and advanced oxygen membrane processes are economically feasible technologies. For this reason, adsorption and the polymeric membrane processes were omitted from consideration here.

Exhibit 2-10 Oxygen Production Cost of Three Different Technologies



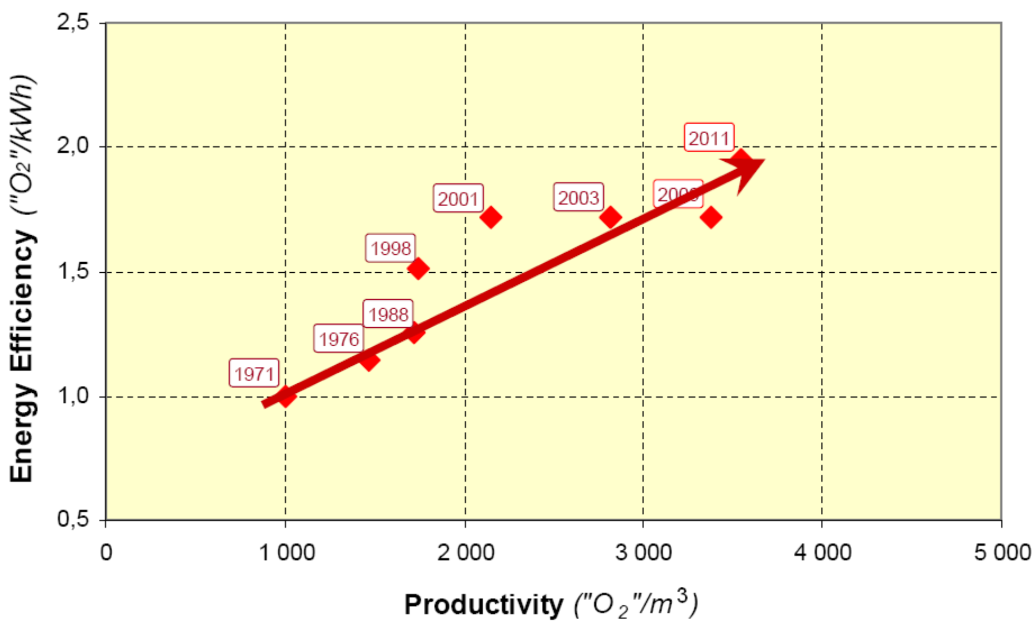
The cryogenic process has been in existence for over a hundred years. It is a mature and well-understood technology. Exhibit 2-11 shows the improvement of its energy efficiency in the past 40 years. The units of the y axis and x axis are normalized energy efficiency and O_2 productivity.

The theoretical minimum work, W_{min}, required to separate 1 mol of air into 0.21 mol O_2 and 0.79 mol of N_2 can be calculated as follows [15]. (In practice, 100 percent O_2 separation with 100 percent purity is never done. However, when the purity is above 95 percent and recovery rate is above 90 percent, the minimum work will be very close to 100 percent purity and 100 percent separation. For simplicity, we assume 100 percent oxygen with 100 percent purity):

$$W_{\min} = -RT[\ln(x_{O2}) + \frac{(1-x_{O2})}{x_{O2}}\ln(1-x_{O2})] = -8.314 \times 298.15 \times 2.447$$
$$= 6.067(kJ/molO_2) = 47.82\ (kWh/tonO_2)$$

The current state-of-the-art cryogenic separation process consumes over 200 kWh/ton O_2 produced, which is almost 4-5 times the theoretical minimum [16], indicating that there is significant room for future improvement. However, due to the nature of the cryogenic distillation process (which involves mostly mechanical processes, such as compression/expansion for refrigeration), the potential efficiency improvement will be relatively limited.

Exhibit 2-11 Cryogenic ASU Developments in the Past 40 Years



2.5.2.1 Advanced Oxygen Membranes

Cases 1 and 1A explore the benefit of using an advanced membrane as the oxygen supply technology. Advanced membranes are relatively new oxygen separation technologies that have only been demonstrated at the pilot scale. The principle of advanced membrane technology is based on the fact that some mixed metal oxides can conduct oxygen ions through their crystal lattice. The ceramic materials used for this application have a high flux and selectivity to oxygen. The selectivity of oxygen diffusing through these dense oxide materials is almost 100 percent. Oxygen molecules are converted to oxygen ions at the surface of the membrane on the oxygen-rich side and transported through the membrane by an applied electric voltage or oxygen partial pressure difference; they then reform oxygen molecules on the oxygen-lean side of the membrane. Impurities, such as nitrogen and argon, are rejected by the membrane at pressure.

Membrane materials can be fabricated into flat sheets or tubes. However, it is necessary to have the operating temperature generally above 600°C in order to activate the ion transport process. In practice, the membrane process is envisioned to be integrated into the power plant design to minimize energy consumption. Multiple options are available for such integrations; however this study examines only two.

High temperature air (~ 1,500°F) is introduced into the membrane module (wafer stack), and the oxygen in the air is ionized on the surface of the ceramic and diffuses through the membrane as oxygen ions, forming oxygen molecules on the other side [17]. Impurities, such as nitrogen and argon, are rejected by the membrane. The hot oxygen product stream is nearly 100 percent pure, and for modeling purposes in this study was assumed to be 100 percent pure. The remaining gas is a pressurized, oxygen-depleted stream from which significant amounts of energy can be recovered.

Integration of the advanced membrane oxygen plant to generate the high temperatures necessary for ionization is critical to an optimized oxycombustion process. ***The membrane operating parameters used in this study are aspirational goals and not necessarily reflective of the current state-of-the-art.*** In the membrane cases modeled for this study (Cases 1, 1a and the cumulative case) ambient air is compressed to 1.5 MPa (215 psia).

For Case 1, the air stream exiting the main air compressor at 391°C (735°F) is further heated to 802°C (1,475°F) by integrating the membrane feed stream with the boiler system. The membrane produces oxygen at ~100 percent purity to be used for coal combustion. The pure oxygen product is recovered at 802°C (1,475°F) and 0.17 MPa (25 psia). Approximately 70 percent of the incoming oxygen can be recovered for the given configuration.

To heat the membrane inlet stream to 802°C (1,475°F), approximately 24 percent of the total heat input to the boiler is required. The oxidant and off-gas stream, composed of vitiated air, are integrated with the boiler feedwater system to recover heat. The vitiated air stream at 1.34 MPa (195 psia) is expanded through a turbine to 0.10 MPa (15 psia) thereby recovering approximately 345 MW of power for Case 1 and 272 MW of power for Case 1A, which uses natural gas to perform the membrane inlet feed air heating. Both the pure oxygen product and vitiated air stream are cooled to 66°C (150°F) in a recuperator that is integrated with the boiler feedwater system. Heat from the oxidant stream supplements the steam superheating system and the high and low pressure feedwater system. The vitiated air stream exits the expansion turbine at 329°C (625°F), and this stream is subsequently cooled in the recuperator that supplements the low and high pressure boiler feedwater systems.

This process configuration differs from the one utilized in the NETL report, *Pulverized Coal Oxycombustion Plants Volume 1: Bituminous Coal to Electricity*. In the previous study, the compressed air from the main air compressor was intercooled, which draws heat out of the gas (and the system) before it can be recovered in the downstream expansion turbine and heat exchangers. This study eliminates intercooling and allows the air feed to the membrane to warm up during compression so that the compression power that went into heating the air can be partially recovered in the expansion turbine. The remainder of the available heat is recovered in the boiler feedwater system. Like in Case 1A of this report, the air stream in the earlier report is further heated to the target temperature of 802°C (1,475°F) using a natural gas-fired direct contact heater. However, instead of recovering the sensible heat of the oxidant prior to combination with fuel and injection into the boiler as is done in this study, the previous process concept uses a direct contact cooler (DCC) to reduce the oxidant temperature which reduces the availability and usefulness of the heat in the oxidant stream.

It is hypothesized that the membrane arrangements proposed here are mor thermodynamically favorable than in prior studies because 1) the vitiated air stream retains energy that is recovered, and 2) the oxidant heat availability is retained and recovered at a higher temperature in the boiler feedwater system.

2.5.3 High Temperature Materials – Ultrasupercritical Steam Conditions (Case 3)

Case 3 adopts a set of USC steam conditions identified as an industry target in a previous NETL/DOE oxycombustion report [7]. Main steam conditions of 27.6 MPa /732°C /760°C (4,000 psig/1,350°F/1,400°F) are used for the cases in this study. These USC steam cycle conditions are considered advanced or next generation, and were chosen to be consistent with the goals of an industry consortium for advanced material development. Depending on actual steam conditions, USC plant efficiencies are generally 3 to 4 percentage points higher than comparable supercritical (SC) plant designs. This results in a direct reduction of CO_2 emissions per net MW of power generated, reducing the penalty of carbon capture. However, advanced steam conditions are limited by the availability and/or cost of materials that can withstand increasingly aggressive conditions. Due to the fact that many of these advanced materials and coatings that support USC conditions are still in the R&D stage of development (and at varying levels of maturity), the future costs are unknown at this time. Therefore, as part of the advanced materials R&D target, a 10 percent incremental cost above current boiler materials is assumed for the high temperature boiler sections—not 10 percent of the entire boiler.

2.5.4 Sulfur-Tolerant Materials – Co-Sequestration (Case 4)

Case 4 does not employ an FGD system. This system is theoretically possible in an oxycombustion configuration if future regulations allow co-sequestering of all flue gas constituents. However, since oxycombustion does not have large amounts of nitrogen diluent in the oxidant, the concentration of constituents in the flue gas stream increases. For once-through air-fired cases that utilize the same design fuel as this study, the boiler SO_2 concentrations are approximately 2,500 ppm. For the cases in this study that employ a FGD system (98% SO_2 removal) within the recycle loop, the sulfur concentration in the boiler is approximately 3,100 ppm. For Case 4, which has no FGD the sulfur concentration in the boiler is approximately 8,400 ppm (a 3.36 fold increase in sulfur concentration from the air-fired case). Since this sulfur concentration exceeds current practical design limits for boiler materials to avoid excess corrosion [17], sulfur-tolerant materials would be required for the boiler system; induced, forced, and primary air fans; the baghouse; and potentially the compression train for Case 4 of this study.

Because there is no FGD in this case, a condensing heat exchanger can cool the flue gas stream entering the CO_2 compression section to 57°C (135°F) using low pressure boiler feedwater. This strategy enables approximately 30 percent of the low pressure boiler feedwater to bypass the feedwater system. By utilizing this configuration, less low pressure steam is extracted from the system, which can increase the power output of the steam cycle and can have a positive effect on overall system efficiency. However, the flue gas condensate will be be quite acidic because of the presence of high SO_2 concentrations and will require additional treatment steps prior to recycle to the cooling tower.

The design of this case is subject to development of advanced materials, specifically sulfur-tolerant materials for most sections of the oxycombustion plant. If these materials are developed, cost premiums have the potential to negatively impact the cost of electricity despite the efficiency improvements shown in this study.

2.5.5 Advanced Recycle (Case 5)

The advanced recycle system as specified here eliminates the FGR superheating system used in the current technology case. The current technology case uses boiler feedwater to superheat the recycle stream by 8°C (15°F). The primary reason the recycle stream is superheated is to ensure that the primary or secondary air streams do not produce condensate in the ducts or enter the air fans at saturated conditions. This case assumes that these problems can be mitigated with new technologies without the need for a superheating system and upgraded fan, and that advanced burner and other necessary equipment designs will not be affected by the saturated conditions of the FGR stream.

2.5.6 Advanced CO_2 Compression (Case 6)

CO_2 compression is one of the two major subsystems of oxycombustion technology. The CO_2 needs to be compressed to supercritical conditions suitable for transport to and injection into an appropriate storage site. Conventional compression technology results in auxiliary loads comprising ~30% of all auxiliary loads in an oxycombustion system.

Supersonic shock wave compression (or shock compression) technology, using the concept of an aircraft's engine, is being developed for CO_2 capture applications with the hopes of decreasing the overall cost and performance impact of CO_2 compression [18]. The shock compressor design features a rotating disk that operates at high peripheral speeds to generate shock waves that compress the CO_2. Compared to conventional compressor technologies, shock compression offers several potential advantages: high compression efficiency; high single-stage compression ratios; opportunity for waste heat recovery; and lower capital cost [19].

For example, shock compression has the potential to develop compression ratios from 8:1 to 15:1 per stage with an adiabatic efficiency of 85 to 90 percent. The assumption used in this study was that the shock compression can achieve 90 percent polytropic efficiency for both the low and high compression stages. For comparison, the conventional compression methodology in the current technology case uses eight stages of compression with compression ratios ranging from 1.5 to 2.4 and operates with a polytropic efficiency of 86 percent. For CO_2 applications, it is anticipated that two stages can meet a ~100:1 compression ratio requirement. As mentioned, a conventional compression configuration typically utilizes 8 to 10 stages of compression with inter-cooling for the same total compression ratio.

A shock compressor uses fewer stages and has a simpler design, and with the same output it will have a smaller size. It is therefore expected that shock compression will be able to reduce the capital cost of compression.

Due to fewer stages, the compressed CO_2 will have a higher interstage temperature (500°F to 620°F, depending on the efficiency), providing an opportunity for heat recovery through integration into either the power plant steam cycle or CO_2 capture process. It is expected that some savings in compression capital cost may be offset by the cost to install additional heat recovery equipment.

Because of the reduced stages required by shock wave technology, the size of a CO_2 compressor can be reduced to ~1/5 of that of a conventional compressor, and the cost per compression ratio is about 1/2 to 1/3 of that of a similar conventional compression system [20]. However, the two-stage configuration of shock compression may not allow the use of multiple interstage cooling points and therefore may have the disadvantage of higher normalized compression loads. The shock compression technology has a normalized compression load of 135 kWh/ton CO_2, while conventional compression has a compression load of 108 kWh/ton CO_2. These figures do not incorporate the auxiliary load associated with cooling water demand and the benefits of integration with the boiler feedwater system.

In Case 6, because of the high compression ratios for shock compression, the CO_2 stream is discharged at a temperature of 321°C (609°F) in the low pressure stage and 274°C (525°F) at the high pressure stage. This provides an opportunity to integrate interstage compression heat with the boiler feedwater system. This increases power output of the steam cycle because of the reduction in steam extraction and helps to compensate for the increased compression power requirements.

Developers of shock compression technology indicate that, because of the simple nature of the design and smaller equipment sizing, the shock compression technology can offer a significant reduction in the capital cost of compression, compared to conventional compression, to compensate for the increased operating cost. Although it is feasible that shock wave compression has the potential to reduce capital costs for CO_2 compression, like other technologies in this report, the shock compression technology is still at an early development stage and there is a lack of reliable information on its cost and performance at commercial scale.

2.5.7 Oxycombustion Boiler Design (Case 7)

Conceptually, an oxycombustion-specific boiler is designed to accommodate a smaller flue gas flow, which results in reduced equipment size. It is also designed to accommodate increased temperatures by increasing heat transfer rates above those of conventional boilers. The current technology case oxycombustion boiler operates with a theoretical adiabatic flame temperature of 2,031°C (3,687°F), while the advanced oxycombustion boiler accommodates a theoretical adiabatic flame temperature of 2,308°C (4,187°F). The increase in boiler adiabatic flame temperature is a result of reducing the flue gas recycle from approximately 69 percent to 63 percent of the flue gas exiting the FGD system. This reduction in recycle gas increases the oxygen concentration in the boiler, which enables the adiabatic flame temperature to rise [21]. The reduced volumetric flow through the boiler system also allows for a decrease in the size of the associated equipment. Furthermore, fan loads required for flue gas recycle are reduced, increasing system efficiency.

The benefit of smaller oxycombustion boilers may be limited due to the need for advanced materials that can handle the high temperatures that result with decreasing levels of flue gas recycle. Furthermore, as FGR is reduced, dilution of sulfur constituents by de-sulfurized flue gas will be reduced. This will create an additional demand for high sulfur materials independent of the desire for co-sequestration.

2.5.8 Cumulative Case

The Cumulative Case combines all of the above-mentioned technological advancements including, advanced membrane ASU, USC steam cycle, co-sequestration, advanced recycle concept, advanced materials, oxycombustion boiler, and advanced compression to quantify the cumulative effect these advances have on the performance and cost of the oxycombustion system.

2.6 COST ESTIMATING METHODOLOGY

The estimates in this study carry an accuracy of ±30 percent, consistent with the screening study level of information available for the various power technologies.

The cost estimating methodology is explained in more detail in "Cost and Performance Baseline for Fossil Energy Power Plants" (Baseline Study) [22]. This reference is the basis for the costs for the air-fired cases and the balance of plant costs for the oxycombustion cases in this study. Some particulars from the study are described below.

2.6.1 Capital, Operation, and Maintenance Costs

This study reports capital cost at four levels: Bare Erected Cost (BEC), Total Plant Cost (TPC), Total Overnight Cost (TOC) and Total As-spent Capital (TASC). BEC, TPC and TOC are "overnight" costs and are expressed in "base-year" dollars. The base year is the first year of capital expenditure, which for this study is assumed to be 2007. TASC is expressed in mixed-year, current-year dollars over the entire capital expenditure period, which is assumed to last five years (2007 to 2012).

The BEC comprises the cost of process equipment, on-site facilities and infrastructure that support the plant (e.g., shops, offices, labs, road), and the direct and indirect labor required for its construction and/or installation. The cost of EPC services and contingencies is not included in BEC. BEC is an overnight cost expressed in base-year (2007) dollars.

The TPC comprises the BEC plus the cost of services provided by the engineering, procurement and construction (EPC) contractor and project and process contingencies. EPC services include: detailed design, contractor permitting (i.e., those permits that individual contractors must obtain to perform their scopes of work, as opposed to project permitting, which is not included here), and project/construction management costs. TPC is an overnight cost expressed in base-year (2007) dollars.

The TOC comprises the TPC plus owner's costs. TOC is an "overnight" cost, expressed in base-year (2007) dollars and as such does not include escalation during construction or interest during construction. TOC is an overnight cost expressed in base-year (2007) dollars.

The TASC is the sum of all capital expenditures as they are incurred during the capital expenditure period including their escalation. TASC also includes interest during construction. Accordingly, TASC is expressed in mixed, current-year dollars over the capital expenditure period.

For the cases in the Baseline Study, capital cost and operating and maintenance cost estimates were developed for each plant based on adjusted vendor-furnished and actual cost data from recent design/build projects, and resulted in determination of a revenue requirement COE based on the power plant costs and assumed financing structure. The boiler and ancillary equipment (baghouse, FGD unit, and condensing heat exchanger) cost estimates were scaled from previous, related studies. The original cost estimates were provided by B&W. The cryogenic air separation unit and CO_2 purification unit cost estimates were also scaled and originally provided by Air Liquide. The balance of plant capital cost estimates were calculated using a factored estimate approach. Each cost account was adjusted using the appropriate process parameter and a scaling exponent derived from the baseline study. The SC PC cases from the Baseline study were used as the reference costs.

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. Operation costs were determined on the basis of the number of operators. Maintenance costs were evaluated on the basis of requirements for each major plant section. The cost results are presented for each case.

System Code of Accounts

The costs are grouped according to a process/system oriented code of accounts. This type of code-of-account structure has the advantage of grouping all reasonably allocable components of a system or process so they are included in the specific system account. (This would not be the case had a facility, area, or commodity account structure been chosen instead).

CO_2 Technology Maturity

The cost estimates provided include technologies at different commercial maturity levels. The estimates for the non-CO_2-capture PC cases represent well-developed, commercial technology or "n^{th} plants." The estimates for the CO_2-capture cases represent developing technology, since the post-combustion CO_2 removal technology remains unproven at commercial scale power generation applications where more than 12,000 tons/day of CO_2 would need to be captured.

Contingency

Process and project contingencies are included in estimates to account for unknown costs that are omitted or unforeseen due to a lack of complete project definition and engineering. Contingencies are added because experience has shown that such costs are likely, and expected, to be incurred even though they cannot be explicitly determined at the time the estimate is prepared.

Capital cost contingencies do not cover uncertainties or risks associated with

- scope changes
- changes in labor availability or productivity
- delays in equipment deliveries
- changes in regulatory requirements
- unexpected cost escalation
- performance of the plant after startup (e.g., availability, efficiency)

Project Contingency

AACE 16R-90 states that project contingency for a "budget-type" estimate (AACE Class 4 or 5) should be 15 to 30 percent of the sum of BEC, EPC fees and process contingency. This was used as a general guideline, but some project contingency values outside of this range occur based on WorleyParsons' in-house experience.

Process Contingency

Process contingency is intended to compensate for uncertainties arising as a result of the state of technology development. Process contingencies have been applied to the estimates as follows:

- Standard SC PC Boiler in Oxycombustion mode with FGD – 0 percent of the total boiler; this is a standard boiler design with possible minimal changes required to burners and heat transfer surface areas.
- SC Oxycombustion-Specific Boiler with FGD – 10 percent of the total boiler account, of which heat transfer areas and advanced materials are a fraction; majority of the boiler is conceptually the same as an air-fired design but contingencies allow for possible risk in advances required for increased heat transfer (advanced materials, increased heat transfer surface areas, etc.) to fully support a smaller boiler design.
- Standard SC PC Boiler in Oxycombustion mode w/o FGD – 15 percent of the total boiler account, of which the advanced materials are a fraction; this is a standard boiler design requiring major advancements in materials for the increased sulfur concentrations produced in a high temperature atmosphere with the high sulfur bituminous coal assumed in this oxycombustion configuration.
- SC Oxycombustion-Specific Boiler w/o FGD – 25 percent of the total boiler account, of which the advanced materials are a fraction; majority of the boiler is conceptually the same as an air-fired design but contingencies allow for possible risk in advances required for increased heat transfer (advanced materials, increased heat transfer surface areas, etc.) in all sections of the boiler (hence the higher contingency than for the standard boiler design w/o FGD) to fully support a smaller boiler design in addition to high temperature, sulfur-tolerant material requirements due to lack of FGD.
- USC PC Boiler – 10 percent of the total boiler; only the superheater and reheater components of the boiler have not been proven commercially at the elevated temperatures. This 10 percent contingency is added to the base contingency of a boiler upgraded from SC to USC conditions. In cases where contingencies have already been applied to the boiler for cost uncertainties with high temperature materials, such as in the Cumulative Case, the contingency here will not be re-applied.
- USC Steam Turbine – 15 percent of the steam turbine; elevated temperature and pressure in HP section of the turbine.
- Advanced Membrane ASU – no explicit process contingency is applied to the advanced membrane process. The capital cost of the membrane-based ASU is based on an nth-plant R&D target of 30 percent less capital cost than a current state-of-the-

art cryogenic ASU [23]. This target includes all process contingencies associated with the advanced membrane technology.

- Boiler with Advanced Membrane Integration – in boilers without contingency already applied for heat transfer surface modification, 10 percent. Case 1 requires modifications to boiler heat transfer surface areas so that membrane feed gas may be preheated. In cases where contingencies have already been applied due to uncertainties in heat transfer configurations, such as in the Cumulative Case, the contingency here will not be re-applied.

AACE International provides standards for process contingency relative to technology status; from commercial technology at 0 to 5 percent to new technology with little or no test data at 40 percent. The process contingencies as applied in this study are consistent with the AACE International standards [24].

Price Fluctuations

During the course of this study and through the recent updates, the prices of equipment and bulk materials fluctuated quite substantially. Some reference quotes pre-dated the 2007 year cost basis while others were received post-2007. All vendor quotes used to develop these estimates were adjusted to June 2007 dollars accounting for the price fluctuations. Adjustments of costs pre-dating 2007 benefitted from a vendor survey of actual and projected pricing increases from 2004 through mid-2007. The results of that survey were used to validate/recalibrate the corresponding escalation factors used in the conceptual estimating models. The more recent economic down turn has resulted in a reduction of commodity prices such that many price indices have similar values in January 2010 compared to June 2007. For example, the Chemical Engineering Plant Cost Index was 532.7 in June 2007 and 532.9 in January 2010, and the Gross Domestic Product Chain-type Price Index was 106.7 on July 1, 2007 and 110.0 on January 1, 2010. While these overall indices are nearly constant, it should be noted that the cost of individual equipment types may still deviate from the June 2007 reference point.

2.6.2 Cost of Electricity

For scenarios that adhere to the global economic assumptions listed in Exhibit 2-12 and utilize one of the finance structures listed in Exhibit 2-13, the following simplified equation can be used to estimate COE as a function of TOC[1], fixed O&M, variable O&M (including fuel), capacity factor and net output. The equation requires the application of one of the capital charge factors (CCF) listed in Exhibit 2-14. These CCFs are valid only for the global economic assumptions listed in Exhibit 2-12, the stated finance structure, and the stated capital expenditure period.

All factors in the COE equation are expressed in base-year dollars. The base year is the first year of capital expenditure, which for this study is assumed to be 2007. All factors (COE, O&M and fuel) are assumed to escalate at a nominal annual general inflation rate of 3.0 percent.

[1] Although TOC is used in the simplified COE equation, the CCF that multiplies it accounts for escalation during construction and interest during construction (along with other factors related to the recovery of capital costs).

Accordingly, all first-year costs (COE and O&M) are equivalent to base-year costs when expressed in base-year (2007) dollars.

$$COE = \frac{\begin{matrix} first\ year \\ capital\ charge \end{matrix} + \begin{matrix} first\ year \\ fixed\ operating \\ costs \end{matrix} + \begin{matrix} first\ year \\ variable\ operating \\ costs \end{matrix}}{\begin{matrix} annual\ net\ megawatt\ hours \\ of\ power\ generated \end{matrix}}$$

$$COE = \frac{(CCF)(TOC) + OC_{FIX} + (CF)(OC_{VAR})}{(CF)(MWH)}$$

where:

COE =	revenue received by the generator ($/MWh, equivalent to mills/kWh) during the power plant's first year of operation (*but expressed in base-year dollars*), assuming that the COE escalates thereafter at a nominal annual rate equal to the general inflation rate, i.e., that it remains constant in real terms over the operational period of the power plant.
CCF =	capital charge factor taken from Exhibit 2-14 that matches the applicable finance structure and capital expenditure period
TOC =	total overnight capital, expressed in *base-year dollars*
OC_{FIX} =	the sum of all fixed annual operating costs, *expressed in base-year dollars*
OC_{VAR} =	the sum of all variable annual operating costs, including fuel at 100 percent capacity factor, *expressed in base-year dollars*
CF =	plant capacity factor, assumed to be constant over the operational period
MWH =	annual net megawatt-hours of power generated at 100 percent capacity factor

The technologies modeled in this study were divided into one of two categories for calculating COE: investor-owned utility (IOU) high risk and IOU low risk. All oxycombustion cases with CO_2 capture are considered high risk. The non-capture SC PC case is considered low risk. The parameters used are shown in exhibits following the cost exhibits for each case. The difference between the high-risk and low-risk categories is manifested in the debt-to-equity ratio and the weighted cost of capital. The values used to generate the capital charge factors in this study are shown in Exhibit 2-12 and Exhibit 2-13.

Exhibit 2-12 Parameter Assumptions for Capital Charge Factors

Parameter	Value
TAXES	
Income Tax Rate	38% (Effective 34% Federal, 6% State)

Parameter	Value
Capital Depreciation	20 years, 150% declining balance
Investment Tax Credit	0%
Tax Holiday	0 years
CONTRACTING AND FINANCING TERMS	
Contracting Strategy	Engineering Procurement Construction Management (owner assumes project risks for performance, schedule and cost)
Type of Debt Financing	Non-Recourse (collateral that secures debt is limited to the real assets of the project)
Repayment Term of Debt	15 years
Grace Period on Debt Repayment	0 years
Debt Reserve Fund	None
ANALYSIS TIME PERIODS	
Capital Expenditure Period	5 Years
Operational Period	30 years
Economic Analysis Period (used for IRROE)	35 Years (capital expenditure period plus operational period)
TREATMENT OF CAPITAL COSTS	
Capital Cost Escalation During Capital Expenditure Period (nominal annual rate)	3.6%[2]
Distribution of Total Overnight Capital over the Capital Expenditure Period (before escalation)	10%, 30%, 25%, 20%, 15%
Working Capital	zero for all parameters
% of Total Overnight Capital that is Depreciated	100% *(this assumption introduces a very small error even if a substantial amount of TOC is actually non-depreciable)*
ESCALATION OF OPERATING REVENUES AND COSTS	
Escalation of COE (revenue), O&M Costs, and Fuel Costs (nominal annual rate)	3.0%[3]

[2] A nominal average annual rate of 3.6 percent is assumed for escalation of capital costs during construction. This rate is equivalent to the nominal average annual escalation rate for process plant construction costs between 1947 and 2008 according to the *Chemical Engineering* Plant Cost Index.

[3] An average annual inflation rate of 3.0 percent is assumed. This rate is equivalent to the average annual escalation rate between 1947 and 2008 for the U.S. Department of Labor's Producer Price Index for Finished Goods, the so-called "headline" index of the various Producer Price Indices. (The Producer Price Index for the Electric Power Generation Industry may be more applicable, but that data does not provide a long-term historical perspective since it only dates back to December 2003.)

Exhibit 2-13 Financial Structure for Investor Owned Utility High- and Low-Risk Projects

Type of Security	% of Total	Current (Nominal) Dollar Cost	Weighted Current (Nominal) Cost	After Tax Weighted Cost of Capital
Low Risk				
Debt	50	4.5%	2.25%	-
Equity	50	12%	6%	-
			8.25%	7.39%
High Risk				
Debt	45	5.5%	2.475%	-
Equity	55	12%	6.6%	-
			9.075%	8.13%

Exhibit 2-14 Economic Parameters for COE Calculation

	High Risk	Low Risk
Capital Charge Factor	0.158	0.148

2.6.3 Costs of CO_2 Avoided

CO_2 is not currently regulated. However, the possibility exists that carbon limits will be imposed in the future, and this study examines cases that include a reduction in CO_2 emissions.

The equation used to calculate the Cost of CO_2 Avoided in $/ton is as follows:

Where,

COE = cost of electricity ($\$/MWh_{net}$)

Emissions = CO_2 emissions for case ($tons/MWh_{net}$)

2.6.4 Costs of CO_2 Transport, Storage, and Monitoring

Transport, storage and monitoring costs were calculated for each case, but were not included in the assessment of whether a technology can help meet the DOE carbon capture goal. TS&M cost reduction targets are governed under DOE programs separate from the program governing capture goals. For those cases that ultimately require carbon sequestration in this report, the capital and operating costs for CO_2 TS&M were independently estimated by NETL for purposes of providing perspective. Those costs were converted to a TS&M COE increment that was added to the plant COE.

CO_2 TS&M costs were estimated based on the following assumptions:

- CO_2 is supplied to the pipeline at the plant fence line at a pressure of 15.3 MPa (2,215 psia). The CO_2 product gas composition varies in each case depending on the level of oxygen purity used (95 versus 99 percent oxygen) and the level of CO_2 purification required. However, in all cases the CO_2 product stream was dried to <0.015 vol% water.
- Excess oxygen: The oxygen flow was regulated in all oxycombustion cases to achieve 2.7 percent oxygen flue gas concentration (on a dry basis) at the boiler exit. This study assumes that extensive dehydration of the CO_2 product stream would minimize pipeline corrosion and allow up to 3 percent excess oxygen in the CO_2 product stream transported—this is considered a "best-case" or "low-cost" CO_2 purification/compression option. In addition, it was assumed that up to 3 percent oxygen would not prohibit storage in a saline formation. This assumption is supported by two recently completed IEA Reports titled "Impact of Impurities on CO_2 Capture, Transport and Storage" [25] and "Oxy Combustion Processes for CO_2 Capture from Power Plant" [26]. Additional engineering designs which focus on extensive flue gas purification from oxycombustion processes (such as the multi-pollutant control processes proposed by Air Products) where deep oxygen removal (< 100 ppm) is required for enhanced oil recovery applications is beyond the scope of this study.
- The CO_2 is transported 80 kilometers (50 miles) via pipeline to a geologic sequestration field for injection into a saline formation.
- The CO_2 is transported and injected as a supercritical fluid in order to avoid two-phase flow and achieve maximum efficiency [27]. The pipeline is assumed to have an outlet pressure (above the supercritical pressure) of 8.3 MPa (1,200 psia) with no recompression along the way. Accordingly, CO_2 flow in the pipeline was modeled to determine the pipe diameter that results in a pressure drop of 6.9 MPa (1,000 psi) over an 80 kilometer (50 mile) pipeline length [28]. (Although not explored in this study, the use of boost compressors and a smaller pipeline diameter could possibly reduce capital costs for sufficiently long pipelines.) The diameter of the injection pipe will be of sufficient size that frictional losses during injection are minimal and no booster compression is required at the well-head in order to achieve an appropriate down-hole pressure, with hydrostatic head making up the difference between the injection and reservoir pressure.
- The saline formation is at a depth of 1,236 meters (4,055 ft) and has a permeability of 22 millidarcy (a measure of permeability defined as roughly 10^{-3} Darcy) and formation pressure of 8.4 MPa (1,220 psig) [29]. This is considered an average storage site and requires roughly one injection well for each 9,360 tonnes (10,320 short tons) of CO_2 injected per day [29]. The assumed aquifer characteristics are tabulated in Exhibit 2-15.

Exhibit 2-15 Deep Saline Formation Specification

Parameter	Units	Current Technology Case
Pressure	MPa (psi)	8.4 (1,220)
Thickness	m (ft)	161 (530)
Depth	m (ft)	1,236 (4,055)
Permeability	md	22
Pipeline Distance	km (miles)	80 (50)
Injection Rate per Well	tonne (ton) CO_2/day	9,360 (10,320)

The cost metrics utilized in this study provide a best estimate of TS&M costs for a "favorable" sequestration project, and may vary significantly based on variables such as terrain to be crossed by the pipeline, reservoir characteristics, and number of land owners from which sub-surface rights must be acquired. Raw capital and operating costs are derived from detailed cost metrics found in the literature, escalated to June 2007-year dollars using appropriate price indices. These costs were then verified against values quoted by industrial sources where possible. Where regulatory uncertainty exists or costs are undefined, such as liability costs and the acquisition of underground pore volume, analogous existing policies were used for representative cost scenarios.

The following sections describe the sources and methodology used for each metric.

TS&M Capital Costs

TS&M capital costs include both a 20 percent process contingency and 30 percent project contingency.

In several areas, such as Pore Volume Acquisition, Monitoring, and Liability, cost outlays occur over a longer time period, up to 100 years. In these cases a capital fund is established based on the net present value of the cost outlay, and this fund is then levelized similar to the other costs.

Transport Costs

CO_2 transport costs are broken down into three categories: pipeline costs, related capital expenditures, and O&M costs.

Pipeline costs are derived from data published in the Oil and Gas Journal's (O&GJ) annual Pipeline Economics Report for existing natural gas, oil, and petroleum pipeline project costs from 1991 to 2003. These costs are expected to be analogous to the cost of building a CO_2 pipeline, as noted in various studies [27, 29, 30]. The University of California performed a regression analysis to generate the following cost curves from the O&GJ data: (1) Pipeline Materials, (2) Direct Labor, (3) Indirect Costs, and (4) Right-of-way acquisition, with each represented as a function of pipeline length and diameter [30]. These cost curves were escalated to the June 2007 year dollars used in this study.

Related capital expenditures were based on the findings of a previous study funded by DOE/NETL, Carbon Dioxide Sequestration in Saline Formations – Engineering and Economic Assessment [29]. This study utilized a similar basis for pipeline costs (O&GJ Pipeline cost data up to the year 2000) but added a CO_2 surge tank and pipeline control system to the project.

Transport O&M costs were assessed using metrics published in a second DOE/NETL sponsored report entitled Economic Evaluation of CO_2 Storage and Sink Enhancement Options [27]. This study was chosen due to the reporting of O&M costs in terms of pipeline length, whereas the other studies mentioned above either (a) do not report operating costs, or (b) report them in absolute terms for one pipeline, as opposed to as a length- or diameter-based metric.

Storage Costs

Storage costs were broken down into five categories: (1) Site Screening and Evaluation, (2) Injection Wells, (3) Injection Equipment, (4) O&M Costs, and (5) Pore Volume Acquisition. With the exception of Pore Volume Acquisition, all of the costs were obtained from Economic Evaluation of CO_2 Storage and Sink Enhancement Options [27]. These costs include all of the costs associated with determining, developing, and maintaining a CO_2 storage location, including site evaluation, well drilling, and the capital equipment required for distributing and injecting CO_2.

Pore Volume Acquisition costs are the costs associated with acquiring rights to use the sub-surface volume where the CO_2 will be stored, i.e., the pore space in the geologic formation. These costs were based on recent research by Carnegie Mellon University, (CMU) which examined existing sub-surface rights acquisition as it pertains to natural gas storage [31]. The regulatory uncertainty in this area combined with unknowns regarding the number and type (private or government) of property owners, require a number of "best engineering judgment" decisions to be made. In this study it was assumed that long-term lease rights were acquired from the property owners in the projected CO_2 plume growth region for a nominal fee, and that an annual "rent" was paid when the plume reached each individual acre of their property for a period of up to 100 years from the injection start date. The present value of the life cycle pore volume costs are assessed at a 10% discount rate and a capital fund is set up to pay for these costs over the 100 year rent scenario.

Liability Protection

Liability Protection addresses the fact that if damages are caused by injection and long-term storage of CO_2, the injecting party may bear financial liability. Several types of liability protection schemes have been suggested for CO_2 storage, including Bonding, Insurance, and Federal Compensation Systems combined with either tort law (as with the Trans-Alaska Pipeline Fund), or with damage caps and preemption, as is used for nuclear energy under the Price Anderson Act [32]. However, at present, a specific liability regime has yet to be dictated either at a Federal or (to our knowledge) State level. However, certain state governments have enacted legislation, which assigns liability to the injecting party, either in perpetuity (Wyoming) or until ten years after the cessation of injection operations, pending reservoir integrity certification, at which time liability is turned over to the state (North Dakota and Louisiana) [33,34,35]. In the case of Louisiana, a trust fund totaling five million dollars is established over the first ten years

(120 months) of injection operations for each injector. This fund is then used by the state for CO_2 monitoring and, in the event of an at-fault incident, damage payments.

Liability costs assume that a bond must be purchased before injection operations are permitted in order to establish the ability and good will of an injector to address damages where they are deemed liable. A figure of five million dollars was used for the bond based on the Louisiana fund level. This bond level may be conservatively high, in that the Louisiana fund covers both liability and monitoring, but that fund also pertains to a certified reservoir where injection operations have ceased, having a reduced risk compared to active operations. The bond cost was not escalated.

Monitoring Costs

Monitoring costs were evaluated based on the methodology set forth in the International Energy Agency (IEA) Greenhouse Gas (GHG) R&D Programme's Overview of Monitoring Projects for Geologic Storage Projects report [36]. In this scenario, operational monitoring of the CO_2 plume occurs over 30 years (during plant operation) and closure monitoring occurs for the following fifty years (for a total of eighty years). Monitoring is via electromagnetic (EM) survey, gravity survey, and periodic seismic survey; EM and gravity surveys are ongoing while seismic survey occurs in years 1, 2, 5, 10, 15, 20, 25, and 30 during the operational period, then in years 40, 50, 60, 70, and 80 after injection ceases.

3. COST AND PERFORMANCE EVALUATION

All eight advanced oxycombustion plants with various technological improvements are described in this section and are compared to the current technology case. The technological improvements can be categorized in four major areas: advanced steam cycle, alternative oxygen production, advanced flue gas treatment, and innovative CO_2 compression. All nine cases, including the current technology case, are described in the following sections:

- Current Technology Case and Advanced Steam Cycle - USC Technology (Current Technology Case and Case 3)
- Advanced Oxygen Separation Technology (Case 1 and 1a)
- Advanced Flue Gas Treatment Technologies (Case 4, 5, and 7)
- Advanced CO_2 Compression (Case 6)
- Cumulative Case

3.1 CURRENT TECHNOLOGY USING SC STEAM CYCLE

The current oxycombustion plant is equipped with a cryogenic distillation ASU, a wet FGD sulfur removal unit, and a conventional CO_2 purification/compression system. The plant employs supercritical single-reheat 24.13MPa/599°C/621°C (3,500 psig/1,110°F/1,150°F) Rankine cycle with a state-of-the art PC steam generator firing bituminous Illinois No. 6 coal and a steam turbine. The CO_2 is captured and compressed to 2,215 psia and sent to a remote geologic location for storage. This case is identical in configuration to the oxycombustion case, Case 5, described in an earlier NETL/DOE report "Pulverized Coal Oxycombustion Power Plants" [37].

Process highlights:

- The amount of flue gas recycled to the boiler is controlled by targeting a theoretical adiabatic flame temperature of 2,031°C (3,678°F), which is equivalent to the adiabatic flame temperature produced in conventional boiler operation [11].
- The oxidant is supplied by conventional ASU technology that produces 95 percent O_2.
- The recycled flue gas stream is superheated 9°C (15°F).
- The CO_2 compression is accomplished by eight stages of centrifugal compression (86 percent polytropic efficiency) with intercooling.

This base plant represents the current oxycombustion technology. Illinois No. 6 coal is the fuel and the plant is located at a generic non-minemouth site in the Midwestern United States.

Major components for a current oxycombustion power plant include the following:

1. Conventional cryogenic ASU
2. Regular PC boiler operating at supercritical steam conditions
3. Baghouse to remove particulates
4. Wet FGD to reduce sulfur emission

5. CPU with compression to 15.3 MPa (2,215 psia)
6. Flue gas recycle superheater
7. Steam turbine/generator

Block Flow Diagram and Stream Table

A process block flow diagram (BFD) for a current oxycombustion power plant is shown in Exhibit 3-1, and the corresponding stream tables are shown in Exhibit 3-2.

Heat and Mass Balance Diagram

Heat and mass balance diagrams are shown for the following subsystems in Exhibit 3-3 and Exhibit 3-4:

- Boiler and flue gas cleanup
- Steam cycle and feed water (power block)

Energy, Carbon, Sulfur, and Water Balances

An overall plant energy balance is provided in tabular form in Exhibit 3-5. The power out is the steam turbine power after generator losses.

Carbon, sulfur, and water balances are shown in Exhibit 3-6 through Exhibit 3-8.

Performance Summary

A performance summary is provided in Exhibit 3-9.

Cost Tables

Capital costs, owner's costs, and O&M costs are provided in Exhibit 3-10 through Exhibit 3-12, respectively.

Equipment List

The combined equipment list for the current oxycombustion technology and Case 3 is shown in Exhibit 3-25.

Exhibit 3-1 Process Block Flow Diagram for Current Technology Case

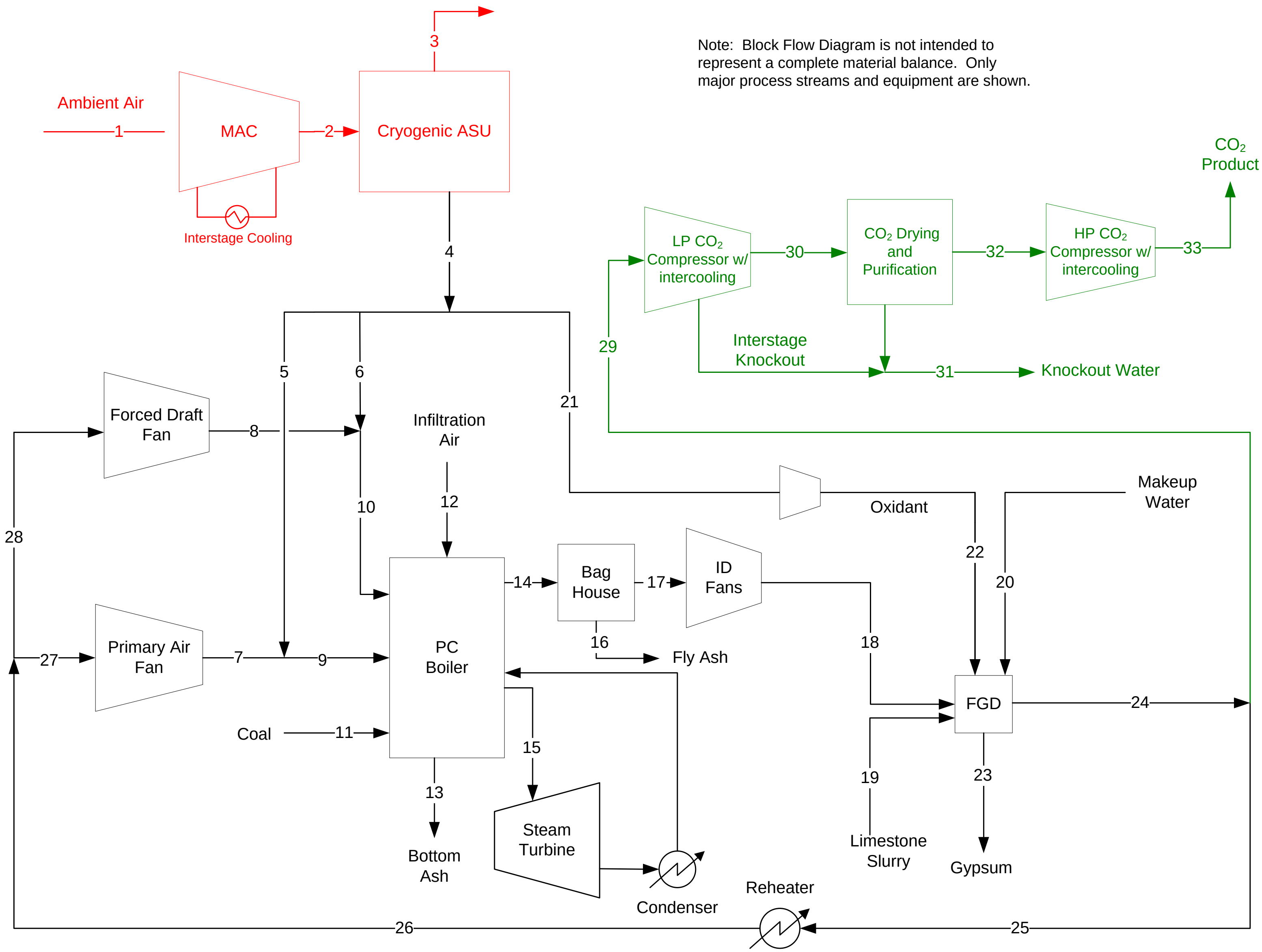


Exhibit 3-2 Stream Table for Current Technology Case

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
V-L Mole Fraction																	
Ar	0.0092	0.0092	0.0024	0.0340	0.0340	0.0340	0.0308	0.0308	0.0317	0.0317	0.0000	0.0092	0.0000	0.0287	0.0000	0.0000	0.0287
CO_2	0.0005	0.0005	0.0006	0.0000	0.0000	0.0000	0.7090	0.7090	0.5076	0.5076	0.0000	0.0005	0.0000	0.6612	0.0000	0.0000	0.6612
H_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	0.0000	0.0000	0.0000
H_2O	0.0101	0.0101	0.0128	0.0000	0.0000	0.0000	0.1514	0.1514	0.1084	0.1084	0.0000	0.0101	0.0000	0.2072	1.0000	0.0000	0.2072
N_2	0.7729	0.7729	0.9778	0.0162	0.0162	0.0162	0.0856	0.0856	0.0659	0.0659	0.0000	0.7729	0.0000	0.0801	0.0000	0.0000	0.0801
O_2	0.2074	0.2074	0.0063	0.9498	0.9498	0.9498	0.0231	0.0231	0.2863	0.2863	0.0000	0.2074	0.0000	0.0197	0.0000	0.0000	0.0197
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0031	0.0000	0.0000	0.0031
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	78,641	78,641	61,879	16,761	3,884	12,643	9,788	31,863	13,672	44,506	0	1,573	0	64,723	123,078	0	64,723
V-L Flowrate (kg/hr)	2,269,256	2,269,256	1,729,457	539,798	125,079	407,171	374,900	1,220,420	499,979	1,627,592	0	45,385	0	2,398,035	2,217,286	0	2,398,035
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	249,312	0	4,846	19,386	0	19,386	0
Temperature (°C)	15	24	17	13	13	13	75	69	60	56	15	15	15	177	599	15	177
Pressure (MPa, abs)	0.10	0.59	0.10	0.16	0.16	0.16	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	24.23	0.10	0.10
Enthalpy (kJ/kg)[A]	30.57	32.03	38.64	11.49	11.49	11.49	247.49	241.88	188.45	184.24	---	30.57	---	495.60	3,493.92	---	428.51
Density (kg/m^3)	1.2	7.0	1.2	2.2	2.2	2.2	1.5	1.4	1.5	1.4	---	1.2	---	1.0	68.5	---	1.0
V-L Molecular Weight	28.856	28.856	27.949	32.205	32.205	32.205	38.303	38.303	36.570	36.570	---	28.856	---	37.051	18.015	---	37.051
V-L Flowrate (lb_{mol}/hr)	173,373	173,373	136,420	36,953	8,562	27,873	21,579	70,245	30,141	98,119	0	3,467	0	142,690	271,341	0	142,690
V-L Flowrate (lb/hr)	5,002,853	5,002,853	3,812,801	1,190,052	275,752	897,659	826,514	2,690,566	1,102,265	3,588,226	0	100,057	0	5,286,763	4,888,279	0	5,286,763
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	549,638	0	10,685	42,739	0	42,739	0
Temperature (°F)	59	75	63	55	56	56	167	157	141	133	59	59	59	350	1,110	59	350
Pressure (psia)	14.7	86.1	14.7	23.2	23.2	23.2	16.2	15.3	16.2	15.3	14.7	14.7	14.7	14.4	3,514.7	14.7	14.2
Enthalpy (Btu/lb)[A]	13.1	13.8	16.6	4.9	4.9	4.9	106.4	104.0	81.0	79.2	---	13.1	---	213.1	1,502.1	---	184.2
Density (lb/ft^3)	0.076	0.435	0.073	0.135	0.135	0.135	0.092	0.089	0.092	0.088	---	0.076	---	0.061	4.274	---	0.061

A - Reference conditions are 32.02 F & 0.089 PSIA

Exhibit 3-2 Stream Table for Current Technology Case (continued)

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
V-L Mole Fraction																
Ar	0.0287	0.0000	0.0000	0.0340	0.0340	0.0099	0.0308	0.0308	0.0308	0.0308	0.0308	0.0308	0.0362	0.0000	0.0363	0.0363
CO_2	0.6612	0.0000	0.0000	0.0000	0.0000	0.9704	0.7090	0.7090	0.7090	0.7090	0.7090	0.7090	0.8338	0.0000	0.8354	0.8354
H_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	0.0000	0.0000
H_2O	0.2072	1.0000	1.0000	0.0000	0.0000	0.0028	0.1514	0.1514	0.1514	0.1514	0.1514	0.1514	0.0021	1.0000	0.0001	0.0001
N_2	0.0801	0.0000	0.0000	0.0162	0.0162	0.0019	0.0856	0.0856	0.0856	0.0856	0.0856	0.0856	0.1007	0.0000	0.1009	0.1009
O_2	0.0197	0.0000	0.0000	0.9498	0.9498	0.0086	0.0231	0.0231	0.0231	0.0231	0.0231	0.0231	0.0272	0.0000	0.0272	0.0272
SO_2	0.0031	0.0000	0.0000	0.0000	0.0000	0.0063	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
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	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	64,723	3,245	1,618	234	234	0	60,634	41,651	41,651	9,788	31,863	18,984	16,143	2,875	16,111	16,111
V-L Flowrate (kg/hr)	2,398,035	58,468	29,148	7,548	7,548	11	2,322,445	1,595,325	1,595,321	374,900	1,220,420	727,145	675,961	51,799	675,389	675,389
Solids Flowrate (kg/hr)	0	25,197	0	0	0	39,188	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	186	15	15	13	95	57	57	57	66	66	66	58	104	22	104	21
Pressure (MPa, abs)	0.11	0.11	0.10	0.16	0.31	0.10	0.10	0.10	0.10	0.10	0.10	0.10	3.35	0.24	3.35	15.27
Enthalpy (kJ/kg)[A]	438.76	---	62.80	11.49	85.68	---	230.24	230.24	238.24	238.24	238.24	230.77	74.45	93.20	72.32	-188.93
Density (kg/m^3)	1.0	---	1,003.1	2.2	3.3	---	1.4	1.4	1.4	1.4	1.4	1.4	47.9	996.0	47.9	691.2
V-L Molecular Weight	37.051	---	18.015	32.205	32.205	---	38.302	38.302	38.303	38.303	38.303	38.303	41.873	18.016	41.920	41.920
V-L Flowrate (lb_{mol}/hr)	142,690	7,155	3,567	517	517	1	133,676	91,824	91,824	21,579	70,245	41,853	35,590	6,339	35,520	35,520
V-L Flowrate (lb/hr)	5,286,763	128,899	64,260	16,641	16,641	24	5,120,116	3,517,090	3,517,080	826,514	2,690,566	1,603,081	1,490,238	114,198	1,488,978	1,488,978
Solids Flowrate (lb/hr)	0	55,549	0	0	0	86,394	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	367	59	59	56	203	135	135	135	150	150	150	136	219	72	219	70
Pressure (psia)	15.3	15.5	14.7	23.2	45.0	14.8	14.8	14.8	14.7	14.7	14.7	14.8	485.8	35.2	485.8	2,214.7
Enthalpy (Btu/lb)[A]	188.6	---	27.0	4.9	36.8	---	99.0	99.0	102.4	102.4	102.4	99.2	32.0	40.1	31.1	-81.2
Density (lb/ft^3)	0.064	---	62.622	0.135	0.204	---	0.089	0.089	0.087	0.087	0.087	0.089	2.989	62.179	2.992	43.147

Exhibit 3-3 Heat and Mass Balance, Boiler and Gas Cleanup Systems for Current Technology Case

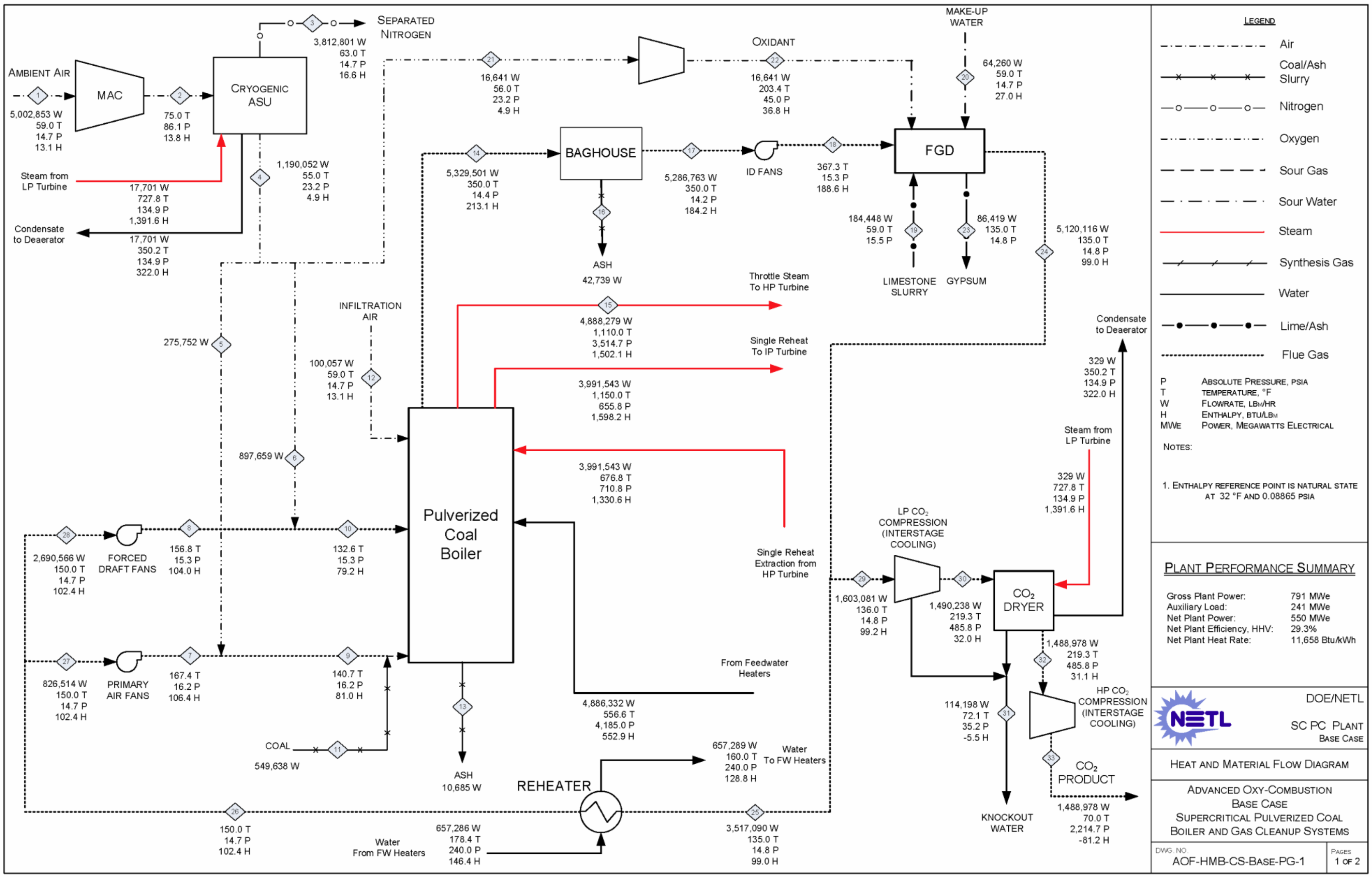


Exhibit 3-4 Heat and Mass Balance, Power Block Systems for Current Technology Case

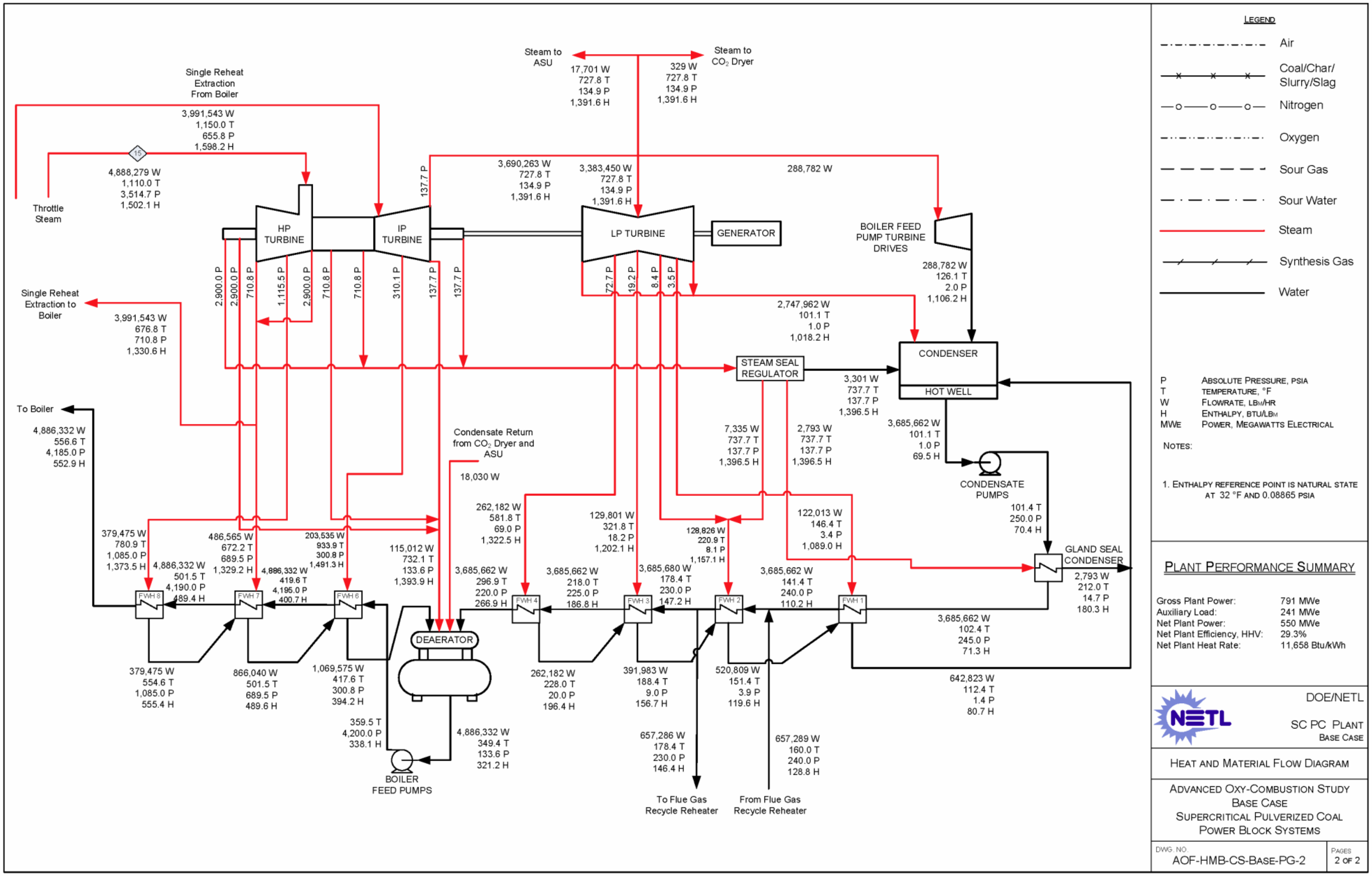


Exhibit 3-5 Current Technology Case Energy Balance

	HHV	Sensible + Latent	Power	Total
Heat In GJ/hr (MMBtu/hr)				
Coal	6,765 (6,412)	*5.7 (5.4)*		6,771 (6,417)
Combustion Air		70.8 (67.1)		70.8 (67.1)
Raw Water Makeup		124.3 (117.8)		124.3 (117.8)
Limestone		0.55 (0.52)		0.55 (0.52)
Auxiliary Power			867 (822)	867 (822)
Totals	**6,754 (6,402)**	**201.3 (190.8)**	**867 (822)**	**7,833 (7,424)**
Heat Out GJ/hr (MMBtu/hr)				
Boiler Loss		61.0 (57.8)		61.0 (57.8)
Bottom Ash		0.6 (0.6)		0.6 (0.6)
Fly Ash + FGD Ash		2.5 (2.3)		2.5 (2.3)
MAC Cooling		435.3 (412.6)		435.3 (412.6)
ASU Vent		66.8 (63.3)		66.8 (63.3)
Condenser		*3,079 (2,918)*		*3,079 (2,918)*
CO_2 Cooling		*546 (518)*		*546 (518)*
CO_2		*-128 (-121)*		*-128 (-121)*
Wet FGD Cooling		*511 (484)*		*511 (484)*
Process Condensate		*42 (40)*		*42 (40)*
Cooling Tower Blowdown		*59.6 (56.5)*		*59.6 (56.5)*
Process Losses*		*310.3 (294.1)*		*310.3 (294.1)*
Power			2,847 (2,698)	2,847 (2,698)
Totals		**4,986 (4,726)**	**2,847 (2,698)**	**7,833 (7,424)**

Note: Italicized numbers are estimated.
Reference conditions are 0°C (32.02°F) & 0.6 kPa (0.089 psia)
* Process losses are estimated to match the heat input to the plant and include losses from: steam turbine, combustion reactions, and gas cooling

Exhibit 3-6 Current Technology Case Carbon Balance

Carbon In		**Carbon Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	159,321 (351,242)	CO_2 Product	161,662 (356,403)
Air (CO_2)	442 (975)	FGD Product	228 (504)
FGD Reagent	2,557 (5,637)	Separated Air	434 (956)
		Convergence Tolerance*	-4 (-9)
Total	162,320 (357,853)	Total	162,320 (357,853)

*by difference

Exhibit 3-7 Current Technology Case Sulfur Balance

Sulfur In		**Sulfur Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	6,264 (13,809)	Gypsum	6,224 (13,721)
		CO_2 Product	40 (88)
		Convergence Tolerance*	0 (0)
Total	6,264 (13,809)	Total	6,264 (13,809)

*by difference

Exhibit 3-8 Current Technology Case Water Balance

Water Use	**Water Demand**	**Internal Recycle**	**Raw Water Withdrawal**	**Process Water Discharge**	**Raw Water Consumption**
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)
FGD Makeup	0.49 (129)	0.0 (0)	0.49 (129)	0.00 (0)	0.49 (129)
BFW Makeup	0.37 (98)	0.0 (0)	0.37 (98)	0.00 (0)	0.37 (98)
Cooling Tower	35.7 (9,422)	3.48 (920)	32.2 (8,503)	8.02 (2119)	24.17 (6384)
Total	**36.5 (9,649)**	**3.48 (920)**	**33.0 (8,729)**	**8.02 (2,119)**	**25.02 (6,610)**

Exhibit 3-9 Current Technology Performance Summary

Plant Output		
Steam Turbine Power	790,800	kW_e
Expander Power	N/A	kW_e
Gross Power	**790,800**	kWe
Auxiliary Load		
Coal Handling and Conveying	500	kW_e
Limestone Handling & Reagent Preparation	1,210	kW_e
Pulverizers	3,740	kW_e
Ash Handling	720	kW_e
Primary Air Fans	1,010	kW_e
Forced Draft Fans	1,280	kW_e
Induced Draft Fans	7,080	kW_e
Air Separation Unit Main Air Compressor	125,720	kW_e
ASU Auxiliaries	1,000	kW_e
Baghouse	90	kW_e
FGD Pumps and Agitators	4,050	kWe
CO_2 Compression	73,410	kW_e
Condensate Pumps	1,040	kW_e
Boiler Feedwater Booster Pumps[2]	N/A	kW_e
Miscellaneous Balance of Plant[3]	2,000	kW_e
Steam Turbine Auxiliaries	400	kW_e
Circulating Water Pumps	9,160	kW_e
Cooling Tower Fans	5,340	kW_e
Transformer Losses	3,030	kW_e
Total	240,780	kW_e
Plant Performance		
Net Auxiliary Load	240,780	kW_e
Net Plant Power	550,020	kW_e
Net Plant Efficiency (HHV)	29.3%	
Net Plant Heat Rate (HHV)	12,300 (11,658)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	249,312 (549,638)	kg/hr (lb/hr)
Thermal Input[1]	1,879,193	kW_{th}
Condenser Duty	3,079 (2,918)	GJ/hr (MMBtu/hr)
Raw Water Usage	33.0 (8,729)	m^3/min (gpm)

1 - HHV of As Received Illinois No. 6 coal is 27,135 kJ/kg (11,666 Btu/lb)

2 - Boiler feed pumps are turbine driven

3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 3-10 Current Technology Base Case Capital Costs

	Department:	NETL Office of Program Planning and Analysis										**Cost Base:**	June 2007	
	Project:	Advancing Oxycombustion Technology										**Prepared:**	13-Apr-12	
	Case:	Base Case - Current Technology Oxycombustion Supercritical PC											**x $1, 000**	
	Plant Size:	550	MW, net			Capital Charge Factor	0.158		Capacity Factor	0.85				
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Bare Erected**	**Eng'g CM H.O. & Fee %**	**Eng'g CM H.O. & Fee Total**	**Process Cont. %**	**Process Cont. Total**	**Project Cont. %**	**Project Cont. Total**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**
1	COAL HANDLING SYSTEM													
1.1	Coal Receive & Unload	3,952	0	1,805	0	5,757	8.9%	514	0%	0	15.0%	941	7,212	13
1.2	Coal Stackout & Reclaim	5,108	0	1,157	0	6,265	8.8%	548	0%	0	15.0%	1,022	7,835	14
1.3	Coal Conveyors & Yd Crus	4,749	0	1,145	0	5,894	8.8%	517	0%	0	15.0%	962	7,372	13
1.4	Other Coal Handling	1,242	0	265	0	1,507	8.7%	132	0%	0	15.0%	246	1,885	3
1.5	Sorbent Receive & Unload	163	0	49	0	212	8.8%	19	0%	0	15.0%	35	266	0
1.6	Sorbent Stackout & Reclaim	2,633	0	483	0	3,116	8.7%	271	0%	0	15.0%	508	3,896	7
1.7	Sorbent Conveyors	940	203	230	0	1,373	8.7%	119	0%	0	15.0%	224	1,716	3
1.8	Other Sorbent Handling	568	133	298	0	998	8.8%	88	0%	0	15.0%	163	1,250	2
1.9	Coal & Sorbent Hnd.Foundations	0	4,860	6,131	0	10,990	9.3%	1,027	0%	0	15.0%	1,803	13,820	25
	SUBTOTAL 1.	**$19,355**	**$5,196**	**$11,563**	**$0**	**$36,114**		**$3,236**		**$0**		**$5,902**	**$45,252**	**$82**
2	COAL PREP & FEED SYSTEMS													
2.1	Coal Crushing & Drying	2,287	0	446	0	2,733	8.7%	238	0%	0	15.0%	446	3,417	6
2.2	Prepared Coal Storage & Feed	5,856	0	1,278	0	7,134	8.7%	624	0%	0	15.0%	1,164	8,922	16
2.3	Slurry Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.4	Misc. Coal Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.5	Sorbent Prep Equipment	4,486	193	932	0	5,611	8.7%	489	0%	0	15.0%	915	7,015	13
2.6	Sorbent Storage & Feed	540	0	207	0	748	8.9%	66	0%	0	15.0%	122	936	2
2.7	Sorbent Injection System	0	0	0	0	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	0.0%	0	0	0
2.9	Coal & Sorbent Feed Foundation	0	573	481	0	1,055	9.2%	97	0%	0	15.0%	173	1,325	2
	SUBTOTAL 2.	**$13,170**	**$767**	**$3,344**	**$0**	**$17,281**		**$1,515**		**$0**		**$2,819**	**$21,615**	**$39**
3	FEEDWATER & MISC. BOP SYSTEMS													
3.1	Feedwater System	21,788	0	7,038	0	28,826	8.8%	2,524	0%	0	15.0%	4,702	36,052	66
3.2	Water Makeup & Pretreating	5,530	0	1,780	0	7,310	9.4%	685	0%	0	20.0%	1,599	9,594	17
3.3	Other Feedwater Subsystems	6,670	0	2,819	0	9,489	8.9%	846	0%	0	15.0%	1,550	11,885	22
3.4	Service Water Systems	1,084	0	590	0	1,674	9.3%	155	0%	0	20.0%	366	2,195	4
3.5	Other Boiler Plant Systems	8,234	0	8,129	0	16,363	9.4%	1,535	0%	0	15.0%	2,685	20,582	37
3.6	FO Supply Sys & Nat Gas	271	0	339	0	611	9.3%	57	0%	0	15.0%	100	768	1
3.7	Waste Treatment Equipment	2,976	0	1,696	0	4,672	9.7%	453	0%	0	20.0%	1,025	6,150	11
3.8	Misc. Power Plant Equipment	2,882	0	881	0	3,763	9.6%	361	0%	0	20.0%	825	4,949	9
	SUBTOTAL 3.	**$49,435**	**$0**	**$23,272**	**$0**	**$72,708**		**$6,616**		**$0**		**$12,852**	**$92,176**	**$168**
4	PC BOILER & ACCESSORIES													
4.1	PC Boiler	186,648	0	104,729	0	291,377	9.7%	28,223	0%	0	10.0%	31,960	351,560	639
4.2	ASU/Oxidant Compression	115,897	0	94,825	0	210,723	9.7%	20,411	0%	0	10.0%	23,113	254,247	462
4.3	Open	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.4	Boiler BoP (w/ID Fans)	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.5	Primary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.6	Secondary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.7	Major Component Rigging	0	w/4.1	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.8	PC Foundations	0	w/14.1	w/14.1	0	0	0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 4.	**$302,546**	**$0**	**$199,554**	**$0**	**$502,100**		**$48,634**		**$0**		**$55,073**	**$605,807**	**$1,101**

Exhibit 3-10 Current Technology Base Case Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & %	Eng'g CM H.O. & Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
5A	FLUE GAS CLEANUP							*						
5.1	Absorber Vessels & Accessories	60,310	0	12,983	0	73,294	9.5%	6,937	0%	0	10.0%	8,023	88,254	160
5.2	Other FGD	3,150	0	3,569	0	6,719	9.6%	647	0%	0	10.0%	737	8,102	15
5.3	Bag House & Accessories	15,077	0	9,568	0	24,645	9.6%	2,357	0%	0	10.0%	2,700	29,703	54
5.4	Other Particulate Removal Materials	995	0	1,064	0	2,059	9.6%	198	0%	0	10.0%	226	2,483	5
5.5	Gypsum Dewatering System	5,465	0	928	0	6,394	9.4%	604	0%	0	10.0%	700	7,698	14
5.6	Mercury Removal System	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.7	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.8	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.9	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 5A.	**$84,997**	**$0**	**$28,114**	**$0**	**$113,111**		**$10,744**		**$0**		**$12,385**	**$136,240**	**$248**
5B	CO2 REMOVAL & COMPRESSION													
5B.1	CO2 Condensing Heat Exchanger	6,045	0	505	0	6,549	10%	655	0%	0	15.0%	1,081	8,285	15
5B.2	CO2 Compression & Drying	43,007	0	35,187	0	78,194	10%	7,819	0%	0	20.0%	17,203	103,216	188
5B.3	CO2 Pipeline											0	0	0
5B.4	CO2 Storage											0	0	0
5B.5	CO2 Monitoring											0	0	0
	SUBTOTAL 5B.	**$49,051**	**$0**	**$35,692**	**$0**	**$84,744**		**$8,474**		**$0**		**$18,283**	**$111,501**	**$203**
6	NITROGEN EXPANDER/GENERATOR													
6.1	Nitrogen Expander/Generator	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.2	Nitrogen Expander/Generator Accessories	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.3	Compressed Air Piping	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.4	Nitrogen Expander/Generator Foundations	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 6.	**$0**	**$0**	**$0**	**$0**	**$0**		**$0**		**$0**		**$0**	**$0**	**$0**
7	HRSG, DUCTING & STACK													
7.1	Flue Gas Recycle Heat Exchanger	1,402	0	117	0	1,519	10%	152	0%	0	15.0%	251	1,921	3
7.2	SCR System	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
7.3	Ductwork	9,344	0	6,003	0	15,347	8.7%	1,340	0%	0	15.0%	2,503	19,191	35
7.4	Stack	1,667	0	975	0	2,642	9.6%	252	0%	0	10.0%	289	3,184	6
7.9	HRSG, Duct & Stack Foundations	0	861	978	0	1,839	9.3%	171	0%	0	20.0%	402	2,413	4
	SUBTOTAL 7.	**$12,412**	**$861**	**$8,074**	**$0**	**$21,347**		**$1,916**		**$0**		**$3,445**	**$26,709**	**$49**
8	STEAM TURBINE GENERATOR													
8.1	Steam TG & Accessories	62,522	0	8,297	0	70,819	9.6%	6,781	0%	0	10.0%	7,760	85,360	155
8.2	Turbine Plant Auxiliaries	421	0	902	0	1,323	9.7%	128	0%	0	10.0%	145	1,597	3
8.3	Condenser & Auxiliaries	7,168	0	2,642	0	9,810	9.5%	932	0%	0	10.0%	1,074	11,816	21
8.4	Steam Piping	20,448	0	10,082	0	30,530	8.3%	2,548	0%	0	15.0%	4,962	38,040	69
8.9	TG Foundations	0	1,318	2,081	0	3,399	9.4%	320	0%	0	20.0%	744	4,463	8
	SUBTOTAL 8.	**$90,559**	**$1,318**	**$24,005**	**$0**	**$115,881**		**$10,709**		**$0**		**$14,685**	**$141,275**	**$257**
9	COOLING WATER SYSTEM													
9.1	Cooling Towers	13,072	0	4,071	0	17,142	9.5%	1,627	0%	0	10.0%	1,877	20,646	38
9.2	Circulating Water Pumps	2,314	0	178	0	2,492	8.6%	213	0%	0	10.0%	271	2,976	5
9.3	Circ. Water System Auxiliaries	614	0	82	0	695	9.4%	66	0%	0	10.0%	76	837	2
9.4	Circ. Water Piping	0	4,864	4,714	0	9,579	9.2%	882	0%	0	15.0%	1,569	12,030	22
9.5	Make-up Water System	526	0	702	0	1,228	9.5%	116	0%	0	15.0%	202	1,546	3
9.6	Component Cooling Water System	486	0	387	0	873	9.4%	82	0%	0	15.0%	143	1,098	2
9.9	Circ. Water System Foundations	0	2,938	4,668	0	7,605	9.4%	716	0%	0	20.0%	1,664	9,985	18
	SUBTOTAL 9.	**$17,011**	**$7,802**	**$14,801**	**$0**	**$39,614**		**$3,702**		**$0**		**$5,802**	**$49,118**	**$89**

Exhibit 3-10 Current Technology Base Case Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
10	ASH/SPENT SORBENT HANDLING SYS													
10.1	Ash Coolers	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.2	Cyclone Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.3	HGCU Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.4	High Temperature Ash Piping	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.5	Other Ash Recovery Equipment	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.6	Ash Storage Silos	681	0	2,098	0	2,778	9.7%	271	0%	0	10.0%	305	3,354	6
10.7	Ash Transport & Feed Equipment	4,407	0	4,514	0	8,921	9.5%	844	0%	0	10.0%	976	10,741	20
10.8	Misc. Ash Handling Equipment	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
10.9	Ash/Spent Sorbent Foundation	0	162	190	0	352	9.3%	33	0%	0	20.0%	77	462	1
	SUBTOTAL 10.	**$5,088**	**$162**	**$6,802**	**$0**	**$12,051**		**$1,147**		**$0**		**$1,358**	**$14,557**	**$26**
11	ACCESSORY ELECTRIC PLANT													
11.1	Generator Equipment	1,863	0	302	0	2,165	9.3%	201	0%	0	7.5%	177	2,543	5
11.2	Station Service Equipment	6,761	0	2,222	0	8,983	9.6%	859	0%	0	7.5%	738	10,580	19
11.3	Switchgear & Motor Control	7,773	0	1,321	0	9,094	9.3%	842	0%	0	10.0%	994	10,930	20
11.4	Conduit & Cable Tray	0	4,873	16,851	0	21,724	9.6%	2,079	0%	0	15.0%	3,571	27,374	50
11.5	Wire & Cable	0	9,196	17,752	0	26,948	8.4%	2,270	0%	0	15.0%	4,383	33,601	61
11.6	Protective Equipment	261	0	888	0	1,149	9.8%	112	0%	0	10.0%	126	1,388	3
11.7	Standby Equipment	1,447	0	33	0	1,480	9.5%	140	0%	0	10.0%	162	1,782	3
11.8	Main Power Transformers	8,293	0	140	0	8,432	7.6%	641	0%	0	10.0%	907	9,980	18
11.9	Electrical Foundations	0	375	919	0	1,294	9.5%	123	0%	0	20.0%	283	1,701	3
	SUBTOTAL 11.	**$26,398**	**$14,444**	**$40,428**	**$0**	**$81,270**		**$7,267**		**$0**		**$11,341**	**$99,879**	**$182**
12	INSTRUMENTATION & CONTROL													
12.1	PC Control Equipment	w/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.2	Combustion Turbine Control	N/A	0	N/A	0	0	0%	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%	0	0	0
12.4	Other Major Component Control	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
12.5	Signal Processing Equipment	W/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.6	Control Boards, Panels & Racks	565	0	339	0	904	9.6%	87	0%	0	15.0%	149	1,140	2
12.7	Computer Accessories	5,708	0	998	0	6,705	9.5%	639	0%	0	10.0%	734	8,078	15
12.8	Instrument Wiring & Tubing	3,095	0	6,139	0	9,234	8.5%	787	0%	0	15.0%	1,503	11,523	21
12.9	Other I & C Equipment	1,613	0	3,660	0	5,273	9.7%	514	0%	0	10.0%	579	6,365	12
	SUBTOTAL 12.	**$10,981**	**$0**	**$11,135**	**$0**	**$22,116**		**$2,026**		**$0**		**$2,965**	**$27,106**	**$49**
13	IMPROVEMENTS TO SITE													
13.1	Site Preparation	0	55	1,106	0	1,161	9.9%	114	0%	0	20.0%	255	1,531	3
13.2	Site Improvements	0	1,836	2,280	0	4,116	9.8%	404	0%	0	20.0%	904	5,424	10
13.3	Site Facilities	3,290	0	3,245	0	6,535	9.8%	641	0%	0	20.0%	1,435	8,611	16
	SUBTOTAL 13.	**$3,290**	**$1,891**	**$6,631**	**$0**	**$11,812**		**$1,160**		**$0**		**$2,594**	**$15,567**	**$28**
14	BUILDINGS & STRUCTURES													
14.1	Boiler Building	0	8,831	7,766	0	16,596	9.0%	1,490	0%	0	15.0%	2,713	20,800	38
14.2	Turbine Building	0	12,761	11,894	0	24,655	9.0%	2,220	0%	0	15.0%	4,031	30,906	56
14.3	Administration Building	0	640	677	0	1,317	9.1%	119	0%	0	15.0%	216	1,652	3
14.4	Circulation Water Pumphouse	0	139	111	0	250	8.9%	22	0%	0	15.0%	41	313	1
14.5	Water Treatment Buildings	0	713	650	0	1,363	9.0%	122	0%	0	15.0%	223	1,708	3
14.6	Machine Shop	0	428	288	0	716	8.9%	64	0%	0	15.0%	117	896	2
14.7	Warehouse	0	290	291	0	581	9.0%	53	0%	0	15.0%	95	729	1
14.8	Other Buildings & Structures	0	237	202	0	439	9.0%	39	0%	0	15.0%	72	550	1
14.9	Waste Treating Building & Str.	0	446	1,352	0	1,798	9.4%	170	0%	0	15.0%	295	2,263	4
	SUBTOTAL 14.	**$0**	**$24,486**	**$23,231**	**$0**	**$47,717**		**$4,299**		**$0**		**$7,802**	**$59,819**	**$109**
	Total Cost	**$684,293**	**$56,927**	**$436,645**	**$0**	**$1,177,865**		**$111,445**		**$0**		**$157,309**	**$1,446,620**	**$2,630**

Exhibit 3-11 Current Technology Base Case Owner's Costs

Owner's Costs	$1,000	$/kW
Preproduction Costs		
6 Months All Labor	$9,719	$18
1 Month Maintenance Materials	$1,474	$3
1 Month Non-fuel Consumables	$806	$1
1 Month Waste Disposal	$316	$1
25% of 1 Months Fuel Cost at 100% CF	$1,915	$3
2% of TPC	$28,932	$53
Total	**$43,163**	**$78**
Inventory Capital		
60 day supply of fuel and consumables at 100% CF	$16,519	$30
0.5% of TPC (spare parts)	$7,233	$13
Total	**$23,752**	**$43**
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$216,993	$395
Financing Costs	$39,059	$71
Total Overnight Costs (TOC)	**$1,770,486**	**$3,219**
TASC Multiplier	1.134	
Total As-Spent Cost (TASC)	**$2,007,732**	**$3,650**

Exhibit 3-12 Current Technology Base Case O&M Costs

INITIAL & ANNUAL O&M EXPENSES						
Case:	Base Case - Current Technology Oxycombustion Supercritical PC					
Plant Size (MWe):	550.02			**Heat Rate (Btu/kWh):**		11,658
Primary/Secondary Fuel:	Illinois #6 Bituminous Coal			**Fuel Cost ($/MM Btu):**		1.64
Design/Construction	5 years			**Book Life (yrs):**		30
TPC (Plant Cost) Year:	June 2007			**TPI Year:**		2012
Capacity Factor (%):	85			**CO**2 Captured (TPD):		15,671
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate (base):		$34.65	$/hour			
Operating Labor Burden:		30.00	% of base			
Labor Overhead Charge:		25.00	% of labor			
Operating Labor Requirements per Shift:		**units/mod.**		**Total Plant**		
Skilled Operator		2.0		2.0		
Operator		9.0		9.0		
Foreman		1.0		1.0		
Lab Tech's etc.		2.0		2.0		
TOTAL Operating Jobs		14.0		14.0		
					$	**$/kW-net**
Annual Operating Labor Cost (calc'd)					5,524,319	10.04
Maintenance Labor Cost (calc'd)					10,026,462	18.23
Administrative & Support Labor (calc'd)					3,887,695	7.07
Property Taxes and Insurance					28,932,399	52.60
TOTAL FIXED OPERATING COSTS					**48,370,875**	**87.94**
VARIABLE OPERATING COSTS						
					$	**$/kWh-net**
Maintenance Material Costs (calc'd)					**$15,039,811**	**0.00367**
Consumables	**Consumption**		**Unit**	**Initial**		
	Initial	**/Day**	**Cost**	**Cost**	**$**	**$/kWh-net**
Water (/1000 gallons)	0	6,285	1.08	$0	$2,109,142	0.00051
Chemicals						
MU & WT Chem. (lb)	0	30,423	0.17	$0	$1,633,536	0.00040
Limestone (ton)	0	667	21.63	$0	$4,474,003	0.00109
Carbon (Hg Removal) (lb)	0	0	1.05	$0	$0	0.00000
MEA Solvent (ton)	0	0	2249.89	$0	$0	0.00000
Caustic Soda, NaOH (ton)	0	0	433.68	$0	$0	0.00000
Sulfuric acid, H_2SO_4 (ton)	0	0	138.78	$0	$0	0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	0.00000
Activated C, MEA (lb)	0	0	1.05	$0	$0	0.00000
Ammonia, 19% soln (ton)	0	0	129.80	$0	$0	0.00000
Subtotal Chemicals				**$0**	**$6,107,540**	**0.00149**
Other						
Supplemental Fuel (MMBtu)	0	0	6.55	$0	$0	0.00000
SCR Catalyst Replacement	w/equip.	0.00	5775.94	$0	$0	0.00000
Emission Penalties	0	0	0.00	$0	$0	0.00000
Subtotal Other				**$0**	**$0**	**0.00000**
Waste Disposal						
Spent Mercury Catalyst (lb)	0	0	0.42	$0	$0	0.00000
Flyash (ton)	0	513	16.23	$0	$2,581,699	0.00063
Bottom Ash (ton)	0	128	16.23	$0	$645,440	0.00016
Subtotal Solid Waste Disposal				**$0**	**$3,227,139**	**0.00079**
By-products & Emissions						
Gypsum (tons)	0	0	0.00	$0	$0	0.00000
Sulfur (tons)	0	0	0.00	$0	$0	0.00000
Subtotal By-Products				**$0**	**$0**	**0.00000**
TOTAL VARIABLE OPERATING COSTS					**$26,483,632**	**0.00647**
Coal FUEL (tons)	**0**	**6,596**	**38.18**	**$0**	**$78,137,029**	**0.01908**
NATURAL GAS FUEL (Mscf)	**0**	**0**	**6.76**	**$0**	**$0**	**0.00000**

3.2 CASE 3: ULTRASUPERCRITICAL (USC) OXYCOMBUSTION

Because of the similarities between the current technology case and Case 3, they are presented in adjacent sections in order to logically condense the content of the report, specifically the equipment accounts.

The USC oxycombustion power plant is similar to the current technology power plant, except that it is operating under ultrasupercritical steam conditions. The plant is equipped with a cryogenic distillation ASU, a wet FGD, and a conventional CO_2 purification/compression system. The plant employs an ultrasupercritical single-reheat 27.6 MPa/732°C/760°C (4,000 psig/1,350°F/1,400°F) Rankine cycle with a state-of-the art pulverized coal steam generator firing bituminous Illinois No. 6 coal and a steam turbine. The CO_2 is captured and compressed to 2,215 psia and sent to a remote geologic location for storage.

- The adiabatic flame temperature of the boiler is controlled to 2,031°C (3,678°F) by varying the amount of flue gas recycled to the boiler.
- The oxidant is supplied by conventional ASU technology that produces 95 percent O_2.
- The recycled flue gas stream is superheated 9°C (15°F).
- The CO_2 compression is accomplished by eight stages of centrifugal compression (86 percent polytropic efficiency) with intercooling.

This base plant represents the current oxycombustion technology. Illinois No. 6 coal is the fuel and the plant is located at a generic non-minemouth site in the Midwestern United States.

Block Flow Diagram and Stream Table

Process BFD and stream tables for the current technology case are displayed in Exhibit 3-13 and Exhibit 3-14.

Heat and Mass Balance Diagram

Heat and mass balance diagrams are shown for the following subsystems in Exhibit 3-15 and Exhibit 3-16:

- Boiler and flue gas cleanup
- Steam cycle and feed water (power block)

Energy, Carbon, Sulfur, and Water Balances

An overall plant energy balance is provided in tabular form in Exhibit 3-17. The power out is the steam turbine power after generator losses.

Carbon, sulfur, and water balances are shown in Exhibit 3-18 through Exhibit 3-20.

Performance Summary

A performance summary is provided in Exhibit 3-21.

Costing Table

Tables of capital costs, owner's costs, and O&M costs are provided in Exhibit 3-22 through Exhibit 3-24, respectively.

Equipment List

The combined equipment list for the current technology case and Case 3 is shown in Exhibit 3-25.

Exhibit 3-13 Process Block Flow Diagram for Case 3

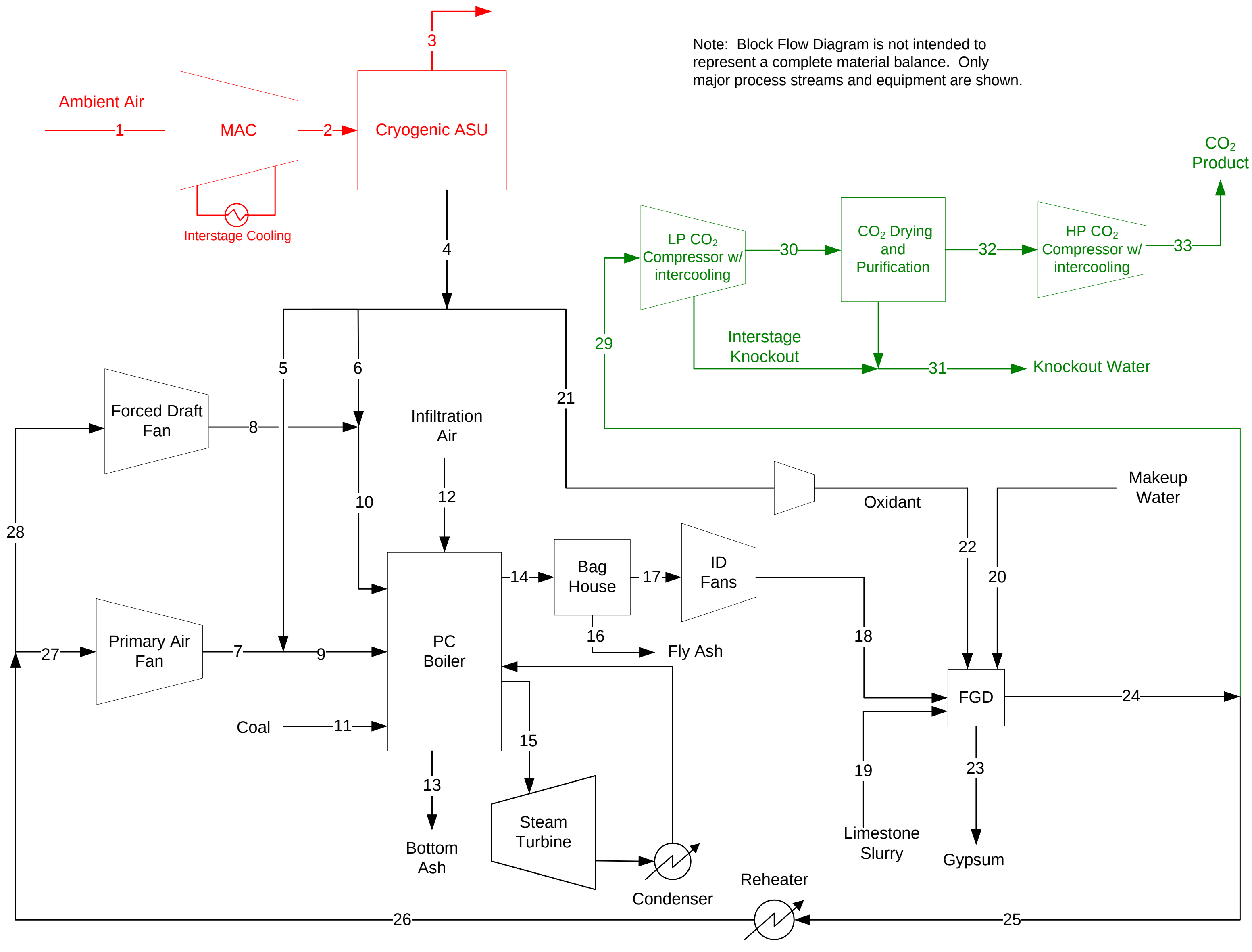


Exhibit 3-14 Stream Table for Case 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
V-L Mole Fraction																	
Ar	0.0092	0.0092	0.0024	0.0340	0.0340	0.0340	0.0308	0.0308	0.0317	0.0317	0.0000	0.0092	0.0000	0.0287	0.0000	0.0000	0.0287
CO_2	0.0005	0.0005	0.0006	0.0000	0.0000	0.0000	0.7090	0.7090	0.5073	0.5073	0.0000	0.0005	0.0000	0.6608	0.0000	0.0000	0.6608
H_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	0.0000	0.0000	0.0000
H_2O	0.0101	0.0101	0.0128	0.0000	0.0000	0.0000	0.1514	0.1514	0.1084	0.1084	0.0000	0.0101	0.0000	0.2076	1.0000	0.0000	0.2076
N_2	0.7729	0.7729	0.9778	0.0162	0.0162	0.0162	0.0856	0.0856	0.0659	0.0659	0.0000	0.7729	0.0000	0.0801	0.0000	0.0000	0.0801
O_2	0.2074	0.2074	0.0063	0.9498	0.9498	0.9498	0.0231	0.0231	0.2867	0.2867	0.0000	0.2074	0.0000	0.0197	0.0000	0.0000	0.0197
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0031	0.0000	0.0000	0.0031
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	70,905	70,905	55,793	15,113	3,502	11,399	8,809	28,675	12,310	40,074	0	1,418	0	58,315	108,630	0	58,315
V-L Flowrate (kg/hr)	2,046,048	2,046,048	1,559,345	486,703	112,770	367,103	337,388	1,098,306	450,158	1,465,409	0	40,921	0	2,159,960	1,956,993	0	2,159,960
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	225,320	0	4,370	17,479	0	17,479	0
Temperature (°C)	15	24	17	13	13	13	75	69	60	56	15	15	15	177	732	15	177
Pressure (MPa, abs)	0.10	0.59	0.10	0.16	0.16	0.16	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	27.68	0.10	0.10
Enthalpy (kJ/kg)[A]	30.57	32.03	38.64	11.49	11.49	11.49	247.49	241.88	188.37	184.16	---	30.57	---	496.37	3,844.30	---	429.20
Density (kg/m^3)	1.2	7.0	1.2	2.2	2.2	2.2	1.5	1.4	1.5	1.4	---	1.2	---	1.0	64.1	---	1.0
V-L Molecular Weight	28.856	28.856	27.949	32.205	32.205	32.205	38.302	38.302	36.568	36.568	---	28.856	---	37.040	18.015	---	37.040
V-L Flowrate (lb_{mol}/hr)	156,320	156,320	123,002	33,318	7,720	25,131	19,419	63,217	27,139	88,347	0	3,126	0	128,562	239,487	0	128,562
V-L Flowrate (lb/hr)	4,510,763	4,510,764	3,437,768	1,072,996	248,616	809,324	743,814	2,421,351	992,430	3,230,675	0	90,215	0	4,761,896	4,314,431	0	4,761,896
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	496,745	0	9,634	38,535	0	38,535	0
Temperature (°F)	59	75	63	55	56	56	167	157	141	133	59	59	59	350	1,350	59	350
Pressure (psia)	14.7	86.1	14.7	23.2	23.2	23.2	16.2	15.3	16.2	15.3	14.7	14.7	14.7	14.4	4,014.7	14.7	14.2
Enthalpy (Btu/lb)[A]	13.1	13.8	16.6	4.9	4.9	4.9	106.4	104.0	81.0	79.2	---	13.1	---	213.4	1,652.7	---	184.5
Density (lb/ft^3)	0.076	0.435	0.073	0.135	0.135	0.135	0.092	0.089	0.092	0.088	---	0.076	---	0.061	4.004	---	0.061

A - Reference conditions are 32.02 F & 0.089 PSIA

Exhibit 3-14 Stream Table for Case 3 (continued)

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
V-L Mole Fraction																
Ar	0.0287	0.0000	0.0000	0.0340	0.0340	0.0000	0.0308	0.0308	0.0308	0.0308	0.0308	0.0308	0.0362	0.0000	0.0363	0.0363
CO_2	0.6608	0.0000	0.0000	0.0000	0.0000	0.0014	0.7090	0.7090	0.7090	0.7090	0.7090	0.7090	0.8337	0.0000	0.8354	0.8354
H_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	0.0000	0.0000
H_2O	0.2076	1.0000	1.0000	0.0000	0.0000	0.9986	0.1514	0.1514	0.1514	0.1514	0.1514	0.1514	0.0021	1.0000	0.0001	0.0001
N_2	0.0801	0.0000	0.0000	0.0162	0.0162	0.0000	0.0856	0.0856	0.0856	0.0856	0.0856	0.0856	0.1007	0.0000	0.1009	0.1009
O_2	0.0197	0.0000	0.0000	0.9498	0.9498	0.0000	0.0231	0.0231	0.0231	0.0231	0.0231	0.0231	0.0272	0.0000	0.0272	0.0272
SO_2	0.0031	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
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	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	58,315	3,022	1,329	212	212	218	54,599	37,483	37,483	8,809	28,675	17,116	14,555	2,592	14,526	14,526
V-L Flowrate (kg/hr)	2,159,960	54,434	23,942	6,829	6,829	3,936	2,091,294	1,435,690	1,435,690	337,388	1,098,306	655,604	609,455	46,703	608,940	608,940
Solids Flowrate (kg/hr)	0	22,696	0	0	0	35,311	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	186	15	15	13	95	57	57	57	66	66	66	58	104	22	104	21
Pressure (MPa, abs)	0.11	0.11	0.10	0.16	0.31	0.10	0.10	0.10	0.10	0.10	0.10	0.10	3.35	0.24	3.35	15.27
Enthalpy (kJ/kg)[A]	439.46	---	62.80	11.49	85.68	---	230.24	230.24	238.24	238.24	238.24	230.77	74.45	93.20	72.32	-188.93
Density (kg/m^3)	1.0	---	1,003.1	2.2	3.3	---	1.4	1.4	1.4	1.4	1.4	1.4	47.9	996.0	47.9	691.1
V-L Molecular Weight	37.040	---	18.015	32.205	32.205	---	38.302	38.302	38.302	38.302	38.302	38.302	41.873	18.016	41.920	41.920
V-L Flowrate (lb_{mol}/hr)	128,562	6,661	2,930	468	468	481	120,371	82,636	82,636	19,419	63,217	37,735	32,088	5,715	32,025	32,025
V-L Flowrate (lb/hr)	4,761,896	120,006	52,782	15,056	15,056	8,678	4,610,514	3,165,156	3,165,156	743,814	2,421,351	1,445,359	1,343,619	102,963	1,342,483	1,342,483
Solids Flowrate (lb/hr)	0	50,036	0	0	0	77,847	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	367	59	59	56	203	135	135	135	150	150	150	136	219	72	219	70
Pressure (psia)	15.3	15.5	14.7	23.2	45.0	14.8	14.8	14.8	14.7	14.7	14.7	14.8	485.8	35.2	485.8	2,214.7
Enthalpy (Btu/lb)[A]	188.9	---	27.0	4.9	36.8	---	99.0	99.0	102.4	102.4	102.4	99.2	32.0	40.1	31.1	-81.2
Density (lb/ft^3)	0.064	---	62.622	0.135	0.204	---	0.089	0.089	0.087	0.087	0.087	0.089	2.989	62.179	2.992	43.147

Exhibit 3-15 Heat and Mass Balance, Boiler and Gas Cleanup Systems for Case 3

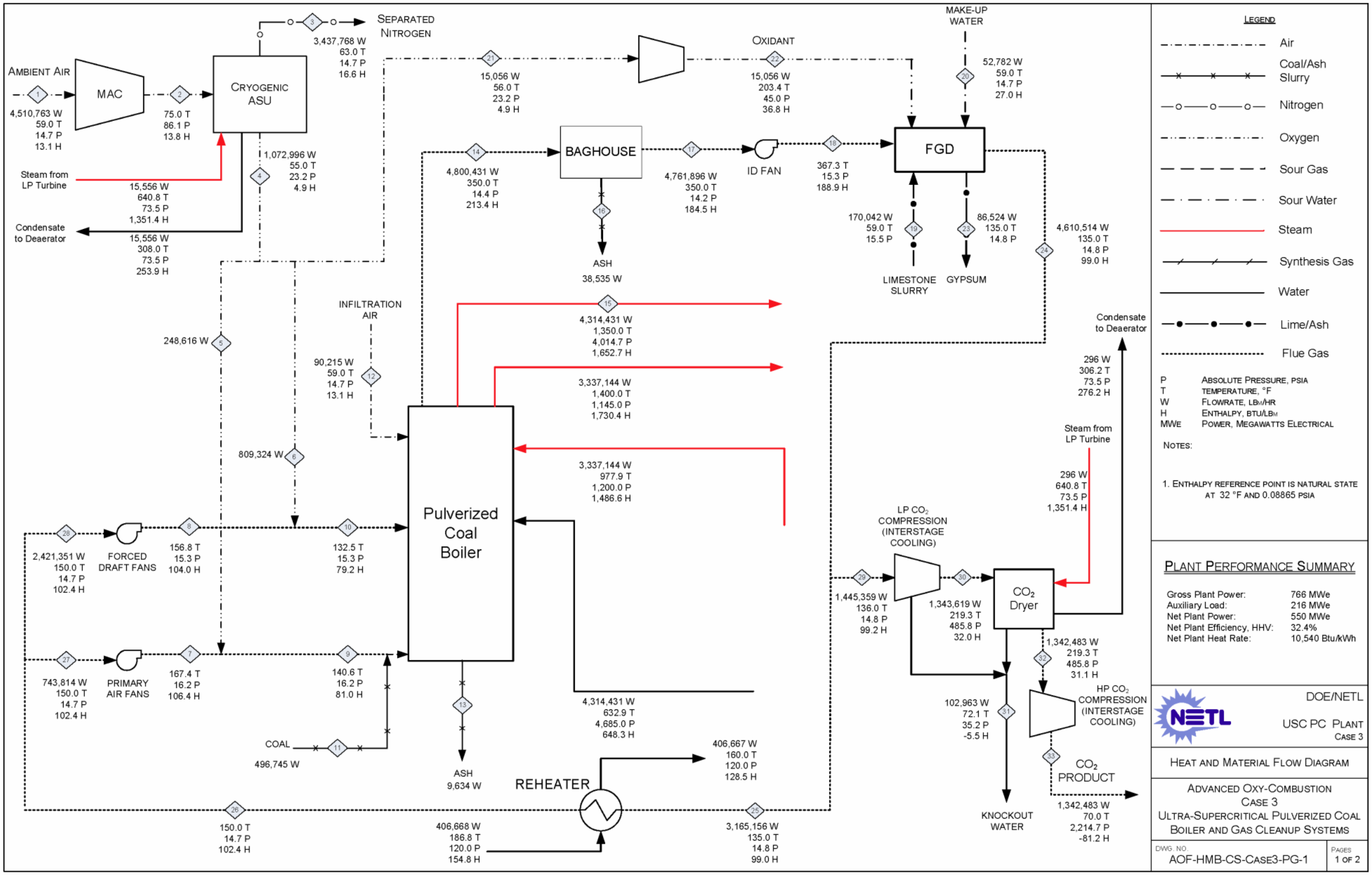


Exhibit 3-16 Heat and Mass Balance, Power Block Systems for Case 3

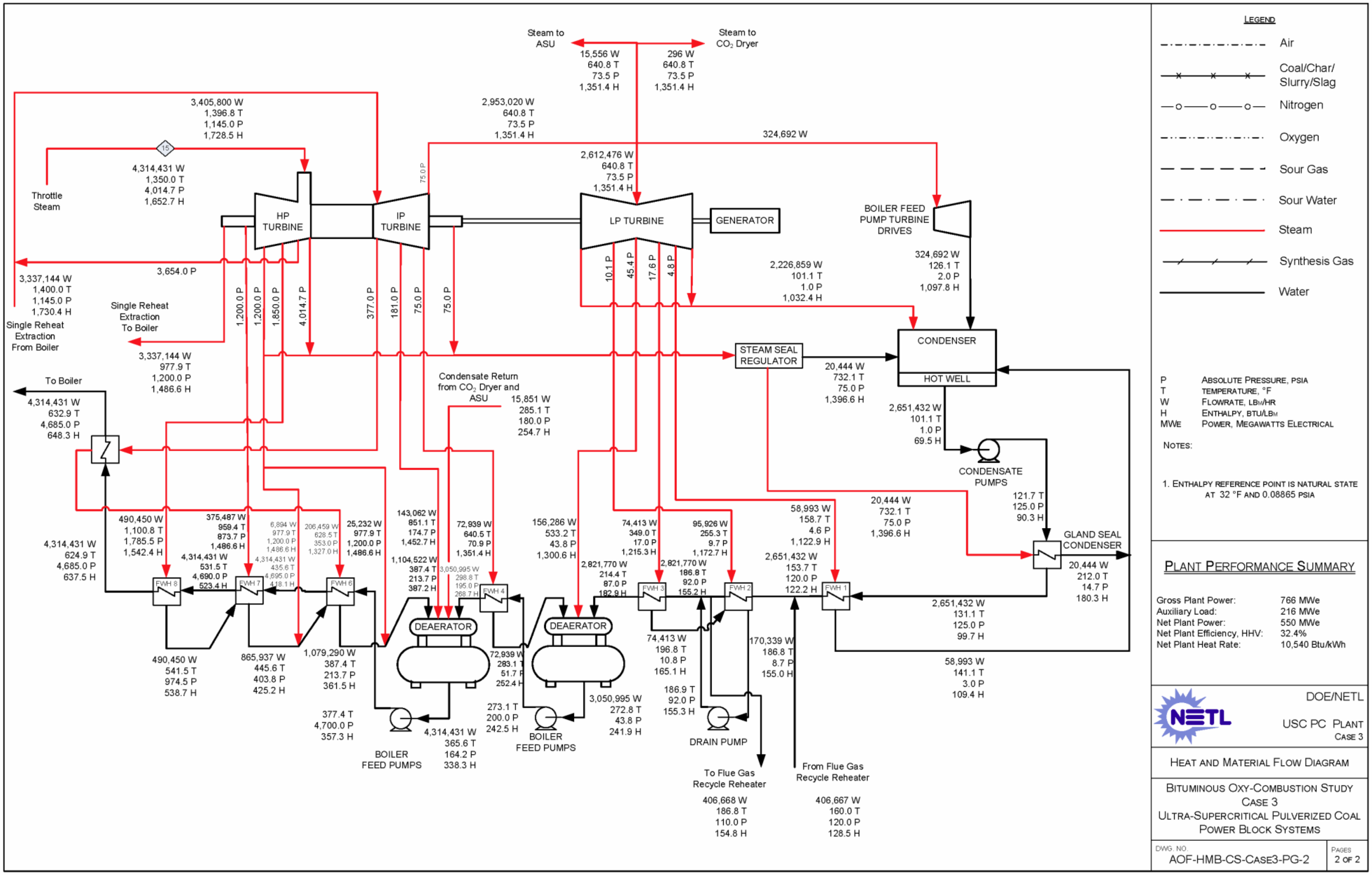


Exhibit 3-17 Case 3 Energy Balance

	HHV	Sensible + Latent	Power	Total
Heat In GJ/hr (MMBtu/hr)				
Coal	6,114 (5,795)	*5.1 (4.8)*		6,119 (5,800)
Combustion Air		63.8 (60.5)		63.8 (60.5)
Raw Water Makeup		111.4 (105.6)		111.4 (105.6)
Limestone		0.49 (0.47)		0.49 (0.47)
Auxiliary Power			778 (737)	778 (737)
Totals	**6,114 (5,795)**	**180.8 (171.4)**	**778 (737)**	**7,073 (6,704)**
Heat Out GJ/hr (MMBtu/hr)				
Boiler Loss		55.0 (52.2)		55.0 (52.2)
Bottom Ash		0.6 (0.5)		0.6 (0.5)
Fly Ash + FGD Ash		2.2 (2.1)		2.2 (2.1)
MAC Cooling		392.5 (372.0)		392.5 (372.0)
ASU Vent		60.3 (57.1)		60.3 (57.1)
Condenser		2,648.1 (2,509.9)		2,648.1 (2,509.9)
CO_2 Cooling		488.5 (463.0)		488.5 (463.0)
CO_2		-115.0 (-109.0)		-115.0 (-109.0)
Wet FGD Cooling		462.7 (438.5)		462.7 (438.5)
Process Condensate		37.3 (35.3)		37.3 (35.3)
Cooling Tower Blowdown		52.0 (49.3)		52.0 (49.3)
Process Losses*		*286.6 (271.6)*		*286.6 (271.6)*
Power			2,757 (2,613)	2,757 (2,613)
Totals		**4,316 (4,090)**	**2,757 (2,613)**	**7,073 (6,704)**

Note: Italicized numbers are estimated.
Reference conditions are 0°C (32.02°F) & 0.6 kPa (0.089 psia)
* Process losses are estimated to match the heat input to the plant and include losses from: steam turbine, combustion reactions, and gas cooling.

Exhibit 3-18 Case 3 Carbon Balance

Carbon In		**Carbon Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	143,650 (316,693)	CO_2 Product	145,756 (321,336)
Air (CO_2)	399 (879)	FGD Product	201 (443)
FGD Reagent	2,303 (5,077)	Separated Air	391 (862)
		Convergence Tolerance*	4 (8)
Total	146,351 (322,649)	Total	146,351 (322,649)

*by difference

Exhibit 3-19 Case 3 Sulfur Balance

Sulfur In		**Sulfur Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	5,647 (12,451)	Gypsum	5,612 (12,371)
		CO_2 Product	36 (79)
		Convergence Tolerance*	0 (0)
Total	5,647 (12,451)	Total	5,647 (12,451)

*by difference

Exhibit 3-20 Case 3 Water Balance

Water Use	**Water Demand**	**Internal Recycle**	**Raw Water Withdrawal**	**Process Water Discharge**	**Raw Water Consumption**
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)
FGD Makeup	1.31 (346)	0.0 (0)	1.31 (346)	0.00 (0)	1.31 (346)
BFW Makeup	0.23 (61)	0.0 (0)	0.23 (61)	0.00 (0)	0.23 (61)
Cooling Tower	31.1 (8,227)	2.29 (605)	28.1 (7,415)	7.00 (1850)	21.07 (5565)
Total	**32.7 (8,633)**	**2.29 (605)**	**29.6 (7,822)**	**7.00 (1,850)**	**22.61 (5,972)**

Exhibit 3-21 Case 3 Performance Summary

Plant Output		
Steam Turbine Power	765,900	kW_e
Gross Power	**765,900**	kWe
Auxiliary Load		
Coal Handling and Conveying	480	kW_e
Limestone Handling & Reagent Preparation	1,090	kW_e
Pulverizers	3,380	kW_e
Ash Handling	650	kW_e
Primary Air Fans	910	kW_e
Forced Draft Fans	1,150	kW_e
Induced Draft Fans	6,380	kW_e
Air Separation Unit Main Air Compressor	113,350	kW_e
ASU Auxiliaries	1,000	kW_e
Baghouse	80	kW_e
FGD Pumps and Agitators	3,650	kWe
CO_2 Compression	65,070	kW_e
Condensate Pumps	960	kW_e
Boiler Feedwater Booster Pumps[2]	N/A	kW_e
Miscellaneous Balance of Plant[3]	2,000	kW_e
Steam Turbine Auxiliaries	400	kW_e
Circulating Water Pumps	7,990	kW_e
Cooling Tower Fans	4,670	kW_e
Transformer Losses	2,880	kW_e
Total	216,090	kW_e
Plant Performance		
Net Auxiliary Load	216,090	kW_e
Net Plant Power	549,810	kW_e
Net Plant Efficiency (HHV)	32.4%	
Net Plant Heat Rate (HHV)	11,120 (10,540)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	225,320 (496,745)	kg/hr (lb/hr)
Thermal Input[1]	1,698,356	kW_{th}
Condenser Duty	2,648 (2,510)	GJ/hr (MMBtu/hr)
Raw Water Usage	29.6 (7,822)	m^3/min (gpm)

1 - HHV of As Received Illinois No. 6 coal is 27,135 kJ/kg (11,666 Btu/lb)
2 - Boiler feed pumps are turbine driven
3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 3-22 Case 3 Capital Costs

Department: NETL Office of Program Planning and Analysis
Project: Advancing Oxycombustion Technology
Case: Case 3 - Advanced Materials for USC Conditions
Plant Size: 549.81 MW, net | Capital Charge Factor 0.158 | Capacity Factor 0.85
Cost Base: June 2007
Prepared: 13-Apr-12
x $1, 000

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & %	Eng'g CM H.O. & Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL HANDLING SYSTEM													
1.1	Coal Receive & Unload	3,712	0	1,695	0	5,407	8.9%	483	0%	0	15.0%	884	6,774	12
1.2	Coal Stackout & Reclaim	4,797	0	1,087	0	5,884	8.8%	515	0%	0	15.0%	960	7,359	13
1.3	Coal Conveyors & Yd Crus	4,460	0	1,075	0	5,536	8.8%	485	0%	0	15.0%	903	6,924	13
1.4	Other Coal Handling	1,167	0	249	0	1,416	8.7%	124	0%	0	15.0%	231	1,770	3
1.5	Sorbent Receive & Unload	152	0	46	0	198	8.8%	18	0%	0	15.0%	32	248	0
1.6	Sorbent Stackout & Reclaim	2,463	0	451	0	2,914	8.7%	254	0%	0	15.0%	475	3,644	7
1.7	Sorbent Conveyors	879	190	216	0	1,284	8.7%	111	0%	0	15.0%	209	1,605	3
1.8	Other Sorbent Handling	531	124	278	0	934	8.8%	83	0%	0	15.0%	152	1,169	2
1.9	Coal & Sorbent Hnd.Foundations	0	4,563	5,757	0	10,320	9.3%	965	0%	0	15.0%	1,693	12,977	24
	SUBTOTAL 1.	**$18,161**	**$4,878**	**$10,855**	**$0**	**$33,894**		**$3,037**		**$0**		**$5,540**	**$42,470**	**$77**
2	COAL PREP & FEED SYSTEMS													
2.1	Coal Crushing & Drying	2,139	0	417	0	2,556	8.7%	223	0%	0	15.0%	417	3,196	6
2.2	Prepared Coal Storage & Feed	5,478	0	1,196	0	6,673	8.7%	584	0%	0	15.0%	1,089	8,346	15
2.3	Slurry Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.4	Misc. Coal Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.5	Sorbent Prep Equipment	4,191	181	871	0	5,243	8.7%	457	0%	0	15.0%	855	6,554	12
2.6	Sorbent Storage & Feed	505	0	193	0	698	8.9%	62	0%	0	15.0%	114	874	2
2.7	Sorbent Injection System	0	0	0	0	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	0.0%	0	0	0
2.9	Coal & Sorbent Feed Foundation	0	538	451	0	989	9.2%	91	0%	0	15.0%	162	1,242	2
	SUBTOTAL 2.	**$12,313**	**$718**	**$3,128**	**$0**	**$16,160**		**$1,416**		**$0**		**$2,636**	**$20,212**	**$37**
3	FEEDWATER & MISC. BOP SYSTEMS													
3.1	Feedwater System	19,989	0	6,457	0	26,446	8.8%	2,316	0%	0	15.0%	4,314	33,076	60
3.2	Water Makeup & Pretreating	5,115	0	1,647	0	6,762	9.4%	634	0%	0	20.0%	1,479	8,875	16
3.3	Other Feedwater Subsystems	6,120	0	2,586	0	8,706	8.9%	776	0%	0	15.0%	1,422	10,904	20
3.4	Service Water Systems	1,003	0	546	0	1,548	9.3%	144	0%	0	20.0%	338	2,031	4
3.5	Other Boiler Plant Systems	7,498	0	7,402	0	14,900	9.4%	1,398	0%	0	15.0%	2,445	18,742	34
3.6	FO Supply Sys & Nat Gas	265	0	331	0	596	9.3%	55	0%	0	15.0%	98	749	1
3.7	Waste Treatment Equipment	2,815	0	1,605	0	4,420	9.7%	428	0%	0	20.0%	970	5,818	11
3.8	Misc. Power Plant Equipment	2,810	0	859	0	3,669	9.6%	352	0%	0	20.0%	804	4,825	9
	SUBTOTAL 3.	**$45,615**	**$0**	**$21,432**	**$0**	**$67,047**		**$6,103**		**$0**		**$11,870**	**$85,020**	**$155**
4	PC BOILER & ACCESSORIES													
4.1	USC PC Boiler	209,417	0	105,169	0	314,586	9.7%	30,471	10%	31,459	10.0%	37,652	414,167	753
4.2	ASU/Oxidant Compression	108,915	0	89,112	0	198,027	9.7%	19,181	0%	0	10.0%	21,721	238,929	435
4.3	Open	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.4	Boiler BoP (w/ID Fans)	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.5	Primary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.6	Secondary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.7	Major Component Rigging	0	w/4.1	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.8	PC Foundations	0	w/14.1	w/14.1	0	0	0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 4.	**$318,332**	**$0**	**$194,281**	**$0**	**$512,613**		**$49,652**		**$31,459**		**$59,372**	**$653,096**	**$1,188**

Exhibit 3-22 Case 3 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
5A	FLUE GAS CLEANUP							*						
5.1	Absorber Vessels & Accessories	55,913	0	12,037	0	67,950	9.5%	6,431	0%	0	10.0%	7,438	81,819	149
5.2	Other FGD	2,920	0	3,309	0	6,229	9.6%	600	0%	0	10.0%	683	7,512	14
5.3	Bag House & Accessories	13,899	0	8,821	0	22,720	9.6%	2,173	0%	0	10.0%	2,489	27,383	50
5.4	Other Particulate Removal Materials	918	0	982	0	1,900	9.6%	183	0%	0	10.0%	208	2,292	4
5.5	Gypsum Dewatering System	5,123	0	870	0	5,993	9.4%	566	0%	0	10.0%	656	7,215	13
5.6	Mercury Removal System	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.7	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.8	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.9	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 5A.	**$78,773**	**$0**	**$26,019**	**$0**	**$104,793**		**$9,954**		**$0**		**$11,475**	**$126,221**	**$230**
5B	CO2 REMOVAL & COMPRESSION													
5B.1	CO2 Condensing Heat Exchanger	5,448	0	455	0	5,903	10%	590	0%	0	15.0%	974	7,467	14
5B.2	CO2 Compression & Drying	40,376	0	33,035	0	73,411	10%	7,341	0%	0	20.0%	16,150	96,902	176
5B.3	CO2 Pipeline											0	0	0
5B.4	CO2 Storage											0	0	0
5B.5	CO2 Monitoring											0	0	0
	SUBTOTAL 5B.	**$45,824**	**$0**	**$33,490**	**$0**	**$79,313**		**$7,931**		**$0**		**$17,124**	**$104,369**	**$190**
6	NITROGEN EXPANDER/GENERATOR													
6.1	Nitrogen Expander/Generator	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.2	Nitrogen Expander/Generator Accessories	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.3	Compressed Air Piping	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.4	Nitrogen Expander/Generator Foundations	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 6.	**$0**	**$0**	**$0**	**$0**	**$0**		**$0**		**$0**		**$0**	**$0**	**$0**
7	HRSG, DUCTING & STACK													
7.1	Flue Gas Recycle Heat Exchanger	1,289	0	108	0	1,397	10%	140	0%	0	15.0%	231	1,767	3
7.2	SCR System	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
7.3	Ductwork	8,991	0	5,777	0	14,768	8.7%	1,290	0%	0	15.0%	2,409	18,467	34
7.4	Stack	1,517	0	887	0	2,404	9.6%	230	0%	0	10.0%	263	2,897	5
7.9	HRSG, Duct & Stack Foundations	0	849	965	0	1,814	9.3%	169	0%	0	20.0%	397	2,380	4
	SUBTOTAL 7.	**$11,797**	**$849**	**$7,737**	**$0**	**$20,383**		**$1,828**		**$0**		**$3,299**	**$25,511**	**$46**
8	STEAM TURBINE GENERATOR													
8.1	Steam TG & Accessories	61,131	0	8,112	0	69,244	9.6%	6,630	15%	10,387	10.0%	8,626	94,886	173
8.2	Turbine Plant Auxiliaries	412	0	882	0	1,294	9.7%	126	0%	0	10.0%	142	1,561	3
8.3	Condenser & Auxiliaries	6,480	0	2,388	0	8,868	9.5%	843	0%	0	10.0%	971	10,682	19
8.4	Steam Piping	18,737	0	9,238	0	27,975	8.3%	2,335	0%	0	15.0%	4,546	34,856	63
8.9	TG Foundations	0	1,289	2,036	0	3,326	9.4%	313	0%	0	20.0%	728	4,366	8
	SUBTOTAL 8.	**$86,759**	**$1,289**	**$22,658**	**$0**	**$110,706**		**$10,246**		**$10,387**		**$15,013**	**$146,352**	**$266**
9	COOLING WATER SYSTEM													
9.1	Cooling Towers	11,882	0	3,700	0	15,582	9.5%	1,479	0%	0	10.0%	1,706	18,767	34
9.2	Circulating Water Pumps	2,059	0	158	0	2,218	8.6%	190	0%	0	10.0%	241	2,648	5
9.3	Circ. Water System Auxiliaries	562	0	75	0	637	9.4%	60	0%	0	10.0%	70	766	1
9.4	Circ. Water Piping	0	4,454	4,316	0	8,770	9.2%	808	0%	0	15.0%	1,437	11,015	20
9.5	Make-up Water System	492	0	657	0	1,150	9.5%	109	0%	0	15.0%	189	1,447	3
9.6	Component Cooling Water System	445	0	354	0	799	9.4%	75	0%	0	15.0%	131	1,005	2
9.9	Circ. Water System Foundations	0	2,708	4,303	0	7,011	9.4%	660	0%	0	20.0%	1,534	9,204	17
	SUBTOTAL 9.	**$15,440**	**$7,162**	**$13,564**	**$0**	**$36,165**		**$3,381**		**$0**		**$5,307**	**$44,853**	**$82**

Exhibit 3-22 Case 3 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & %	Eng'g CM H.O. & Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
10	ASH/SPENT SORBENT HANDLING SYS													
10.1	Ash Coolers	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.2	Cyclone Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.3	HGCU Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.4	High Temperature Ash Piping	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.5	Other Ash Recovery Equipment	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.6	Ash Storage Silos	642	0	1,979	0	2,622	9.7%	255	0%	0	10.0%	288	3,165	6
10.7	Ash Transport & Feed Equipment	4,159	0	4,260	0	8,418	9.5%	796	0%	0	10.0%	921	10,136	18
10.8	Misc. Ash Handling Equipment	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
10.9	Ash/Spent Sorbent Foundation	0	153	180	0	332	9.3%	31	0%	0	20.0%	73	436	1
	SUBTOTAL 10.	**$4,801**	**$153**	**$6,419**	**$0**	**$11,373**		**$1,082**		**$0**		**$1,282**	**$13,737**	**$25**
11	ACCESSORY ELECTRIC PLANT													
11.1	Generator Equipment	1,830	0	297	0	2,127	9.3%	197	0%	0	7.5%	174	2,498	5
11.2	Station Service Equipment	6,452	0	2,120	0	8,572	9.6%	820	0%	0	7.5%	704	10,096	18
11.3	Switchgear & Motor Control	7,418	0	1,261	0	8,679	9.3%	803	0%	0	10.0%	948	10,430	19
11.4	Conduit & Cable Tray	0	4,651	16,081	0	20,731	9.6%	1,984	0%	0	15.0%	3,407	26,123	48
11.5	Wire & Cable	0	8,776	16,941	0	25,716	8.4%	2,167	0%	0	15.0%	4,182	32,065	58
11.6	Protective Equipment	261	0	888	0	1,149	9.8%	112	0%	0	10.0%	126	1,388	3
11.7	Standby Equipment	1,426	0	33	0	1,458	9.5%	138	0%	0	10.0%	160	1,756	3
11.8	Main Power Transformers	8,208	0	138	0	8,346	7.6%	634	0%	0	10.0%	898	9,879	18
11.9	Electrical Foundations	0	367	899	0	1,266	9.5%	120	0%	0	20.0%	277	1,664	3
	SUBTOTAL 11.	**$25,595**	**$13,793**	**$38,658**	**$0**	**$78,046**		**$6,976**		**$0**		**$10,878**	**$95,900**	**$174**
12	INSTRUMENTATION & CONTROL													
12.1	PC Control Equipment	w/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.2	Combustion Turbine Control	N/A	0	N/A	0	0	0%	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%	0	0	0
12.4	Other Major Component Control	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
12.5	Signal Processing Equipment	W/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.6	Control Boards, Panels & Racks	558	0	334	0	892	9.6%	86	0%	0	15.0%	147	1,124	2
12.7	Computer Accessories	5,629	0	984	0	6,613	9.5%	630	0%	0	10.0%	724	7,967	14
12.8	Instrument Wiring & Tubing	3,052	0	6,054	0	9,107	8.5%	776	0%	0	15.0%	1,482	11,365	21
12.9	Other I & C Equipment	1,591	0	3,610	0	5,200	9.7%	506	0%	0	10.0%	571	6,277	11
	SUBTOTAL 12.	**$10,830**	**$0**	**$10,982**	**$0**	**$21,812**		**$1,998**		**$0**		**$2,924**	**$26,733**	**$49**
13	IMPROVEMENTS TO SITE													
13.1	Site Preparation	0	55	1,101	0	1,156	9.9%	114	0%	0	20.0%	254	1,524	3
13.2	Site Improvements	0	1,827	2,269	0	4,097	9.8%	402	0%	0	20.0%	900	5,399	10
13.3	Site Facilities	3,275	0	3,229	0	6,504	9.8%	638	0%	0	20.0%	1,428	8,571	16
	SUBTOTAL 13.	**$3,275**	**$1,882**	**$6,600**	**$0**	**$11,757**		**$1,155**		**$0**		**$2,582**	**$15,493**	**$28**
14	BUILDINGS & STRUCTURES													
14.1	Boiler Building	0	8,820	7,757	0	16,577	9.0%	1,489	0%	0	15.0%	2,710	20,775	38
14.2	Turbine Building	0	12,737	11,871	0	24,609	9.0%	2,216	0%	0	15.0%	4,024	30,848	56
14.3	Administration Building	0	639	675	0	1,314	9.1%	119	0%	0	15.0%	215	1,648	3
14.4	Circulation Water Pumphouse	0	129	102	0	231	8.9%	21	0%	0	15.0%	38	289	1
14.5	Water Treatment Buildings	0	663	605	0	1,268	9.0%	114	0%	0	15.0%	207	1,589	3
14.6	Machine Shop	0	427	287	0	714	8.9%	63	0%	0	15.0%	117	894	2
14.7	Warehouse	0	290	290	0	580	9.0%	52	0%	0	15.0%	95	727	1
14.8	Other Buildings & Structures	0	237	201	0	438	9.0%	39	0%	0	15.0%	72	549	1
14.9	Waste Treating Building & Str.	0	442	1,342	0	1,784	9.4%	169	0%	0	15.0%	293	2,246	4
	SUBTOTAL 14.	**$0**	**$24,384**	**$23,131**	**$0**	**$47,515**		**$4,281**		**$0**		**$7,769**	**$59,566**	**$108**
	Total Cost	**$677,516**	**$55,108**	**$418,952**	**$0**	**$1,151,577**		**$109,039**		**$41,845**		**$157,073**	**$1,459,534**	**$2,655**

Exhibit 3-23 Case 3 Owner's Costs

Owner's Costs	$1,000	$/kW
Preproduction Costs		
6 Months All Labor	$9,579	$17
1 Month Maintenance Materials	$1,442	$3
1 Month Non-fuel Consumables	$724	$1
1 Month Waste Disposal	$285	$1
25% of 1 Months Fuel Cost at 100% CF	$1,731	$3
2% of TPC	$29,191	$53
Total	**$42,952**	**$78**
Inventory Capital		
60 day supply of fuel and consumables at 100% CF	$14,924	$27
0.5% of TPC (spare parts)	$7,298	$13
Total	**$22,221**	**$40**
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$218,930	$398
Financing Costs	$39,407	$72
Total Overnight Costs (TOC)	**$1,783,944**	**$3,245**
TASC Multiplier	1.134	
Total As-Spent Cost (TASC)	**$2,022,993**	**$3,679**

Exhibit 3-24 Case 3 O&M Costs

INITIAL & ANNUAL O&M EXPENSES						
Case:	Case 3 - Advanced Materials for USC Conditions					
Plant Size (MWe):	549.81			**Heat Rate (Btu/kWh):**		10,540
Primary/Secondary Fuel:	Illinois #6 Bituminous Coal			**Fuel Cost ($/MM Btu):**		1.64
Design/Construction	5 years			**Book Life (yrs):**		30
TPC (Plant Cost) Year:	June 2007			**TPI Year:**		2012
Capacity Factor (%):	85			**CO2** Captured (TPD):		14,129
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate (base):		$34.65	$/hour			
Operating Labor Burden:		30.00	% of base			
Labor Overhead Charge:		25.00	% of labor			
Operating Labor Requirements per Shift:		**units/mod.**		**Total Plant**		
Skilled Operator		2.0		2.0		
Operator		9.0		9.0		
Foreman		1.0		1.0		
Lab Tech's etc.		2.0		2.0		
TOTAL Operating Jobs		14.0		14.0		
					$	**$/kW-net**
Annual Operating Labor Cost (calc'd)					5,524,319	10.05
Maintenance Labor Cost (calc'd)					9,802,680	17.83
Administrative & Support Labor (calc'd)					3,831,750	6.97
Property Taxes and Insurance					29,190,671	53.09
TOTAL FIXED OPERATING COSTS					**48,349,420**	**87.94**
VARIABLE OPERATING COSTS						
					$	**$/kWh-net**
Maintenance Material Costs (calc'd)					**$14,704,135**	**0.00359**
Consumables	**Consumption**		**Unit**	**Initial**		
	Initial	**/Day**	**Cost**	**Cost**	**$**	**$/kWh-net**
Water (/1000 gallons)	0	5,632	1.08	$0	$1,889,988	0.00046
Chemicals						
MU & WT Chem. (lb)	0	27,262	0.17	$0	$1,463,801	0.00036
Limestone (ton)	0	600	21.63	$0	$4,029,978	0.00098
Carbon (Hg Removal) (lb)	0	0	1.05	$0	$0	0.00000
MEA Solvent (ton)	0	0	2249.89	$0	$0	0.00000
Caustic Soda, NaOH (ton)	0	0	433.68	$0	$0	0.00000
Sulfuric acid, H_2SO_4 (ton)	0	0	138.78	$0	$0	0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	0.00000
Activated C, MEA (lb)	0	0	1.05	$0	$0	0.00000
Ammonia, 19% soln (ton)	0	0	129.80	$0	$0	0.00000
Subtotal Chemicals				**$0**	**$5,493,779**	**0.00134**
Other						
Supplemental Fuel (MMBtu)	0	0	6.55	$0	$0	0.00000
SCR Catalyst Replacement	w/equip.	0.0	5775.94	$0	$0	0.00000
Emission Penalties	0	0	0.00	$0	$0	0.00000
Subtotal Other				**$0**	**$0**	**0.00000**
Waste Disposal						
Spent Mercury Catalyst (lb)	0	0	0.42	$0	$0	0.00000
Flyash (ton)	0	462	16.23	$0	$2,327,752	0.00057
Bottom Ash (ton)	0	116	16.23	$0	$581,953	0.00014
Subtotal Solid Waste Disposal				**$0**	**$2,909,705**	**0.00071**
By-products & Emissions						
Gypsum (tons)	0	0	0.00	$0	$0	0.00000
Sulfur (tons)	0	0	0.00	$0	$0	0.00000
Subtotal By-Products				**$0**	**$0**	**0.00000**
TOTAL VARIABLE OPERATING COSTS					**$24,997,607**	**0.00611**
Coal FUEL (tons)	**0**	**5,961**	**38.18**	**$0**	**$70,617,713**	**0.01725**
NATURAL GAS FUEL (Mscf)	**0**	**0**	**6.76**	**$0**	**$0**	**0.00000**

Exhibit 3-25 Equipment List for Current Technology Case and Case 3

ACCOUNT 1 FUEL AND SORBENT HANDLING

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
1	Bottom Trestle Dumper and Receiving Hoppers	N/A	181 tonne (200 ton)	181 tonne (200 ton)	2 (0)
2	Feeder	Belt	572 tonne/hr (630 tph)	572 tonne/hr (630 tph)	2 (0)
3	Conveyor No. 1	Belt	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1 (0)
4	Transfer Tower No. 1	Enclosed	N/A	N/A	1 (0)
5	Conveyor No. 2	Belt	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1 (0)
6	As-Received Coal Sampling System	Two-stage	N/A	N/A	1 (0)
7	Stacker/Reclaimer	Traveling, linear	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1 (0)
8	Reclaim Hopper	N/A	54 tonne (60 ton)	45 tonne (50 ton)	2 (1)
9	Feeder	Vibratory	209 tonne/hr (230 tph)	181 tonne/hr (200 tph)	2 (1)
10	Conveyor No. 3	Belt w/ tripper	408 tonne/hr (450 tph)	372 tonne/hr (410 tph)	1 (0)
11	Crusher Tower	N/A	N/A	N/A	1 (0)
12	Coal Surge Bin w/ Vent Filter	Dual outlet	209 tonne (230 ton)	181 tonne (200 ton)	2 (0)
13	Crusher	Impactor reduction	8 cm x 0 - 3 cm x 0 (3 in x 0 - 1-1/4 in x 0)	8 cm x 0 - 3 cm x 0 (3 in x 0 - 1-1/4 in x 0)	2 (0)
14	As-Fired Coal Sampling System	Swing hammer	N/A	N/A	1 (1)

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
15	Conveyor No. 4	Belt w/tripper	408 tonne/hr (450 tph)	372 tonne/hr (410 tph)	1 (0)
16	Transfer Tower No. 2	Enclosed	N/A	N/A	1 (0)
17	Conveyor No. 5	Belt w/ tripper	408 tonne/hr (450 tph)	372 tonne/hr (410 tph)	1 (0)
18	Coal Silo w/ Vent Filter and Slide Gates	Field erected	907 tonne (1,000 ton)	816 tonne (900 ton)	3 (0)
19	Limestone Truck Unloading Hopper	N/A	36 tonne (40 ton)	36 tonne (40 ton)	1 (0)
20	Limestone Feeder	Belt	109 tonne/hr (120 tph)	100 tonne/hr (110 tph)	1 (0)
21	Limestone Conveyor No. L1	Belt	109 tonne/hr (120 tph)	100 tonne/hr (110 tph)	1 (0)
22	Limestone Reclaim Hopper	N/A	18 tonne (20 ton)	18 tonne (20 ton)	1 (0)
23	Limestone Reclaim Feeder	Belt	82 tonne/hr (90 tph)	73 tonne/hr (80 tph)	1 (0)
24	Limestone Conveyor No. L2	Belt	82 tonne/hr (90 tph)	73 tonne/hr (80 tph)	1 (0)
25	Limestone Day Bin	w/ actuator	336 tonne (370 ton)	299 tonne (330 ton)	2 (0)

ACCOUNT 2 COAL AND SORBENT PREPARATION AND FEED

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
1	Coal Feeder	Gravimetric	45 tonne/hr (50 tph)	45 tonne/hr (50 tph)	6 (0)
2	Coal Pulverizer	Ball type or equivalent	45 tonne/hr (50 tph)	45 tonne/hr (50 tph)	6 (0)
3	Limestone Weigh Feeder	Gravimetric	28 tonne/hr (31 tph)	25 tonne/hr (28 tph)	1 (1)

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
4	Limestone Ball Mill	Rotary	28 tonne/hr (31 tph)	25 tonne/hr (28 tph)	1 (1)
5	Limestone Mill Slurry Tank with Agitator	N/A	105,992 liters (28,000 gal)	98,421 liters (26,000 gal)	1 (1)
6	Limestone Mill Recycle Pumps	Horizontal centrifugal	1,779 lpm @ 12m H_2O (470 gpm @ 40 ft H_2O)	1,628 lpm @ 12m H_2O (430 gpm @ 40 ft H_2O)	1 (1)
7	Hydroclone Classifier	4 active cyclones in a 5 cyclone bank	454 lpm (120 gpm) per cyclone	416 lpm (110 gpm) per cyclone	1 (1)
8	Distribution Box	2-way	N/A	N/A	1 (1)
9	Limestone Slurry Storage Tank with Agitator	Field erected	598,095 liters (158,000 gal)	541,314 liters (143,000 gal)	1 (1)
10	Limestone Slurry Feed Pumps	Horizontal centrifugal	1,249 lpm @ 9m H_2O (330 gpm @ 30 ft H_2O)	1,136 lpm @ 9m H_2O (300 gpm @ 30 ft H_2O)	1 (1)

ACCOUNT 3 FEEDWATER AND MISCELLANEOUS SYSTEMS AND EQUIPMENT

Equipment No.	Description	Type	Current Technology Case Design Condition	Operating Qty. (Spares)	Case 3 Design Condition	Operating Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	1,464,954 liters (387,000 gal)	2 (0)	916,070 liters (242,000 gal)	2 (0)
2	Condensate Pumps	Vertical canned	31,040 lpm @ 213 m H_2O (8,200 gpm @ 700 ft H_2O)	1 (1)	22,334 lpm @ 91 m H_2O (5,900 gpm @ 300 ft H_2O)	1 (1)
3	Deaerators and Storage Tank	Horizontal spray type	2,438,059 kg/hr (5,375,000 lb/hr), 5 min. tank	2 (0)	3,675,005 kg/hr (8,102,000 lb/hr), 5 min. tank	1 (0)

Equipment No.	Description	Type	Current Technology Case Design Condition	Operating Qty. (Spares)	Case 3 Design Condition	Operating Qty. (Spares)
4	Boiler Feed Pump/Turbine	Barrel type, multi-stage, centrifugal	40,882 lpm @ 3,444 m H_2O (10,800 gpm @ 11,300 ft H_2O)	1 (1)	25,362 lpm @ 122 m H_2O (6,700 gpm @ 400 ft H_2O)	1 (1)
5	Startup Boiler Feed Pump, Electric Motor Driven	Barrel type, multi-stage, centrifugal	12,113 lpm @ 3,444 m H_2O (3,200 gpm @ 11,300 ft H_2O)	1 (0)	7,571 lpm @ 122 m H_2O (2,000 gpm @ 400 ft H_2O)	1 (0)
6	LP Feedwater Heater 1A/1B	Horizontal U-tube	920,793 kg/hr (2,030,000 lb/hr)	2 (0)	662,245 kg/hr (1,460,000 lb/hr)	2 (0)
7	LP Feedwater Heater 2A/2B	Horizontal U-tube	920,793 kg/hr (2,030,000 lb/hr)	2 (0)	662,245 kg/hr (1,460,000 lb/hr)	2 (0)
8	LP Feedwater Heater 3A/3B	Horizontal U-tube	920,793 kg/hr (2,030,000 lb/hr)	2 (0)	662,245 kg/hr (1,460,000 lb/hr)	2 (0)
9	LP Feedwater Heater 4A/4B	Horizontal U-tube	920,793 kg/hr (2,030,000 lb/hr)	2 (0)	662,245 kg/hr (1,460,000 lb/hr)	2 (0)
10	HP Feedwater Heater 6	Horizontal U-tube	2,435,791 kg/hr (5,370,000 lb/hr)	1 (0)	1,524,070 kg/hr (3,360,000 lb/hr)	1 (0)
11	HP Feedwater Heater 7	Horizontal U-tube	2,435,791 kg/hr (5,370,000 lb/hr)	1 (0)	1,524,070 kg/hr (3,360,000 lb/hr)	1 (0)
12	HP Feedwater heater 8	Horizontal U-tube	2,435,791 kg/hr (5,370,000 lb/hr)	1 (0)	1,524,070 kg/hr (3,360,000 lb/hr)	1 (0)
13	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)	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	1 (0)
14	Fuel Oil System	No. 2 fuel oil for light off	1,135,624 liter (300,000 gal)	1 (0)	1,135,624 liter (300,000 gal)	1 (0)
15	Service Air Compressors	Flooded Screw	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	2 (1)	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	2 (1)

Equipment No.	Description	Type	Current Technology Case Design Condition	Operating Qty. (Spares)	Case 3 Design Condition	Operating Qty. (Spares)
16	Instrument Air Dryers	Duplex, regenerative	28 m^3/min (1,000 scfm)	2 (1)	28 m^3/min (1,000 scfm)	2 (1)
17	Closed Cycle Cooling Heat Exchangers	Shell and tube	53 GJ/hr (50 MMBtu/hr) each	2 (0)	53 GJ/hr (50 MMBtu/hr) each	2 (0)
18	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	20,820 lpm @ 30 m H_2O (5,500 gpm @ 100 ft H_2O)	2 (1)	20,820 lpm @ 30 m H_2O (5,500 gpm @ 100 ft H_2O)	2 (1)
19	Engine-Driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 88 m H_2O (1,000 gpm @ 290 ft H_2O)	1 (1)	3,785 lpm @ 88 m H_2O (1,000 gpm @ 290 ft H_2O)	1 (1)
20	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 64 m H_2O (700 gpm @ 210 ft H_2O)	1 (1)	2,650 lpm @ 64 m H_2O (700 gpm @ 210 ft H_2O)	1 (1)
21	Raw Water Pumps	Stainless steel, single suction	20,176 lpm @ 43 m H_2O (5,330 gpm @ 140 ft H_2O)	2 (1)	17,526 lpm @ 43 m H_2O (4,630 gpm @ 140 ft H_2O)	2 (1)
22	Filtered Water Pumps	Stainless steel, single suction	757 lpm @ 49 m H_2O (200 gpm @ 160 ft H_2O)	2 (1)	530 lpm @ 49 m H_2O (140 gpm @ 160 ft H_2O)	2 (1)
23	Filtered Water Tank	Vertical, cylindrical	719,228 liter (190,000 gal)	1 (0)	518,601 liter (137,000 gal)	1 (0)
24	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly, electrodeionization unit	984 lpm (260 gpm)	1 (1)	644 lpm (170 gpm)	1 (1)
25	Liquid Waste Treatment System	--	10 years, 24-hour storm	1 (0)	10 years, 24-hour storm	1 (0)

ACCOUNT 4 BOILER AND ACCESSORIES

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
1	Boiler	Supercritical, drum, wall-fired, low NOx burners, overfire air	2,440,327 kg/hr steam @ 25.5 MPa/607°C/629°C (5,380,000 lb/hr steam @ 3,700 psig/1,125°F/1,165°F)	2,154,564 kg/hr steam @ 29.0 MPa/741°C/768°C (4,750,000 lb/hr steam @ 4,200 psig/1,365°F/1,415°F)	1 (0)
2	Primary Air Fan	Centrifugal	206,385 kg/hr, 2,475 m^3/min @ 47 cm WG (455,000 lb/hr, 87,400 acfm @ 19 in. WG)	185,519 kg/hr, 2,229 m^3/min @ 47 cm WG (409,000 lb/hr, 78,700 acfm @ 19 in. WG)	2 (0)
3	Forced Draft Fan	Centrifugal	671,317 kg/hr, 8,062 m^3/min @ 123 cm WG (1,480,000 lb/hr, 284,700 acfm @ 48 in. WG)	604,185 kg/hr, 7,255 m^3/min @ 123 cm WG (1,332,000 lb/hr, 256,200 acfm @ 48 in. WG)	2 (0)
4	Induced Draft Fan	Centrifugal	1,319,047 kg/hr, 22,628 m^3/min @ 95 cm WG (2,908,000 lb/hr, 799,100 acfm @ 37 in. WG)	1,187,958 kg/hr, 20,388 m^3/min @ 95 cm WG (2,619,000 lb/hr, 720,000 acfm @ 37 in. WG)	2 (0)
5	ASU Main Air Compressor	Centrifugal, multi-stage	17,075 m^3/min @ 0.6 MPa (603,000 scfm @ 086 psia)	15,404 m^3/min @ 0.6 MPa (544,000 scfm @ 086 psia)	2 (0)
6	Cold Box	Vendor design	7,167 tonne/day (7,900 tpd) of 95% purity oxygen	6,441 tonne/day (7,100 tpd) of 95% purity oxygen	2 (0)

ACCOUNT 5 FLUE GAS CLEANUP

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
1	Fabric Filter	Single stage, high-ratio with pulse-jet online cleaning system	1,319,047 kg/hr (2,908,000 lb/hr) 99.8% efficiency	1,187,958 kg/hr (2,619,000 lb/hr) 99.8% efficiency	2 (0)
2	Absorber Module	Counter-current open spray	44,627 m^3/min (1,576,000 acfm)	40,210 m^3/min (1,420,000 acfm)	1 (0)
3	Recirculation Pumps	Horizontal centrifugal	155,202 lpm @ 64 m H_2O (41,000 gpm @ 210 ft H_2O)	140,060 lpm @ 64 m H_2O (37,000 gpm @ 210 ft H_2O)	5 (1)
4	Bleed Pumps	Horizontal centrifugal	5,451 lpm (1,440 gpm) at 20 wt% solids	4,921 lpm (1,300 gpm) at 20 wt% solids	2 (1)
5	Oxidation Air Blowers	Centrifugal	21 m^3/min @ 0.3 MPa (750 acfm @ 42 psia)	19 m^3/min @ 0.3 MPa (680 acfm @ 42 psia)	2 (1)
6	Agitators	Side entering	50 hp	50 hp	5 (1)
7	Dewatering Cyclones	Radial assembly, 5 units each	1,363 lpm (360 gpm) per cyclone	1,249 lpm (330 gpm) per cyclone	2 (0)
8	Vacuum Filter Belt	Horizontal belt	44 tonne/hr (48 tph) of 50 wt % slurry	39 tonne/hr (43 tph) of 50 wt % slurry	2 (1)
9	Filtrate Water Return Pumps	Horizontal centrifugal	833 lpm @ 12 m H_2O (220 gpm @ 40 ft H_2O)	757 lpm @ 12 m H_2O (200 gpm @ 40 ft H_2O)	1 (1)

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
10	Filtrate Water Return Storage Tank	Vertical, lined	529,958 lpm (140,000 gal)	492,104 lpm (130,000 gal)	1 (0)
11	Process Makeup Water Pumps	Horizontal centrifugal	530 lpm @ 21 m H_2O (140 gpm @ 70 ft H_2O)	454 lpm @ 21 m H_2O (120 gpm @ 70 ft H_2O)	1 (1)

ACCOUNT 5B CARBON DIOXIDE RECOVERY

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
1	CO_2 Compressor	Centrifugal	325,792 kg/h @ 15.3 MPa (718,248 lb/h @ 2,215 psia)	293,737 kg/h @ 15.3 MPa (647,579 lb/h @ 2,215 psia)	2 (0)

ACCOUNT 7 HRSG, DUCTING & STACK

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
1	Stack	Reinforced concrete with FRP liner	46 m (150 ft) high x 3.6 m (12 ft) diameter	46 m (150 ft) high x 3.4 m (11 ft) diameter	1 (0)

ACCOUNT 8 STEAM TURBINE GENERATOR AND AUXILIARIES

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Conditions	Operating Qty. (Spares)
1	Steam Turbine	Commercially available advanced steam turbine	832 MW 24.1 MPa/599°C/621°C (3500 psig/ 1110°F/1150°F)	806 MW 27.6 MPa/732°C/760°C (4000 psig/ 1350°F/1400°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	920 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	900 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)
3	Surface Condenser	Single pass, divided waterbox including vacuum pumps	3,387 GJ/hr (3,210 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	2,912 GJ/hr (2,760 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	919,900 lpm @ 30 m (243,000 gpm @ 100 ft)	802,500 lpm @ 30 m (212,000 gpm @ 100 ft)	2 (1)
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT / 5,128 GJ/hr (4,860 MMBtu/hr) heat duty	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT / 4,473 GJ/hr (4,240 MMBtu/hr) heat duty	1 (0)

ACCOUNT 10 ASH/SPENT SORBENT RECOVERY AND HANDLING

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
1	Economizer Hopper (part of boiler scope of supply)	--	--	--	4 (0)
2	Bottom Ash Hopper (part of boiler scope of supply)	--	--	--	2 (0)
3	Clinker Grinder	--	5.4 tonne/hr (6 tph)	4.5 tonne/hr (5 tph)	1 (1)
4	Pyrites Hopper (part of pulverizer scope of supply included with boiler)	--	--	--	6 (0)
5	Hydroejectors	--	--	--	12 (1)
6	Economizer /Pyrites Transfer Tank	--	--	--	1 (0)
7	Ash Sluice Pumps	Vertical, wet pit	227 lpm @ 17 m H_2O (60 gpm @ 56 ft H_2O)	189 lpm @ 17 m H_2O (50 gpm @ 56 ft H_2O)	1 (1)
8	Ash Seal Water Pumps	Vertical, wet pit	7,571 lpm @ 9 m H_2O (2000 gpm @ 28 ft H_2O)	7,571 lpm @ 9 m H_2O (2000 gpm @ 28 ft H_2O)	1 (1)
9	Hydrobins	--	227 lpm (60 gpm)	189 lpm (50 gpm)	1 (1)
10	Baghouse Hopper (part of baghouse scope of supply)	--	--	--	24 (0)

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
11	Air Heater Hopper (part of boiler scope of supply)	--	--	--	10 (0)
12	Air Blower	--	20 m^3/min @ 0.2 MPa (690 scfm @ 24 psi)	18 m^3/min @ 0.2 MPa (620 scfm @ 24 psi)	1 (1)
13	Fly Ash Silo	Reinforced concrete	635 tonne (1,400 ton)	590 tonne (1,300 ton)	2 (0)
14	Slide Gate Valves	--	--	--	2 (0)
15	Unloader	--	--	--	1 (0)
16	Telescoping Unloading Chute	--	118 tonne/hr (130 tph)	109 tonne/hr (120 tph)	1 (0)

ACCOUNT 11 ACCESSORY ELECTRIC PLANT

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
1	STG Transformer	Oil-filled	24 kV/345 kV, 650 MVA, 3-ph, 60 Hz	24 kV/345 kV, 650 MVA, 3-ph, 60 Hz	1 (0)
2	Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 264 MVA, 3-ph, 60 Hz	24 kV/4.16 kV, 237 MVA, 3-ph, 60 Hz	1 (1)
3	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 40 MVA, 3-ph, 60 Hz	4.16 kV/480 V, 36 MVA, 3-ph, 60 Hz	1 (1)
4	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	24 kV, 3-ph, 60 Hz	1 (0)
5	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	4.16 kV, 3-ph, 60 Hz	1 (1)

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 Design Condition	Operating Qty. (Spares)
6	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	480 V, 3-ph, 60 Hz	1 (1)
7	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

ACCOUNT 12 INSTRUMENTATION AND CONTROL

Equipment No.	Description	Type	Current Technology Case Design Condition	Case 3 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	Operator stations/printers and engineering stations/printers	1 (0)
2	DCS - Processor	Microprocessor with redundant input/output	N/A	N/A	1 (0)
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	Fully redundant, 25% spare	1 (0)

3.3 CASES 1 - ADVANCED OXYGEN SEPARATION/MEMBRANE TECHNOLOGY

Advanced membrane air separation technology shows promise due to its high temperature and high pressure operation, which allows for a relatively high amount of heat and power recovery. Membrane system integration, performance enhancements, and capital cost reduction should be the main areas of focus based on the results of this study.

Two different system integration approaches are explored in this study. Results are presented below. Refer to Section 2.5.2.1 for more details on this technology.

3.3.1 Case 1 – Advanced Membrane Oxycombustion Process with PC Boiler Integration

This case includes a SC PC oxycombustion plant with a wet FGD unit. This plant employs an advanced membrane to produce nearly 100 vol% purity O_2 for combustion. The high temperatures are generated through integration of the membrane feed stream with the PC boiler system. Optimizing the integration of the advanced membrane oxygen plant with low cost process heat to achieve ionization temperatures is anticipated to increase efficiency and therefore drive down the cost of the oxy-fired power generation. Due to the high temperatures generated in the membrane separation process, the oxidant cooling scheme is integrated with both the high- and low-pressure boiler feed water heating system. This reduces the amount of steam extracted from the steam cycle for boiler feed water heating, which can increase the power output of the steam cycle.

For Case 1, the air stream exiting the main air compressor at 391°C (735°F) is further heated to 802°C (1,475°F) by integrating the membrane feed stream with the boiler system. The pure oxygen product is recovered at 802°C (1,475°F) and 0.17 MPa (25 psia). Approximately 70 percent of the incoming oxygen can be recovered in the process for the given configuration.

To heat the membrane inlet stream to 802°C (1,475°F), approximately 24 percent of the total heat input to the boiler is required. The recovered oxygen and the off-gas stream, composed of vitiated air, are integrated with the boiler feedwater system to recover heat. The vitiated air stream at 1.34 MPa (195 psia) is expanded through a turbine to 0.10 MPa (15 psia) and recovers approximately 345 MW of power.

The oxidant stream supplements the steam superheating system and the high and low pressure feedwater system. The vitiated air stream exits the expansion turbine at 329°C (625°F) and this stream is subsequently cooled in the recuperator that supplements the low and high pressure boiler feedwater systems.

Block Flow Diagram and Stream Table

BFD and stream tables for Case 1 are displayed in Exhibit 3-26 and Exhibit 3-27.

Heat and Mass Balance Diagram

Heat and mass balance diagrams are shown for the following subsystems in Exhibit 3-28 and Exhibit 3-29:

- Boiler and flue gas cleanup
- Steam cycle and feed water (power block)

Energy, Carbon, Sulfur, and Water Balances

An overall plant energy balance is provided in tabular form in Exhibit 3-30. The power out is the steam turbine power after generator losses.

Carbon, sulfur and water balances are shown in Exhibit 3-31 through Exhibit 3-33.

Performance Summary

A performance summary is provided in Exhibit 3-34.

Costing Table

Tables of capital costs, owner's costs, and O&M costs are provided in Exhibit 3-35 through Exhibit 3-37, respectively.

Equipment List

The combined equipment list for Case 1 and Case 1a is shown in Exhibit 3-50.

Exhibit 3-26 Process Block Flow Diagram for Case 1

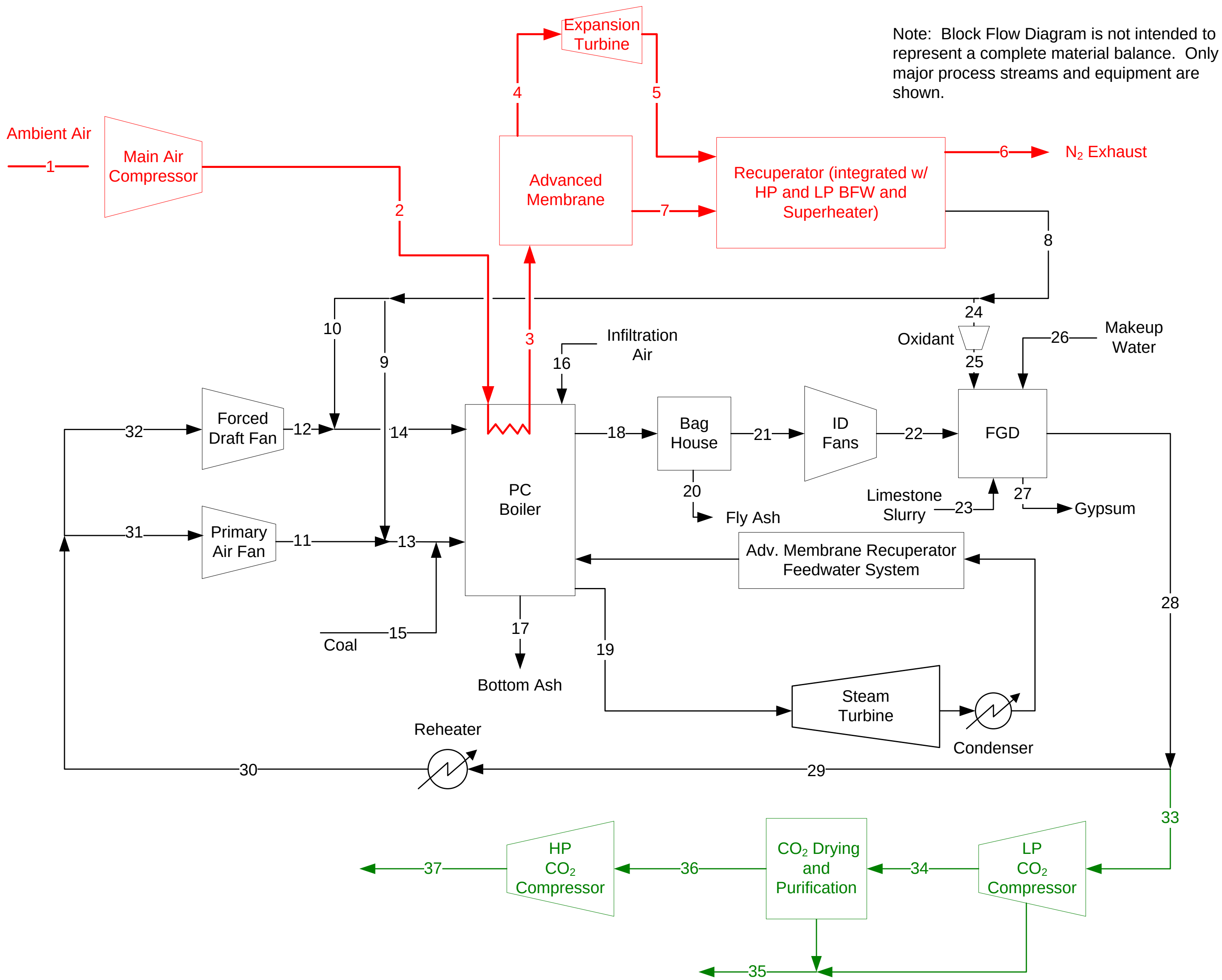


Exhibit 3-27 Stream Table for Case 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
V-L Mole Fraction																			
Ar	0.0092	0.0092	0.0092	0.0107	0.0107	0.0107	0.0000	0.0000	0.0000	0.0000	0.0011	0.0011	0.0008	0.0008	0.0000	0.0092	0.0000	0.0010	0.0000
CO_2	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0000	0.0000	0.0000	0.0000	0.7311	0.7311	0.5315	0.5315	0.0000	0.0005	0.0000	0.6800	0.0000
H_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	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0101	0.0101	0.0101	0.0118	0.0118	0.0118	0.0000	0.0000	0.0000	0.0000	0.1515	0.1515	0.1101	0.1101	0.0000	0.0101	0.0000	0.2092	1.0000
N_2	0.7729	0.7729	0.7729	0.9041	0.9041	0.9041	0.0000	0.0000	0.0000	0.0000	0.0982	0.0982	0.0714	0.0714	0.0000	0.7729	0.0000	0.0918	0.0000
O_2	0.2074	0.2074	0.2074	0.0728	0.0728	0.0728	1.0000	1.0000	1.0000	1.0000	0.0181	0.0181	0.2861	0.2861	0.0000	0.2074	0.0000	0.0149	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0031	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	0.0000	1.0000	0.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	98,131	98,131	98,131	83,884	83,884	83,884	14,247	14,247	3,300	10,744	8,790	28,615	12,091	39,359	0	1,963	0	57,927	90,182
V-L Flowrate (kg/hr)	2,831,675	2,831,674	2,831,674	2,375,775	2,375,775	2,375,775	455,900	455,900	105,610	343,793	336,500	1,095,414	442,109	1,439,207	0	56,633	0	2,142,317	1,624,654
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	226,371	0	4,401	17,602	0
Temperature (°C)	15	391	802	802	330	66	802	66	66	66	75	69	73	68	15	15	15	177	599
Pressure (MPa, abs)	0.10	1.48	1.48	1.34	0.10	0.10	0.17	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	24.23
Enthalpy (kJ/kg)^A	30.57	419.33	880.54	893.11	362.11	85.95	814.14	59.93	59.93	59.93	248.36	242.74	203.35	199.07	---	30.57	---	503.89	3,493.92
Density (kg/m^3)	1.2	7.7	4.8	4.2	0.6	1.0	0.6	1.4	1.4	1.4	1.5	1.4	1.4	1.4	---	1.2	---	1.0	68.5
V-L Molecular Weight	28.856	28.856	28.856	28.322	28.322	28.322	31.999	31.999	31.999	31.999	38.282	38.282	36.567	36.567	---	28.856	---	36.983	18.015
V-L Flowrate (lb_{mol}/hr)	216,342	216,342	216,342	184,932	184,932	184,932	31,410	31,410	7,276	23,686	19,379	63,084	26,655	86,771	0	4,327	0	127,707	198,817
V-L Flowrate (lb/hr)	6,242,774	6,242,773	6,242,773	5,237,686	5,237,686	5,237,686	1,005,086	1,005,086	232,829	757,933	741,855	2,414,974	974,684	3,172,908	0	124,855	0	4,723,001	3,581,749
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	499,062	0	9,701	38,806	0
Temperature (°F)	59	735	1,475	1,475	625	150	1,475	150	150	150	167	157	163	155	59	59	59	350	1,110
Pressure (psia)	14.7	215.0	215.0	195.0	15.2	15.0	25.0	17.5	17.5	17.5	16.2	15.3	16.2	15.3	14.7	14.7	14.7	14.4	3,514.7
Enthalpy (Btu/lb)^A	13.1	180.3	378.6	384.0	155.7	37.0	350.0	25.8	25.8	25.8	106.8	104.4	87.4	85.6	---	13.1	---	216.6	1,502.1
Density (lb/ft^3)	0.076	0.482	0.298	0.265	0.037	0.065	0.039	0.086	0.086	0.086	0.092	0.089	0.089	0.085	---	0.076	---	0.061	4.274

A - Reference conditions are 32.02 F & 0.089 PSIA

Exhibit 3-27 Stream Table for Case 1 (Continued)

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
V-L Mole Fraction																		
Ar	0.0000	0.0010	0.0010	0.0000	0.0000	0.0000	0.0000	0.0003	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0013	0.0000	0.0013	0.0013
CO_2	0.0000	0.6800	0.6800	0.0000	0.0000	0.0000	0.0000	0.9822	0.7311	0.7311	0.7311	0.7311	0.7311	0.7311	0.8598	0.0000	0.8615	0.8615
H_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	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.2092	0.2092	1.0000	0.0000	0.0000	1.0000	0.0024	0.1515	0.1515	0.1515	0.1515	0.1515	0.1515	0.0021	1.0000	0.0001	0.0001
N_2	0.0000	0.0918	0.0918	0.0000	0.0000	0.0000	0.0000	0.0022	0.0982	0.0982	0.0982	0.0982	0.0982	0.0982	0.1155	0.0000	0.1158	0.1158
O_2	0.0000	0.0149	0.0149	0.0000	1.0000	1.0000	0.0000	0.0066	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0212	0.0000	0.0213	0.0213
SO_2	0.0000	0.0031	0.0031	0.0000	0.0000	0.0000	0.0000	0.0063	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
Total	0.0000	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	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	57,927	57,927	2,992	203	203	1,341	0	54,120	37,405	37,405	8,790	28,615	16,715	14,214	2,532	14,186	14,186
V-L Flowrate (kg/hr)	0	2,142,317	2,142,317	53,897	6,497	6,497	24,152	13	2,071,804	1,431,915	1,431,914	336,500	1,095,414	639,889	594,820	45,610	594,318	594,318
Solids Flowrate (kg/hr)	17,602	0	0	22,881	0	0	0	35,585	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	177	186	15	66	206	15	57	57	57	66	66	66	57	103	22	103	21
Pressure (MPa, abs)	0.10	0.10	0.11	0.11	0.12	0.31	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	3.35	0.24	3.35	15.27
Enthalpy (kJ/kg)[A]	---	433.86	444.13	---	59.93	192.48	62.80	---	230.99	230.99	239.10	239.10	239.10	230.99	74.06	93.12	71.94	-197.78
Density (kg/m^3)	---	1.0	1.0	---	1.4	2.5	1,003.1	---	1.4	1.4	1.4	1.4	1.4	1.4	48.2	996.1	48.2	709.9
V-L Molecular Weight	---	36.983	36.983	---	31.999	31.999	18.015	---	38.282	38.282	38.282	38.282	38.282	38.282	41.848	18.016	41.895	41.895
V-L Flowrate (lb_{mol}/hr)	0	127,707	127,707	6,596	448	448	2,956	1	119,314	82,463	82,463	19,379	63,084	36,851	31,336	5,581	31,274	31,274
V-L Flowrate (lb/hr)	0	4,723,001	4,723,001	118,822	14,324	14,324	53,246	28	4,567,547	3,156,832	3,156,829	741,855	2,414,974	1,410,714	1,311,353	100,552	1,310,247	1,310,247
Solids Flowrate (lb/hr)	38,806	0	0	50,443	0	0	0	78,452	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	350	367	59	150	403	59	135	135	135	150	150	150	135	217	72	217	70
Pressure (psia)	14.7	14.2	15.3	15.5	17.5	45.0	14.7	14.8	14.8	14.8	14.7	14.7	14.7	14.8	485.8	35.2	485.8	2,214.7
Enthalpy (Btu/lb)[A]	---	186.5	190.9	---	25.8	82.8	27.0	---	99.3	99.3	102.8	102.8	102.8	99.3	31.8	40.0	30.9	-85.0
Density (lb/ft^3)	---	0.061	0.064	---	0.086	0.156	62.622	---	0.089	0.089	0.087	0.087	0.087	0.089	3.006	62.182	3.009	44.318

Exhibit 3-28 Heat and Mass Balance, Boiler and Gas Cleanup Systems for Case 1

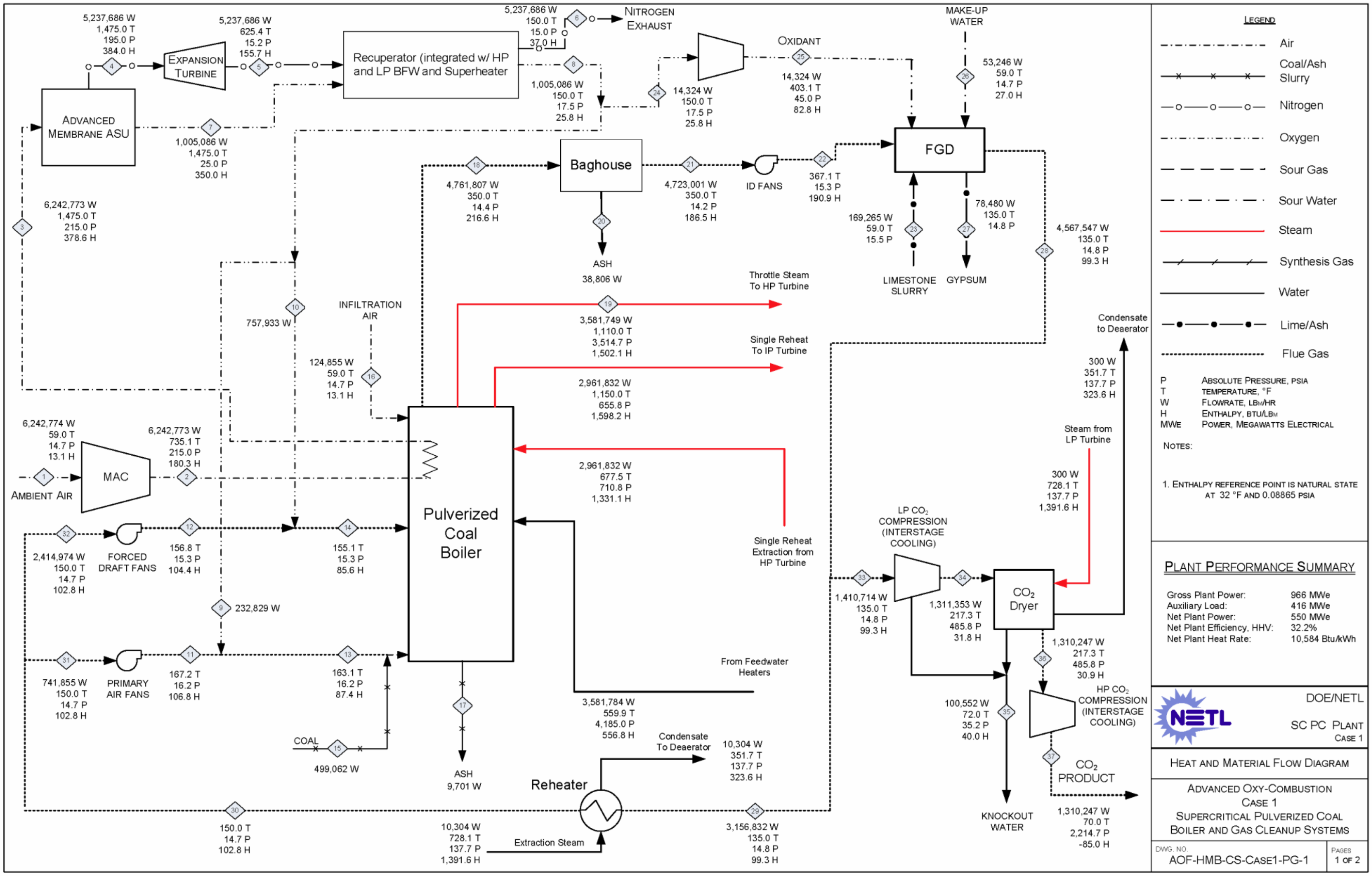


Exhibit 3-29 Heat and Mass Balance, Power Block Systems for Case 1

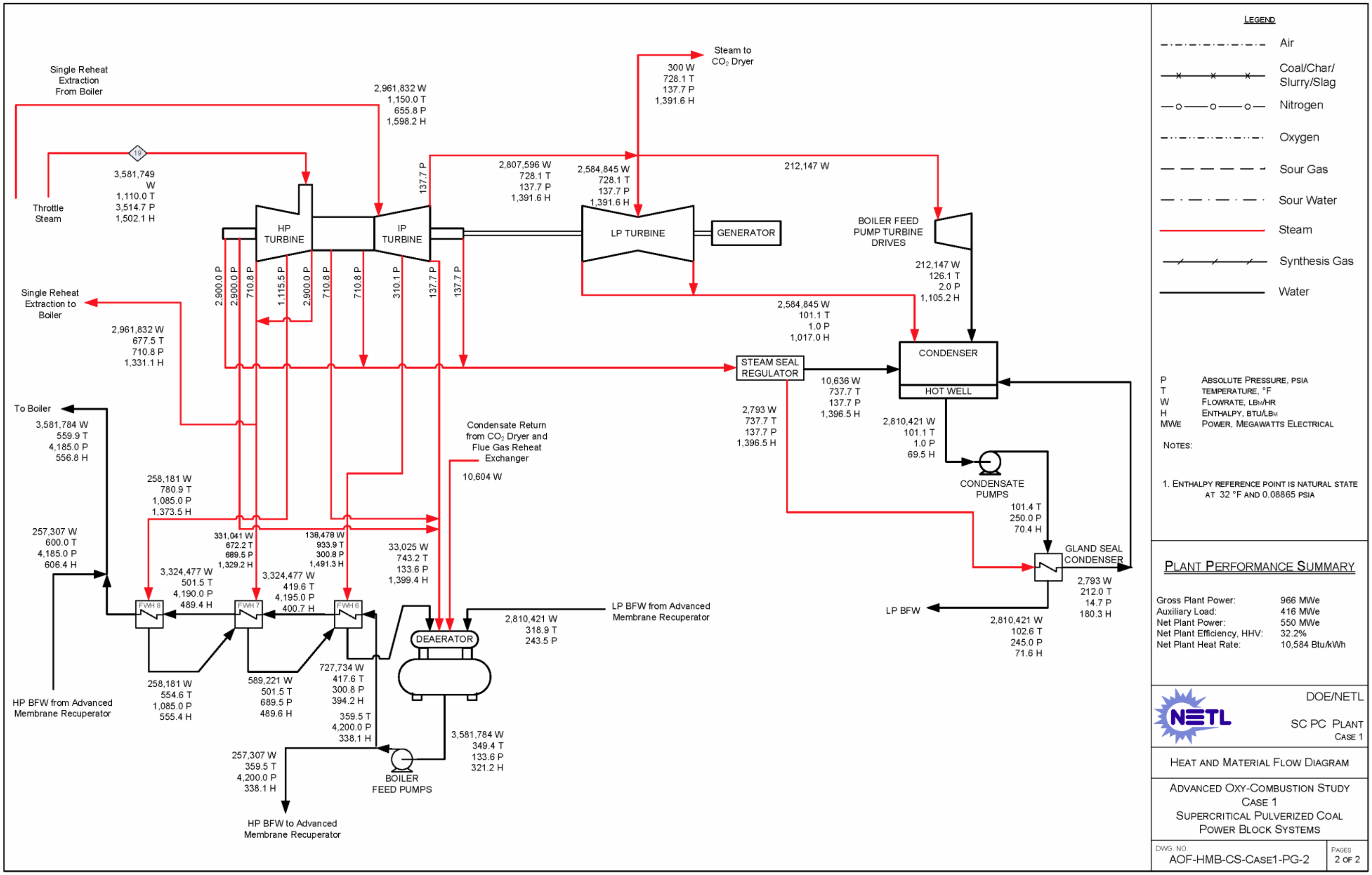


Exhibit 3-30 Case 1 Energy Balance

	HHV	Sensible + Latent	Power	Total
Heat In (GJ/hr)				
Coal	6,143 (5,822)	*5.1 (4.9)*		6,148 (5,827)
Air		88.3 (83.7)		88.3 (83.7)
Raw Water Makeup		104.0 (98.6)		104.0 (98.6)
Limestone		0.50 (0.47)		0.50 (0.47)
Auxiliary Power			1,496 (1,418)	1,496 (1,418)
Totals	**6,143 (5,822)**	**198.0 (187.6)**	**1,496 (1,418)**	**7,837 (7,428)**
Heat Out (GJ/hr)				
Boiler Loss		42.5 (40.3)		42.5 (40.3)
Bottom Ash		0.6 (0.5)		0.6 (0.5)
Fly Ash + FGD Ash		2.2 (2.1)		2.2 (2.1)
MAC Cooling		0.0 (0.0)		0.0 (0.0)
ASU Vent		204.2 (193.5)		204.2 (193.5)
Condenser		2,831 (2,683)		2,831 (2,683)
CO_2 Cooling		484 (459)		484 (459)
CO_2		-118 (-111)		-118 (-111)
Wet FGD Cooling		468 (444)		468 (444)
Process Condensate		38 (36)		38 (36)
Cooling Tower Blowdown		50.3 (47.7)		50.3 (47.7)
Process Losses*		*356.0 (337.4)*		*356.0 (337.4)*
Power			3,477 (3,295)	3,477 (3,295)
Totals		**4,360 (4,133)**	**3,477 (3,295)**	**7,837 (7,428)**

Note: Italicized numbers are estimated
Reference conditions are 0°C (32.02°F) & 0.6 kPa (0.089 psia)
* Process losses are estimated to match the heat input to the plant and include losses from: steam turbine, combustion reactions, and gas cooling.

Exhibit 3-31 Case 1 Carbon Balance

Carbon In		Carbon Out	
kg/hr(lb/hr)		kg/hr (lb/hr)	
Coal	144,660 (318,922)	CO_2 Product	146,784 (323,602)
Air (CO_2)	552 (1,216)	FGD Product	208 (459)
FGD Reagent	2,322 (5,118)	Separated Air	541 (1,193)
		Convergence Tolerance*	1 (3)
Total	147,534 (325,257)	Total	147,534 (325,257)

*by difference

Exhibit 3-32 Case 1 Sulfur Balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	5,687 (12,538)	Gypsum	5,652 (12,459)
		CO_2 Product	36 (78)
		Convergence Tolerance*	0 (0)
Total	5,687 (12,538)	Total	5,687 (12,538)

*by difference

Exhibit 3-33 Case 1 Water Balance

Water Use	Water Demand	Internal Recycle	Raw Water Withdrawal	Process Water Discharge	Raw Water Consumption
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)
FGD Makeup	0.40 (106)	0.0 (0)	0.40 (106)	0.0 (0)	0.40 (106)
BFW Makeup	0.25 (66)	0.0 (0)	0.25 (66)	0.0 (0)	0.25 (66)
Cooling Tower	30.1 (7,960)	3.14 (829)	27.0 (7,131)	6.8 (1,790)	20.2 (5,341)
Total	**30.8 (8,133)**	**3.14 (829)**	**27.6 (7,304)**	**6.8 (1,790)**	**20.9 (5,514)**

Exhibit 3-34 Case 1 Performance Summary

Plant Output		
Steam Turbine Power	620,500	kW_e
Nitrogen Expander Power	345,200	kW_e
Gross Power	**965,700**	kWe
Auxiliary Load		
Coal Handling and Conveying	480	kW_e
Limestone Handling & Reagent Preparation	1,100	kW_e
Pulverizers	3,390	kW_e
Ash Handling	650	kW_e
Primary Air Fans	910	kW_e
Forced Draft Fans	1,150	kW_e
Induced Draft Fans	6,330	kW_e
Air Separation Unit Main Air Compressor	315,240	kW_e
ASU Auxiliaries	0	kW_e
Baghouse	90	kW_e
FGD Pumps and Agitators	3,680	kWe
CO_2 Compression	64,170	kW_e
Condensate Pumps	810	kW_e
Boiler Feedwater Booster Pumps[2]	N/A	kW_e
Miscellaneous Balance of Plant[3]	2,000	kW_e
Steam Turbine Auxiliaries	400	kW_e
Circulating Water Pumps	7,730	kW_e
Cooling Tower Fans	4,510	kW_e
Transformer Losses	3,000	kW_e
Total	415,640	kW_e
Plant Performance		
Net Auxiliary Load	415,640	kW_e
Net Plant Power	550,060	kW_e
Net Plant Efficiency (HHV)	32.2%	
Net Plant Heat Rate (HHV)	11,167 (10,584)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	226,371 (499,062)	kg/hr (lb/hr)
Thermal Input[1]	1,706,276	kW_{th}
Condenser Duty	2,831 (2,683)	GJ/hr (MMBtu/hr)
Raw Water Usage	27.6 (7,304)	m^3/min (gpm)

1 - HHV of As Received Illinois No. 6 coal is 27,135 kJ/kg (11,666 Btu/lb)

2 - Boiler feed pumps are turbine driven

3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

4 - Includes work recovered by ITM vitiated air expander

Exhibit 3-35 Case 1 Capital Costs

Department: NETL Office of Program Planning and Analysis
Project: Advancing Oxycombustion Technology
Case: Case 1 - Advanced O2 Membrane with Boiler Integration
Plant Size: 550.06 MW, net — Capital Charge Factor 0.158 — Capacity Factor 0.85

Cost Base: June 2007
Prepared: 13-Apr-12
x $1, 000

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL HANDLING SYSTEM													
1.1	Coal Receive & Unload	3,723	0	1,700	0	5,423	8.9%	484	0%	0	15.0%	886	6,793	12
1.2	Coal Stackout & Reclaim	4,811	0	1,090	0	5,901	8.8%	517	0%	0	15.0%	963	7,380	13
1.3	Coal Conveyors & Yd Crus	4,473	0	1,079	0	5,552	8.8%	487	0%	0	15.0%	906	6,944	13
1.4	Other Coal Handling	1,170	0	250	0	1,420	8.7%	124	0%	0	15.0%	232	1,776	3
1.5	Sorbent Receive & Unload	153	0	46	0	200	8.8%	18	0%	0	15.0%	33	250	0
1.6	Sorbent Stackout & Reclaim	2,476	0	454	0	2,930	8.7%	255	0%	0	15.0%	478	3,663	7
1.7	Sorbent Conveyors	883	191	217	0	1,291	8.7%	112	0%	0	15.0%	210	1,613	3
1.8	Other Sorbent Handling	534	125	280	0	939	8.8%	83	0%	0	15.0%	153	1,175	2
1.9	Coal & Sorbent Hnd.Foundations	0	4,577	5,774	0	10,352	9.3%	968	0%	0	15.0%	1,698	13,018	24
	SUBTOTAL 1.	**$18,223**	**$4,894**	**$10,889**	**$0**	**$34,006**		**$3,047**		**$0**		**$5,558**	**$42,611**	**$77**
2	COAL PREP & FEED SYSTEMS													
2.1	Coal Crushing & Drying	2,146	0	418	0	2,564	8.7%	224	0%	0	15.0%	418	3,206	6
2.2	Prepared Coal Storage & Feed	5,495	0	1,199	0	6,694	8.7%	585	0%	0	15.0%	1,092	8,371	15
2.3	Slurry Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.4	Misc. Coal Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.5	Sorbent Prep Equipment	4,214	182	875	0	5,270	8.7%	459	0%	0	15.0%	859	6,589	12
2.6	Sorbent Storage & Feed	508	0	194	0	702	8.9%	62	0%	0	15.0%	115	879	2
2.7	Sorbent Injection System	0	0	0	0	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	0.0%	0	0	0
2.9	Coal & Sorbent Feed Foundation	0	539	453	0	992	9.2%	91	0%	0	15.0%	162	1,246	2
	SUBTOTAL 2.	**$12,362**	**$721**	**$3,140**	**$0**	**$16,222**		**$1,422**		**$0**		**$2,647**	**$20,291**	**$37**
3	FEEDWATER & MISC. BOP SYSTEMS													
3.1	Feedwater System	17,580	0	5,679	0	23,259	8.8%	2,037	0%	0	15.0%	3,794	29,090	53
3.2	Water Makeup & Pretreating	4,873	0	1,568	0	6,441	9.4%	604	0%	0	20.0%	1,409	8,454	15
3.3	Other Feedwater Subsystems	5,382	0	2,275	0	7,657	8.9%	682	0%	0	15.0%	1,251	9,590	17
3.4	Service Water Systems	955	0	520	0	1,475	9.3%	137	0%	0	20.0%	322	1,934	4
3.5	Other Boiler Plant Systems	6,521	0	6,438	0	12,959	9.4%	1,216	0%	0	15.0%	2,126	16,301	30
3.6	FO Supply Sys & Nat Gas	265	0	331	0	596	9.3%	55	0%	0	15.0%	98	749	1
3.7	Waste Treatment Equipment	2,827	0	1,612	0	4,438	9.7%	430	0%	0	20.0%	974	5,842	11
3.8	Misc. Power Plant Equipment	2,814	0	860	0	3,673	9.6%	353	0%	0	20.0%	805	4,831	9
	SUBTOTAL 3.	**$41,216**	**$0**	**$19,282**	**$0**	**$60,498**		**$5,513**		**$0**		**$10,779**	**$76,791**	**$140**
4	PC BOILER & ACCESSORIES													
4.1	PC Boiler	150,356	0	84,365	0	234,721	9.7%	22,735	10%	23,472	10.0%	28,093	309,022	562
4.2	ASU (Adv. Membrane)/Oxidant Compression	73,307	0	59,979	0	133,286	9.7%	12,910	0%	0	10.0%	14,620	160,816	292
4.3	Open	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.4	Boiler BoP (w/ID Fans)	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.5	Primary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.6	Secondary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.7	Major Component Rigging	0	w/4.1	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.8	PC Foundations	0	w/14.1	w/14.1	0	0	0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 4.	**$223,664**	**$0**	**$144,344**	**$0**	**$368,007**		**$35,645**		**$23,472**		**$42,712**	**$469,837**	**$854**

Exhibit 3-35 Case 1 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
5A	FLUE GAS CLEANUP							*						
5.1	Absorber Vessels & Accessories	55,631	0	11,976	0	67,607	9.5%	6,399	0%	0	10.0%	7,401	81,406	148
5.2	Other FGD	2,905	0	3,292	0	6,197	9.6%	597	0%	0	10.0%	679	7,474	14
5.3	Bag House & Accessories	13,827	0	8,775	0	22,602	9.6%	2,162	0%	0	10.0%	2,476	27,240	50
5.4	Other Particulate Removal Materials	913	0	977	0	1,891	9.6%	182	0%	0	10.0%	207	2,280	4
5.5	Gypsum Dewatering System	5,148	0	874	0	6,022	9.4%	569	0%	0	10.0%	659	7,250	13
5.6	Mercury Removal System	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.7	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.8	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.9	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 5A.	**$78,423**	**$0**	**$25,895**	**$0**	**$104,318**		**$9,908**		**$0**		**$11,423**	**$125,649**	**$228**
5B	CO2 REMOVAL & COMPRESSION													
5B.1	CO2 Condensing Heat Exchanger	5,547	0	463	0	6,010	10%	601	0%	0	15.0%	992	7,602	14
5B.2	CO2 Compression & Drying	40,549	0	33,177	0	73,726	10%	7,373	0%	0	20.0%	16,220	97,318	177
5B.3	CO2 Pipeline											0	0	0
5B.4	CO2 Storage											0	0	0
5B.5	CO2 Monitoring											0	0	0
	SUBTOTAL 5B.	**$46,096**	**$0**	**$33,640**	**$0**	**$79,736**		**$7,974**		**$0**		**$17,211**	**$104,921**	**$191**
6	NITROGEN EXPANDER/GENERATOR													
6.1	Nitrogen Expander/Generator	42,372	0	18,160	0	60,532	9.6%	5,796	0%	0	10.0%	6,633	72,961	133
6.2	Nitrogen Expander/Generator Accessories	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.3	Compressed Air Piping	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.4	Nitrogen Expander/Generator Foundations	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 6.	**$42,372**	**$0**	**$18,160**	**$0**	**$60,532**		**$5,796**		**$0**		**$6,633**	**$72,961**	**$133**
7	HRSG, DUCTING & STACK													
7.1	Flue Gas Recycle Heat Exchanger	1,299	0	108	0	1,408	10.0%	141	0%	0	15.0%	232	1,781	3
7.2	ASU Superheater	13,108	0	1,095	0	14,203	10.0%	1,420	20%	2,841	15.0%	2,770	21,233	39
7.3	ASU HP FWH	5,647	0	471	0	6,118	10.0%	612	10%	612	15.0%	1,101	8,443	15
7.4	ASU LP FWH	35,227	0	2,941	0	38,169	10.0%	3,817	0%	0	15.0%	6,298	48,283	88
7.5	SCR System	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
7.6	Ductwork	9,007	0	5,787	0	14,794	8.7%	1,292	0%	0	15.0%	2,413	18,499	34
7.7	Stack	1,472	0	862	0	2,334	9.6%	223	0%	0	10.0%	256	2,813	5
7.9	HRSG, Duct & Stack Foundations	0	850	966	0	1,815	9.3%	169	0%	0	20.0%	397	2,381	4
	SUBTOTAL 7.	**$65,761**	**$850**	**$12,230**	**$0**	**$78,841**		**$7,674**		**$3,452**		**$13,466**	**$103,434**	**$188**
8	STEAM TURBINE GENERATOR													
8.1	Steam TG & Accessories	52,756	0	7,001	0	59,757	9.6%	5,722	0%	0	10.0%	6,548	72,027	131
8.2	Turbine Plant Auxiliaries	355	0	761	0	1,116	9.7%	108	0%	0	10.0%	122	1,347	2
8.3	Condenser & Auxiliaries	6,776	0	2,498	0	9,274	9.5%	881	0%	0	10.0%	1,016	11,171	20
8.4	Steam Piping	16,448	0	8,110	0	24,558	8.3%	2,050	0%	0	15.0%	3,991	30,599	56
8.9	TG Foundations	0	1,117	1,765	0	2,882	9.4%	271	0%	0	20.0%	631	3,784	7
	SUBTOTAL 8.	**$76,336**	**$1,117**	**$20,135**	**$0**	**$97,588**		**$9,032**		**$0**		**$12,308**	**$118,927**	**$216**
9	COOLING WATER SYSTEM													
9.1	Cooling Towers	11,605	0	3,614	0	15,219	9.5%	1,445	0%	0	10.0%	1,666	18,330	33
9.2	Circulating Water Pumps	2,002	0	154	0	2,156	8.6%	184	0%	0	10.0%	234	2,574	5
9.3	Circ. Water System Auxiliaries	550	0	73	0	623	9.4%	59	0%	0	10.0%	68	750	1
9.4	Circ. Water Piping	0	4,359	4,225	0	8,584	9.2%	791	0%	0	15.0%	1,406	10,781	20
9.5	Make-up Water System	472	0	631	0	1,103	9.5%	105	0%	0	15.0%	181	1,389	3
9.6	Component Cooling Water System	436	0	346	0	782	9.4%	73	0%	0	15.0%	128	984	2
9.9	Circ. Water System Foundations	0	2,655	4,218	0	6,873	9.4%	647	0%	0	20.0%	1,504	9,024	16
	SUBTOTAL 9.	**$15,064**	**$7,014**	**$13,262**	**$0**	**$35,340**		**$3,303**		**$0**		**$5,188**	**$43,832**	**$80**

Exhibit 3-35 Case 1 Capital Costs (continued)

Acct No.		Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & %	Eng'g CM H.O. & Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
10		ASH/SPENT SORBENT HANDLING SYS													
	10.1	Ash Coolers	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
	10.2	Cyclone Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
	10.3	HGCU Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
	10.4	High Temperature Ash Piping	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
	10.5	Other Ash Recovery Equipment	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
	10.6	Ash Storage Silos	645	0	1,987	0	2,632	9.7%	256	0%	0	10.0%	289	3,177	6
	10.7	Ash Transport & Feed Equipment	4,175	0	4,277	0	8,451	9.5%	799	0%	0	10.0%	925	10,176	18
	10.8	Misc. Ash Handling Equipment	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	10.9	Ash/Spent Sorbent Foundation	0	153	180	0	334	9.3%	31	0%	0	20.0%	73	438	1
		SUBTOTAL 10.	**$4,820**	**$153**	**$6,444**	**$0**	**$11,417**		**$1,087**		**$0**		**$1,287**	**$13,791**	**$25**
11		ACCESSORY ELECTRIC PLANT													
	11.1	Generator Equipment	1,630	0	265	0	1,895	9.3%	175	0%	0	7.5%	155	2,225	4
	11.2	Station Service Equipment	8,562	0	2,813	0	11,375	9.6%	1,088	0%	0	7.5%	935	13,398	24
	11.3	Switchgear & Motor Control	9,843	0	1,673	0	11,516	9.3%	1,066	0%	0	10.0%	1,258	13,841	25
	11.4	Conduit & Cable Tray	0	6,171	21,338	0	27,510	9.6%	2,633	0%	0	15.0%	4,521	34,664	63
	11.5	Wire & Cable	0	11,645	22,480	0	34,124	8.4%	2,875	0%	0	15.0%	5,550	42,549	77
	11.6	Protective Equipment	261	0	888	0	1,149	9.8%	112	0%	0	10.0%	126	1,388	3
	11.7	Standby Equipment	1,297	0	30	0	1,327	9.5%	126	0%	0	10.0%	145	1,597	3
	11.8	Main Power Transformers	7,447	0	125	0	7,572	7.6%	575	0%	0	10.0%	815	8,962	16
	11.9	Electrical Foundations	0	318	779	0	1,097	9.5%	104	0%	0	20.0%	240	1,442	3
		SUBTOTAL 11.	**$29,040**	**$18,134**	**$50,391**	**$0**	**$97,566**		**$8,755**		**$0**		**$13,746**	**$120,066**	**$218**
12		INSTRUMENTATION & CONTROL													
	12.1	PC Control Equipment	w/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
	12.2	Combustion Turbine Control	N/A	0	N/A	0	0	0%	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%	0	0	0
	12.4	Other Major Component Control	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
	12.5	Signal Processing Equipment	W/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
	12.6	Control Boards, Panels & Racks	606	0	363	0	969	9.6%	93	0%	0	15.0%	159	1,222	2
	12.7	Computer Accessories	6,121	0	1,070	0	7,191	9.5%	685	0%	0	10.0%	788	8,663	16
	12.8	Instrument Wiring & Tubing	3,319	0	6,584	0	9,903	8.5%	844	0%	0	15.0%	1,612	12,359	22
	12.9	Other I & C Equipment	1,729	0	3,924	0	5,654	9.7%	551	0%	0	10.0%	620	6,825	12
		SUBTOTAL 12.	**$11,776**	**$0**	**$11,942**	**$0**	**$23,717**		**$2,172**		**$0**		**$3,179**	**$29,069**	**$53**
13		IMPROVEMENTS TO SITE													
		SUBTOTAL 13.	**$3,260**	**$1,874**	**$6,570**	**$0**	**$11,703**		**$1,149**		**$0**		**$2,571**	**$15,423**	**$28**
14		BUILDINGS & STRUCTURES													
	14.1	Boiler Building	0	8,810	7,748	0	16,558	9.0%	1,487	0%	0	15.0%	2,707	20,752	38
	14.2	Turbine Building	0	12,714	11,850	0	24,564	9.0%	2,212	0%	0	15.0%	4,016	30,792	56
	14.3	Administration Building	0	637	674	0	1,311	9.1%	119	0%	0	15.0%	215	1,645	3
	14.4	Circulation Water Pumphouse	0	126	100	0	226	8.9%	20	0%	0	15.0%	37	283	1
	14.5	Water Treatment Buildings	0	634	578	0	1,212	9.0%	109	0%	0	15.0%	198	1,519	3
	14.6	Machine Shop	0	426	286	0	713	8.9%	63	0%	0	15.0%	116	892	2
	14.7	Warehouse	0	289	290	0	579	9.0%	52	0%	0	15.0%	95	726	1
	14.8	Other Buildings & Structures	0	236	201	0	437	9.0%	39	0%	0	15.0%	71	548	1
	14.9	Waste Treating Building & Str.	0	440	1,336	0	1,776	9.4%	168	0%	0	15.0%	292	2,235	4
		SUBTOTAL 14.	**$0**	**$24,313**	**$23,062**	**$0**	**$47,376**		**$4,269**		**$0**		**$7,747**	**$59,391**	**$108**
		Total Cost	**$668,413**	**$59,070**	**$399,384**	**$0**	**$1,126,868**		**$106,747**		**$26,924**		**$156,455**	**$1,416,994**	**$2,576**

Exhibit 3-36 Case 1 Owner's Costs

Owner's Costs	$1,000	$/kW
Preproduction Costs		
6 Months All Labor	$9,448	$17
1 Month Maintenance Materials	$1,411	$3
1 Month Non-fuel Consumables	$705	$1
1 Month Waste Disposal	$287	$1
25% of 1 Months Fuel Cost at 100% CF	$1,739	$3
2% of TPC	$28,340	$52
Total	**$41,930**	**$76**
Inventory Capital		
60 day supply of fuel and consumables at 100% CF	$14,976	$27
0.5% of TPC (spare parts)	$3	$0
Total	**$14,979**	**$27**
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$212,549	$386
Financing Costs	$38,259	$70
Total Overnight Costs (TOC)	**$1,725,610**	**$3,137**
TASC Multiplier	1.134	
Total As-Spent Cost (TASC)	**$1,956,842**	**$3,558**

Exhibit 3-37 Case 1 O&M Costs

INITIAL & ANNUAL O&M EXPENSES

Case:	Case 1 - Advanced O2 Membrane with Boiler Integration		
Plant Size (MWe):	550.06	**Heat Rate (Btu/kWh):**	10,584
Primary/Secondary Fuel:	Illinois #6 Bituminous Coal	**Fuel Cost ($/MM Btu):**	1.64
Design/Construction	5 years	**Book Life (yrs):**	30
TPC (Plant Cost) Year:	June 2007	**TPI Year:**	2012
Capacity Factor (%):	85	**CO2 Captured (TPD):**	14,229

OPERATING & MAINTENANCE LABOR

Operating Labor

Operating Labor Rate (base):	$34.65	$/hour
Operating Labor Burden:	30.00	% of base
Labor Overhead Charge:	25.00	% of labor

Operating Labor Requirements per Shift:	**units/mod.**	**Total Plant**
Skilled Operator	2.0	2.0
Operator	9.0	9.0
Foreman	1.0	1.0
Lab Tech's etc.	2.0	2.0
TOTAL Operating Jobs	14.0	14.0

	$	**$/kW-net**
Annual Operating Labor Cost (calc'd)	5,524,319	10.04
Maintenance Labor Cost (calc'd)	9,592,348	17.44
Administrative & Support Labor (calc'd)	3,779,167	6.87
Property Taxes and Insurance	28,339,874	51.52
TOTAL FIXED OPERATING COSTS	**47,235,707**	**85.87**

VARIABLE OPERATING COSTS

	$	**$/kWh-net**
Maintenance Material Costs (calc'd)	**$14,388,634**	**0.00351**

Consumables	**Consumption Initial**	**Consumption /Day**	**Unit Cost**	**Initial Cost**	**$**	**$/kWh-net**
Water (/1000 gallons)	0	5,259	1.08	$0	$1,764,837	0.00043
Chemicals						
MU & WT Chem. (lb)	0	25,456	0.17	$0	$1,366,871	0.00033
Limestone (ton)	0	605	21.63	$0	$4,062,773	0.00099
Carbon (Hg Removal) (lb)	0	0	1.05	$0	$0	0.00000
MEA Solvent (ton)	0	0	2249.89	$0	$0	0.00000
Caustic Soda, NaOH (ton)	0	0	433.68	$0	$0	0.00000
Sulfuric acid, H_2SO_4 (ton)	0	0	138.78	$0	$0	0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	0.00000
Activated C, MEA (lb)	0	0	1.05	$0	$0	0.00000
Ammonia, 19% soln (ton)	0	0	129.80	$0	$0	0.00000
Subtotal Chemicals				**$0**	**$5,429,643**	**0.00133**
Other						
Supplemental Fuel (MMBtu)	0	0	6.55	$0	$0	0.00000
SCR Catalyst Replacement	w/equip.	0.0	5775.94	$0	$0	0.00000
Emission Penalties	0	0	0.00	$0	$0	0.00000
Subtotal Other				**$0**	**$0**	**0.00000**
Waste Disposal						
Spent Mercury Catalyst (lb)	0	0	0.42	$0	$0	0.00000
Flyash (ton)	0	466	16.23	$0	$2,344,117	0.00057
Bottom Ash (ton)	0	116	16.23	$0	$586,029	0.00014
Subtotal Solid Waste Disposal				**$0**	**$2,930,146**	**0.00072**
By-products & Emissions						
Gypsum (tons)	0	0	0.00	$0	$0	0.00000
Sulfur (tons)	0	0	0.00	$0	$0	0.00000
TOTAL VARIABLE OPERATING COSTS					**$24,513,260**	**0.00599**
Coal FUEL (tons)	**0**	**5,989**	**38.18**	**$0**	**$70,947,061**	**0.01732**
NATURAL GAS FUEL (Mscf)	**0**	**0**	**6.76**	**$0**	**$0**	**0.00000**

3.3.2 Case 1a – Advanced Membrane Oxycombustion Process with Natural Gas-fired Integration

Similar to Case 1, Case 1a also uses an advanced membrane process to produce the oxygen necessary for combustion. Instead of pre-heating the membrane inlet stream by integration with the boiler, a natural gas-fired direct contact heater is used to achieve ionization temperatures. While a heat recovery strategy similar to the boiler-integrated case was used here, natural gas was used as a heating fuel because of its lower inherent carbon content per Btu. This was anticipated to mitigate CO_2 compression auxiliary loads and thus raise efficiency, however overall carbon capture is reduced since CO_2 from natural gas combustion is not captured in this system.

Process highlights include the following:

- The air stream exiting the main air compressor is preheated to 571°C (1,060°F) and further heated to 802°C (1,475°F) by a natural gas-fired direct contact heater.
- Both the pure oxygen product and vitiated air stream are cooled to 66°C (150°F) by a recuperator and a series of heat exchangers integrated with the boiler feedwater system.
- The membrane produces oxygen at ~100 percent purity to be mixed with recycled flue gas and used as the oxidant for coal combustion.
- The vitiated air stream at 1.34 MPa (195 psia) is expanded through a turbine to 0.10 MPa (15 psia) and recovers approximately 272 MW of power.

Block Flow Diagram and Stream Table

BFD and stream tables for Case 1a are displayed in Exhibit 3-38 and Exhibit 3-39.

Heat and Mass Balance Diagram

Heat and mass balance diagrams are shown for the following subsystems in Exhibit 3-40 and Exhibit 3-41:

- Boiler and flue gas cleanup
- Steam cycle and feed water (power block)

Energy, Carbon, Sulfur and Water Balances

An overall plant energy balance is provided in tabular form in Exhibit 3-42. The power out is the steam turbine power after generator losses.

Carbon, sulfur and water balances are shown in Exhibit 3-43 through Exhibit 3-45.

Performance Summary

A performance summary is provided in Exhibit 3-46.

Costing Table

Tables of capital costs, owner's costs, and O&M costs are provided in Exhibit 3-47 through Exhibit 3-49, respectively.

Equipment List

The combined equipment list for Case 1 and Case 1a is shown Exhibit 3-50.

Exhibit 3-38 Process Block Flow Diagram for Case 1a

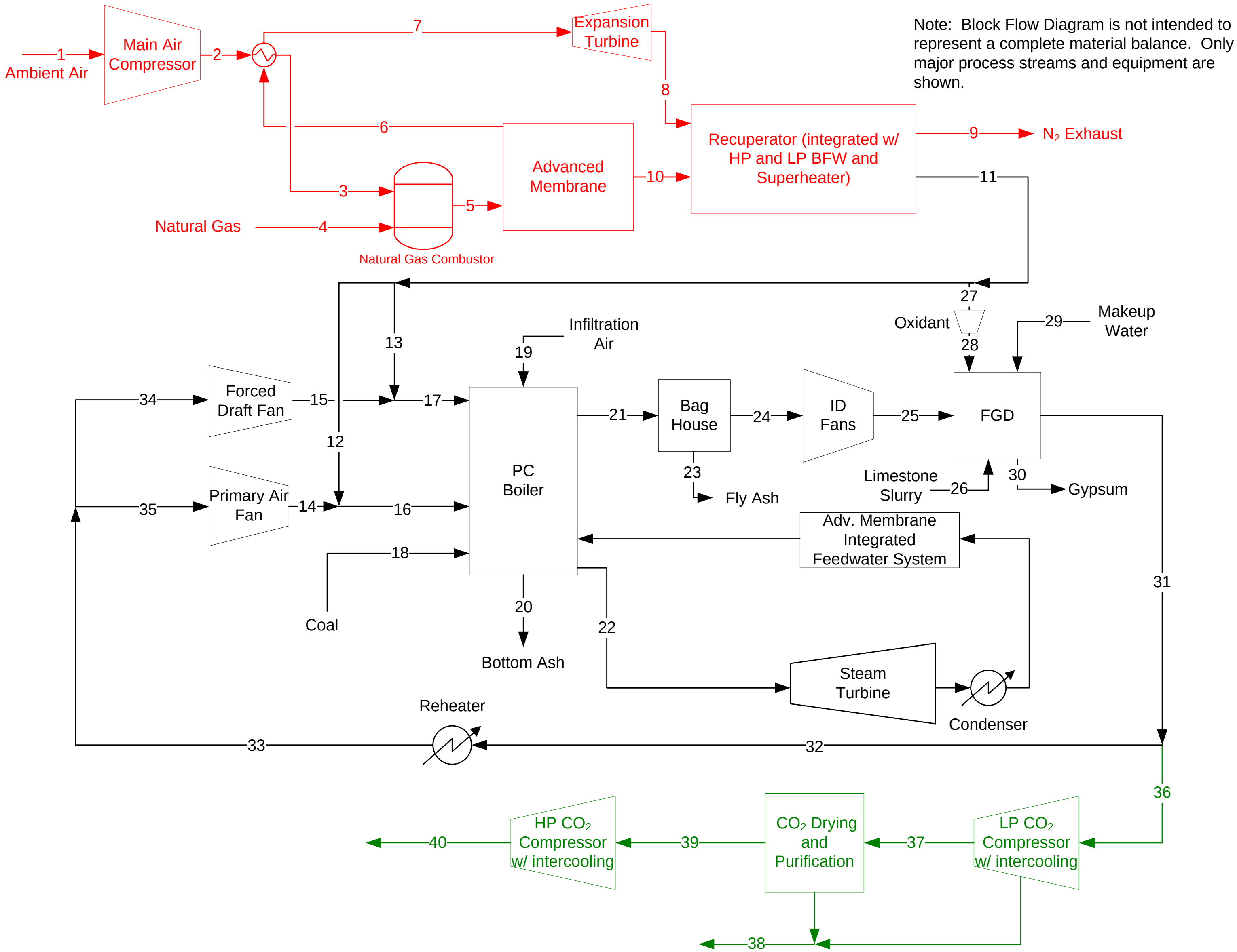


Exhibit 3-39 Stream Table for Case 1a

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
V-L Mole Fraction																				
Ar	0.0092	0.0092	0.0092	0.0000	0.0091	0.0104	0.0104	0.0104	0.0104	0.0000	0.0000	0.0000	0.0000	0.0012	0.0012	0.0009	0.0009	0.0000	0.0092	0.0000
CO_2	0.0005	0.0005	0.0005	0.0100	0.0106	0.0122	0.0122	0.0122	0.0122	0.0000	0.0000	0.0000	0.0000	0.7158	0.7158	0.5205	0.5205	0.0000	0.0005	0.0000
H_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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Methane	0.0000	0.0000	0.0000	0.9390	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	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0320	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	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0070	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	0.0000	0.0000
N-Butane	0.0000	0.0000	0.0000	0.0040	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	0.0000	0.0000
H_2O	0.0101	0.0101	0.0101	0.0000	0.0296	0.0340	0.0340	0.0340	0.0340	0.0000	0.0000	0.0000	0.0000	0.1514	0.1514	0.1101	0.1101	0.0000	0.0101	0.0000
N_2	0.7729	0.7729	0.7729	0.0080	0.7652	0.8794	0.8794	0.8794	0.8794	0.0000	0.0000	0.0000	0.0000	0.1063	0.1063	0.0773	0.0773	0.0000	0.7729	0.0000
O_2	0.2074	0.2074	0.2074	0.0000	0.1855	0.0639	0.0639	0.0639	0.0639	1.0000	1.0000	1.0000	1.0000	0.0253	0.0253	0.2912	0.2912	0.0000	0.2074	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	0.0001	0.0001	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	1.0000	1.0000	1.0000	0.0000	1.0000	0.0000
V-L Flowrate (kg_{mol}/hr)	92,174	92,174	92,174	902	93,102	81,014	81,014	81,014	81,014	12,087	12,087	2,799	9,113	7,463	24,293	10,262	33,407	0	1,843	0
V-L Flowrate (kg/hr)	2,659,766	2,659,765	2,659,765	15,544	2,675,309	2,288,527	2,288,527	2,288,527	2,288,527	386,782	386,782	89,579	291,609	284,076	924,758	373,655	1,216,367	0	53,195	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	190,935	0	3,712
Temperature (°C)	15	391	572	35	802	802	605	211	66	802	66	66	66	75	69	73	68	15	15	15
Pressure (MPa, abs)	0.10	1.48	1.45	1.38	1.45	1.41	1.38	0.10	0.10	0.17	0.17	0.17	0.17	0.11	0.11	0.11	0.11	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	30.57	419.33	617.99	58.85	922.15	940.31	709.43	274.36	122.00	814.14	59.81	59.81	59.81	249.55	243.90	204.06	199.77	---	30.57	---
Density (kg/m^3)	1.2	7.7	5.9	9.6	4.6	4.5	5.3	0.7	1.0	0.6	2.0	2.0	2.0	1.5	1.4	1.4	1.4	---	1.2	---
V-L Molecular Weight	28.856	28.856	28.856	17.232	28.735	28.248	28.248	28.248	28.248	31.999	31.999	31.999	31.999	38.066	38.066	36.411	36.411	---	28.856	---
V-L Flowrate (lb_{mol}/hr)	203,208	203,208	203,208	1,989	205,255	178,606	178,606	178,606	178,606	26,648	26,648	6,172	20,091	16,452	53,558	22,624	73,649	0	4,064	0
V-L Flowrate (lb/hr)	5,863,780	5,863,778	5,863,778	34,268	5,898,046	5,045,338	5,045,338	5,045,338	5,045,338	852,708	852,708	197,488	642,888	626,280	2,038,742	823,768	2,681,629	0	117,276	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	420,941	0	8,183
Temperature (°F)	59	735	1,061	95	1,475	1,475	1,121	411	150	1,475	150	150	150	167	157	163	155	59	59	59
Pressure (psia)	14.7	215.0	210.0	200.0	210.0	205.0	200.0	15.2	15.0	25.0	25.0	25.0	25.0	16.2	15.3	16.2	15.3	14.7	14.7	14.7
Enthalpy (Btu/lb)[A]	13.1	180.3	265.7	25.3	396.5	404.3	305.0	118.0	52.5	350.0	25.7	25.7	25.7	107.3	104.9	87.7	85.9	---	13.1	---
Density (lb/ft^3)	0.076	0.482	0.370	0.597	0.290	0.278	0.332	0.046	0.065	0.039	0.122	0.122	0.122	0.092	0.088	0.088	0.085	---	0.076	---

A - Reference conditions are 32.02 F & 0.089 PSIA

Exhibit 3-39 Stream Table for Case 1a (Continued)

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
V-L Mole Fraction																				
Ar	0.0011	0.0000	0.0000	0.0011	0.0011	0.0000	0.0000	0.0000	0.0000	0.0004	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0014	0.0000	0.0014	0.0014
CO_2	0.6669	0.0000	0.0000	0.6669	0.6669	0.0000	0.0000	0.0000	0.0000	0.9780	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.8418	0.0000	0.8434	0.8434
H_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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Methane	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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N-Butane	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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.2079	1.0000	0.0000	0.2079	0.2079	1.0000	0.0000	0.0000	1.0000	0.0035	0.1514	0.1514	0.1514	0.1514	0.1514	0.1514	0.0021	1.0000	0.0001	0.0001
N_2	0.0995	0.0000	0.0000	0.0995	0.0995	0.0000	0.0000	0.0000	0.0000	0.0024	0.1063	0.1063	0.1063	0.1063	0.1063	0.1063	0.1250	0.0000	0.1252	0.1252
O_2	0.0216	0.0000	0.0000	0.0216	0.0216	0.0000	1.0000	1.0000	0.0000	0.0094	0.0253	0.0253	0.0253	0.0253	0.0253	0.0253	0.0297	0.0000	0.0298	0.0298
SO_2	0.0031	0.0000	0.0000	0.0031	0.0031	0.0000	0.0000	0.0000	0.0000	0.0063	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
Total	1.0000	1.0000	0.0000	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	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	49,320	97,950	0	49,320	49,320	2,548	175	175	1,141	0	46,157	31,756	31,756	7,463	24,293	14,401	12,246	2,181	12,222	12,222
V-L Flowrate (kg/hr)	1,815,594	1,764,596	0	1,815,594	1,815,594	45,901	5,594	5,594	20,563	9	1,757,024	1,208,833	1,208,833	284,076	924,758	548,192	509,363	39,294	508,931	508,931
Solids Flowrate (kg/hr)	14,847	0	14,847	0	0	19,261	0	0	0	29,976	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	177	599	15	177	186	15	66	148	15	57	57	57	66	66	66	57	103	22	103	21
Pressure (MPa, abs)	0.10	24.23	0.10	0.10	0.11	0.11	0.17	0.31	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	3.35	0.24	3.35	15.27
Enthalpy (kJ/kg)[A]	502.42	3,493.92	---	433.62	443.93	---	59.81	136.85	62.80	---	232.12	232.12	240.24	240.24	240.24	232.12	74.90	93.14	72.76	-190.99
Density (kg/m^3)	1.0	68.5	---	1.0	1.0	---	2.0	2.8	1,003.1	---	1.4	1.4	1.4	1.4	1.4	1.4	47.7	996.1	47.7	685.3
V-L Molecular Weight	36.812	18.015	---	36.812	36.812	---	31.999	31.999	18.015	---	38.066	38.066	38.066	38.066	38.066	38.066	41.595	18.016	41.641	41.641
V-L Flowrate (lb_{mol}/hr)	108,733	215,943	0	108,733	108,733	5,617	385	385	2,516	0	101,759	70,010	70,010	16,452	53,558	31,749	26,997	4,808	26,944	26,944
V-L Flowrate (lb/hr)	4,002,700	3,890,268	0	4,002,700	4,002,700	101,194	12,332	12,332	45,334	19	3,873,575	2,665,020	2,665,022	626,280	2,038,742	1,208,555	1,122,954	86,628	1,122,000	1,122,000
Solids Flowrate (lb/hr)	32,731	0	32,731	0	0	42,462	0	0	0	66,086	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	350	1,110	59	350	367	59	150	298	59	135	135	135	150	150	150	135	218	72	218	70
Pressure (psia)	14.4	3,514.7	14.7	14.2	15.3	15.5	25.0	45.0	14.7	14.8	14.8	14.8	14.7	14.7	14.7	14.8	485.8	35.2	485.8	2,214.7
Enthalpy (Btu/lb)[A]	216.0	1,502.1	---	186.4	190.9	---	25.7	58.8	27.0	---	99.8	99.8	103.3	103.3	103.3	99.8	32.2	40.0	31.3	-82.1
Density (lb/ft^3)	0.061	4.274	---	0.060	0.064	---	0.122	0.177	62.622	---	0.089	0.089	0.086	0.086	0.086	0.089	2.978	62.182	2.981	42.783

Exhibit 3-40 Heat and Mass Balance, Boiler and Gas Cleanup Systems for Case 1a

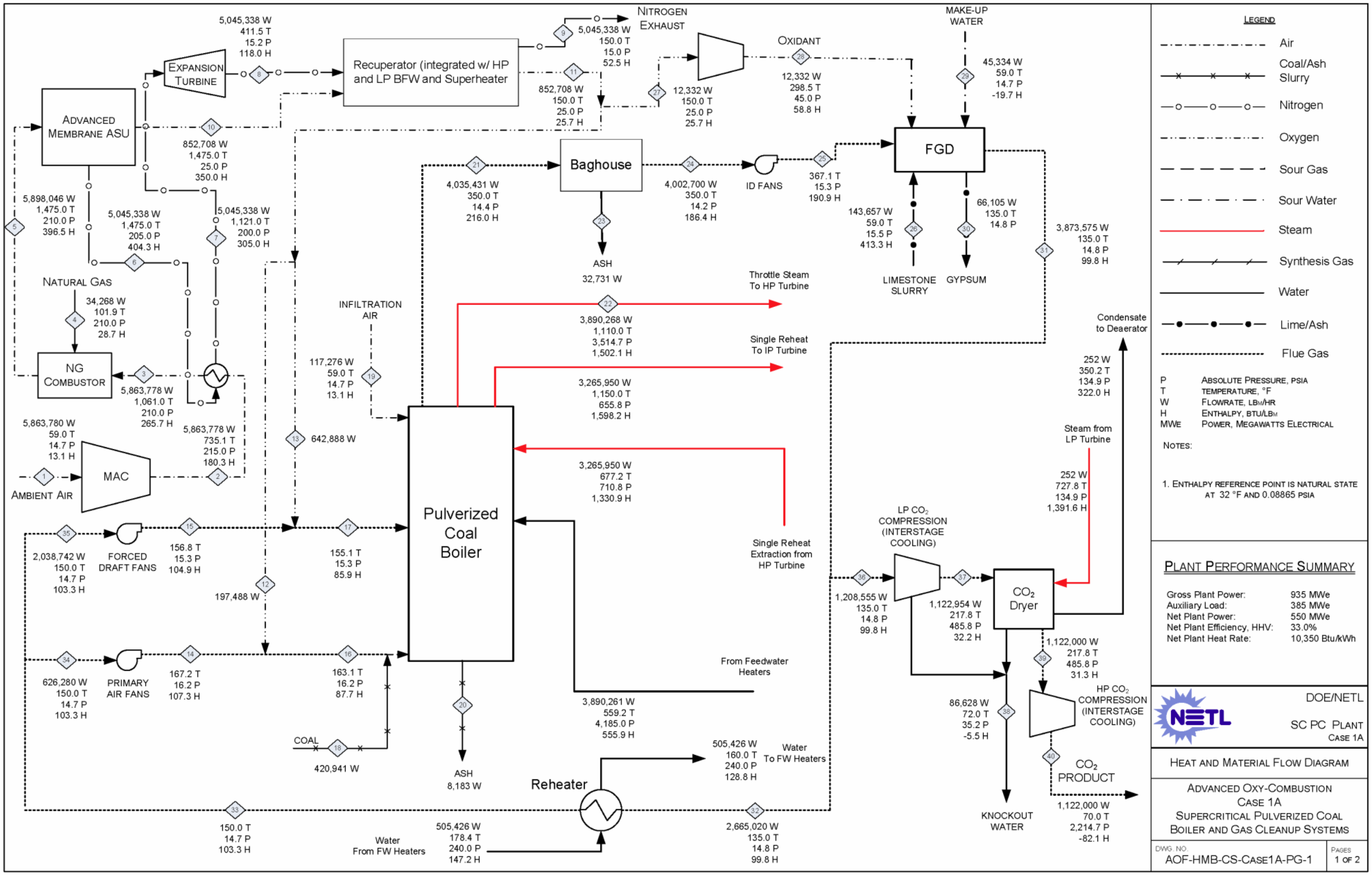


Exhibit 3-41 Heat and Mass Balance, Power Block Systems for Case 1a

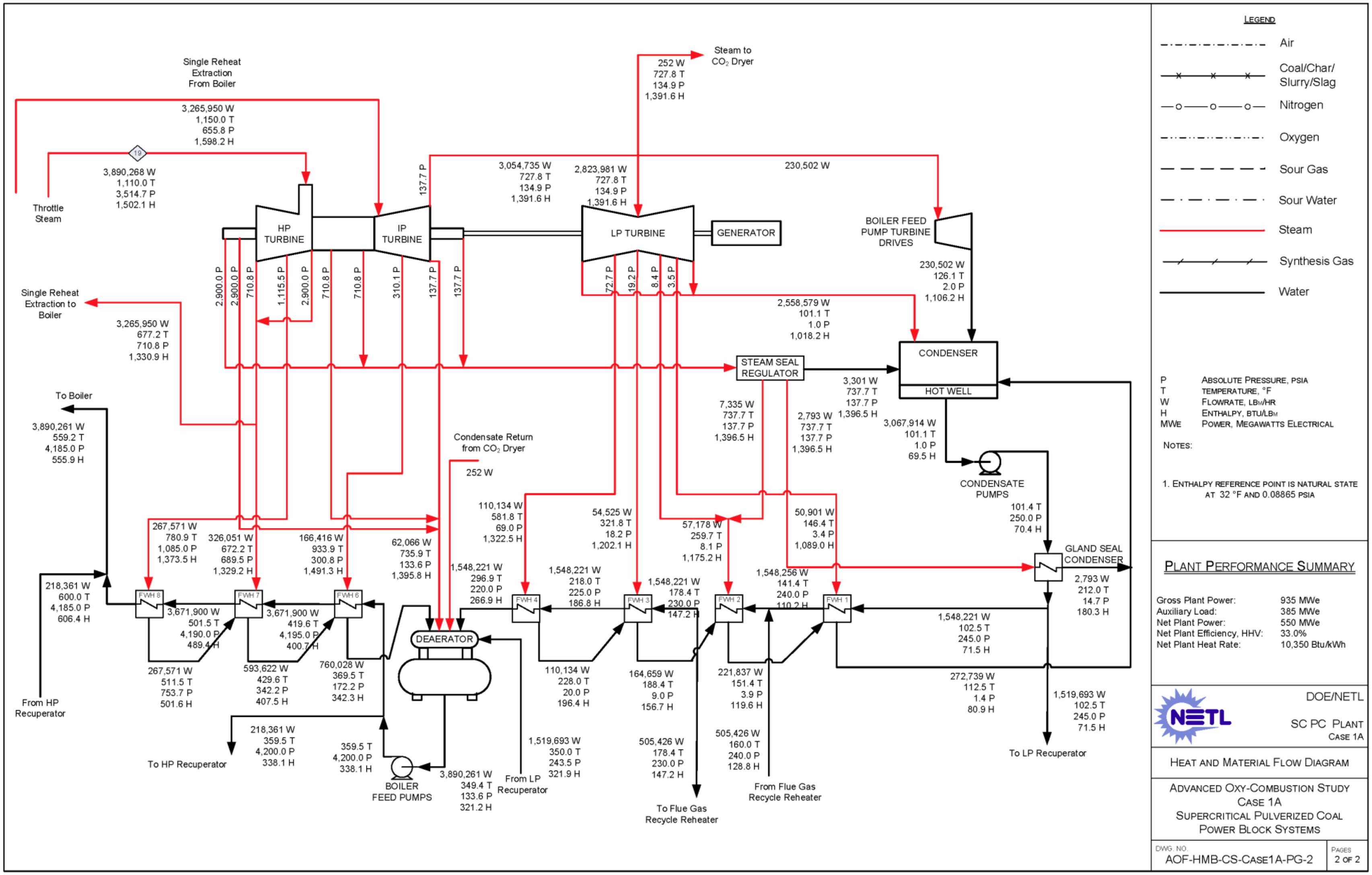


Exhibit 3-42 Case 1a Energy Balance

	HHV	Sensible + Latent	Power	Total
Heat In MMBTU/hr (GJ/hr)				
Coal	5,181 (4,911)	*4.3 (4.1)*		5,185 (4,915)
Natural Gas	815 (773)	0.5 (0.5)		815.8 (773.2)
Air		82.9 (78.6)		82.9 (78.6)
Raw Water Makeup		102.4 (97.0)		102.4 (97.0)
Limestone		0.42 (0.40)		0.42 (0.40)
Auxiliary Power			1,385 (1,313)	1,385 (1,313)
Totals	**5,996 (5,683)**	**190.6 (180.6)**	**1,385 (1,313)**	**7,572 (7,177)**
Heat Out MMBTU/hr (GJ/hr)				
Boiler Loss		46.9 (44.4)		46.9 (44.4)
Bottom Ash		0.5 (0.4)		0.5 (0.4)
Fly Ash + FGD Ash		1.9 (1.8)		1.9 (1.8)
MAC Cooling		0.0 (0.0)		0.0 (0.0)
ASU Vent		279.2 (264.6)		279.2 (264.6)
Condenser		2,821.2 (2,674.0)		2,821.2 (2,674.0)
CO_2 Cooling		414.1 (392.5)		414.1 (392.5)
CO_2		-97.2 (-92.1)		-97.2 (-92.1)
Wet FGD Cooling		393.3 (372.8)		393.3 (372.8)
Process Condensate		32.4 (30.7)		32.4 (30.7)
Cooling Tower Blowdown		*47.6 (45.1)*		*47.6 (45.1)*
Process Losses*		*267.4 (253.4)*		*267.4 (253.4)*
Power			3,365 (3,189)	3,365 (3,189)
Totals		**4,207 (3,988)**	**3,365 (3,189)**	**7,572 (7,177)**

Note: Italicized numbers are estimated
Reference conditions are 0°C (32.02°F) & 0.6 kPa (0.089 psia)
* Process losses are estimated to match the heat input to the plant and include losses from: steam turbine, combustion reactions, and gas cooling.

Exhibit 3-43 Case 1a Carbon Balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	122,016 (268,999)	CO_2 Product	123,808 (272,951)
Natural Gas	11,376 (25,080)		
Air (CO_2)	518 (1,143)	FGD Product	169 (372)
FGD Reagent	1,954 (4,309)	Separated Air	11,884 (26,200)
		Convergence Tolerance*	3 (7)
Total	135,865 (299,530)	Total	135,865 (299,530)

*by difference

Exhibit 3-44 Case 1a Sulfur Balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	4,797 (10,575)	Gypsum	4,767 (10,508)
		CO_2 Product	30 (67)
		Convergence Tolerance*	0 (0)
Total	4,797 (10,575)	Total	4,797 (10,575)

*by difference

Exhibit 3-45 Case 1a Water Balance

Water Use	Water Demand	Internal Recycle	Raw Water Withdrawal	Process Water Discharge	Raw Water Consumption
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)
FGD Makeup	1.11 (293)	0.0 (0)	1.11 (293)	0.00 (0)	1.11 (293)
BFW Makeup	0.28 (73)	0.0 (0)	0.28 (73)	0.00 (0)	0.28 (73)
Cooling Tower	28.5 (7,522)	2.66 (702)	25.8 (6,820)	6.40 (1692)	19.41 (5128)
Total	**29.9 (7,888)**	**2.66 (702)**	**27.2 (7,186)**	**6.40 (1,692)**	**20.80 (5,495)**

Exhibit 3-46 Case 1A Performance Summary

Plant Output		
Steam Turbine Power	662,300	kW_e
Nitrogen Expander Power	272,400	kW_e
Gross Power	934,700	kWe
Auxiliary Load		
Coal Handling and Conveying	440	kW_e
Limestone Handling & Reagent Preparation	930	kW_e
Pulverizers	2,860	kW_e
Ash Handling	550	kW_e
Primary Air Fans	770	kW_e
Forced Draft Fans	990	kW_e
Induced Draft Fans	5,390	kW_e
Air Separation Unit Main Air Compressor	296,100	kW_e
ASU Auxiliaries	0	kW_e
Baghouse	70	kW_e
FGD Pumps, Agitators and O_2 Blower	3,230	kWe
CO_2 Compression	55,550	kW_e
Condensate Pumps	880	kW_e
Boiler Feedwater Booster Pumps[2]	N/A	kW_e
Miscellaneous Balance of Plant[3]	2,000	kW_e
Steam Turbine Auxiliaries	400	kW_e
Circulating Water Pumps	7,310	kW_e
Cooling Tower Fans	4,270	kW_e
Transformer Losses	3,040	kW_e
Total	384,780	kW_e
Plant Performance		
Net Auxiliary Load	384,780	kW_e
Net Plant Power	549,920	kW_e
Net Plant Efficiency (HHV)	33.0%	
Net Plant Heat Rate (HHV)	10,904 (10,335)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	190,935 (420,941)	kg/hr (lb/hr)
Natural Gas	15,544 (34,268)	kg/hr (lb/hr)
Coal Thermal Input	1,439,182	kW_{th}
Natural Gas Thermal Input	226,458	kW_{th}
Thermal Input[1,4] (Coal + Natural Gas)	1,665,640	kW_{th}
Condenser Duty	2,821 (2,674)	GJ/hr (MMBtu/hr)
Raw Water Usage	27.2 (7,186)	m^3/min (gpm)

1 - HHV of As Received Illinois No. 6 coal is 27,135 kJ/kg (11,666 Btu/lb)

2 - Boiler feed pumps are turbine driven

3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

4 - HHV of natural gas is 22,549 Btu/lb

Exhibit 3-47 Case 1A Capital Costs

	Department:	NETL Office of Program Planning and Analysis										**Cost Base:**	June 2007	
	Project:	Advancing Oxycombustion Technology										**Prepared:**	13-Apr-12	
	Case:	Case 1A - Advanced O2 Membrane with Natural Gas Preheater											x $1, 000	
	Plant Size:	550	MW, net			Capital Charge Factor	0.158	Capacity Factor		0.85				
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Bare Erected**	**Eng'g CM H.O. & %**	**Eng'g CM H.O. & Total**	**Process Cont. %**	**Process Cont. Total**	**Project Cont. %**	**Project Cont. Total**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**
1	COAL HANDLING SYSTEM													
1.1	Coal Receive & Unload	3,350	0	1,530	0	4,880	8.9%	436	0%	0	15.0%	797	6,113	11
1.2	Coal Stackout & Reclaim	4,329	0	981	0	5,310	8.8%	465	0%	0	15.0%	866	6,641	12
1.3	Coal Conveyors & Yd Crus	4,025	0	971	0	4,995	8.8%	438	0%	0	15.0%	815	6,248	11
1.4	Other Coal Handling	1,053	0	225	0	1,278	8.7%	112	0%	0	15.0%	208	1,598	3
1.5	Sorbent Receive & Unload	137	0	41	0	179	8.8%	16	0%	0	15.0%	29	224	0
1.6	Sorbent Stackout & Reclaim	2,217	0	406	0	2,624	8.7%	229	0%	0	15.0%	428	3,280	6
1.7	Sorbent Conveyors	791	171	194	0	1,156	8.7%	100	0%	0	15.0%	188	1,445	3
1.8	Other Sorbent Handling	478	112	251	0	841	8.8%	74	0%	0	15.0%	137	1,052	2
1.9	Coal & Sorbent Hnd.Foundations	0	4,118	5,195	0	9,314	9.3%	871	0%	0	15.0%	1,528	11,712	21
	SUBTOTAL 1.	**$16,381**	**$4,402**	**$9,794**	**$0**	**$30,576**		**$2,740**		**$0**		**$4,997**	**$38,313**	**$70**
2	COAL PREP & FEED SYSTEMS													
2.1	Coal Crushing & Drying	1,918	0	374	0	2,292	8.7%	200	0%	0	15.0%	374	2,865	5
2.2	Prepared Coal Storage & Feed	4,911	0	1,072	0	5,983	8.7%	523	0%	0	15.0%	976	7,482	14
2.3	Slurry Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.4	Misc. Coal Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.5	Sorbent Prep Equipment	3,767	162	782	0	4,712	8.7%	410	0%	0	15.0%	768	5,891	11
2.6	Sorbent Storage & Feed	454	0	174	0	628	8.9%	56	0%	0	15.0%	103	786	1
2.7	Sorbent Injection System	0	0	0	0	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	0.0%	0	0	0
2.9	Coal & Sorbent Feed Foundation	0	484	406	0	890	9.2%	82	0%	0	15.0%	146	1,118	2
	SUBTOTAL 2.	**$11,050**	**$646**	**$2,808**	**$0**	**$14,504**		**$1,271**		**$0**		**$2,366**	**$18,142**	**$33**
3	FEEDWATER & MISC. BOP SYSTEMS													
3.1	Feedwater System	18,612	0	6,012	0	24,624	8.8%	2,156	0%	0	15.0%	4,017	30,796	56
3.2	Water Makeup & Pretreating	4,817	0	1,550	0	6,367	9.4%	597	0%	0	20.0%	1,393	8,357	15
3.3	Other Feedwater Subsystems	5,698	0	2,408	0	8,106	8.9%	722	0%	0	15.0%	1,324	10,152	18
3.4	Service Water Systems	944	0	514	0	1,458	9.3%	135	0%	0	20.0%	319	1,912	3
3.5	Other Boiler Plant Systems	6,938	0	6,850	0	13,787	9.4%	1,293	0%	0	15.0%	2,262	17,343	32
3.6	FO Supply Sys & Nat Gas	254	0	317	0	571	9.3%	53	0%	0	15.0%	94	718	1
3.7	Waste Treatment Equipment	2,589	0	1,476	0	4,064	9.7%	394	0%	0	20.0%	892	5,349	10
3.8	Misc. Power Plant Equipment	2,696	0	824	0	3,520	9.6%	338	0%	0	20.0%	772	4,630	8
	SUBTOTAL 3.	**$42,547**	**$0**	**$19,950**	**$0**	**$62,497**		**$5,689**		**$0**		**$11,072**	**$79,257**	**$144**
4	PC BOILER & ACCESSORIES													
4.1	PC Boiler	159,247	0	89,354	0	248,600	9.7%	24,080	0%	0	10.0%	27,268	299,948	545
4.2	ASU (Advanced Membrane)/Oxidant Compression	66,421	0	54,344	0	120,766	9.7%	11,697	0%	0	10.0%	13,246	145,709	265
4.3	Open	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.4	Boiler BoP (w/ID Fans)	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.5	Primary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.6	Secondary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.7	Major Component Rigging	0	w/4.1	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.8	PC Foundations	0	w/14.1	w/14.1	0	0	0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 4.	**$225,668**	**$0**	**$143,698**	**$0**	**$369,366**		**$35,777**		**$0**		**$40,514**	**$445,657**	**$810**

Exhibit 3-47 Case 1A Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor		Bare Erected	Eng'g CM H.O. & Fee		Process Cont.		Project Cont.		TOTAL PLANT COST	
				Direct	Indirect		%	Total	%	Total	%	Total	$	$/kW
5A	FLUE GAS CLEANUP							*						
5.1	Absorber Vessels & Accessories	49,503	0	10,657	0	60,160	9.5%	5,694	0%	0	10.0%	6,585	72,440	132
5.2	Other FGD	2,585	0	2,930	0	5,515	9.6%	531	0%	0	10.0%	605	6,651	12
5.3	Bag House & Accessories	12,197	0	7,740	0	19,937	9.6%	1,907	0%	0	10.0%	2,184	24,029	44
5.4	Other Particulate Removal Materials	807	0	863	0	1,670	9.6%	161	0%	0	10.0%	183	2,014	4
5.5	Gypsum Dewatering System	4,627	0	786	0	5,413	9.4%	511	0%	0	10.0%	592	6,517	12
5.6	Mercury Removal System	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.7	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.8	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.9	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 5A.	**$69,719**	**$0**	**$22,976**	**$0**	**$92,696**		**$8,804**		**$0**		**$10,150**	**$111,650**	**$203**
5B	CO2 REMOVAL & COMPRESSION													
5B.1	CO2 Condensing Heat Exchanger	4,891	0	408	0	5,299	10%	530	0%	0	15.0%	874	6,704	12
5B.2	CO2 Compression & Drying	36,553	0	29,907	0	66,461	10%	6,646	0%	0	20.0%	14,621	87,728	160
5B.3	CO2 Pipeline											0	0	0
5B.4	CO2 Storage											0	0	0
5B.5	CO2 Monitoring											0	0	0
	SUBTOTAL 5B.	**$41,444**	**$0**	**$30,316**	**$0**	**$71,760**		**$7,176**		**$0**		**$15,496**	**$94,432**	**$172**
6	NITROGEN EXPANDER/GENERATOR													
6.1	Nitrogen Expander/Generator	35,907	0	15,389	0	51,296	9.6%	4,912	0%	0	10.0%	5,621	61,829	112
6.2	Nitrogen Expander/Generator Accessories	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.3	Compressed Air Piping	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.4	Nitrogen Expander/Generator Foundations	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 6.	**$35,907**	**$0**	**$15,389**	**$0**	**$51,296**		**$4,912**		**$0**		**$5,621**	**$61,829**	**$112**
7	HRSG, DUCTING & STACK													
7.1	Flue Gas Recycle Heat Exchanger	1,136	0	95	0	1,231	10.0%	123	0%	0	15.0%	203	1,557	3
7.2	ASU Superheater	34,724	0	2,899	0	37,623	10.0%	3,762	20%	7,525	15.0%	7,337	56,247	102
7.3	ASU HP FWH	4,952	0	413	0	5,365	10.0%	537	10%	537	15.0%	966	7,404	13
7.4	ASU LP FWH	22,118	0	1,847	0	23,965	10.0%	2,397	0%	0	15.0%	3,954	30,316	55
7.5	SCR System	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
7.6	Ductwork	8,443	0	5,424	0	13,867	8.7%	1,211	0%	0	15.0%	2,262	17,340	32
7.7	Stack	1,363	0	797	0	2,160	9.6%	206	0%	0	10.0%	237	2,603	5
7.9	HRSG, Duct & Stack Foundations	0	830	943	0	1,774	9.3%	165	0%	0	20.0%	388	2,327	4
	SUBTOTAL 7.	**$72,736**	**$830**	**$12,420**	**$0**	**$85,986**		**$8,401**		**$8,061**		**$15,346**	**$117,794**	**$214**
8	STEAM TURBINE GENERATOR													
8.1	Steam TG & Accessories	55,217	0	7,328	0	62,545	9.6%	5,989	0%	0	10.0%	6,853	75,386	137
8.2	Turbine Plant Auxiliaries	372	0	797	0	1,168	9.7%	113	0%	0	10.0%	128	1,410	3
8.3	Condenser & Auxiliaries	6,760	0	2,492	0	9,252	9.5%	879	0%	0	10.0%	1,013	11,145	20
8.4	Steam Piping	17,428	0	8,593	0	26,020	8.3%	2,172	0%	0	15.0%	4,229	32,421	59
8.9	TG Foundations	0	1,168	1,845	0	3,013	9.4%	284	0%	0	20.0%	659	3,955	7
	SUBTOTAL 8.	**$79,777**	**$1,168**	**$21,054**	**$0**	**$101,998**		**$9,436**		**$0**		**$12,883**	**$124,317**	**$226**
9	COOLING WATER SYSTEM													
9.1	Cooling Towers	11,165	0	3,477	0	14,642	9.5%	1,390	0%	0	10.0%	1,603	17,636	32
9.2	Circulating Water Pumps	1,906	0	147	0	2,053	8.6%	176	0%	0	10.0%	223	2,452	4
9.3	Circ. Water System Auxiliaries	530	0	71	0	601	9.4%	57	0%	0	10.0%	66	723	1
9.4	Circ. Water Piping	0	4,202	4,072	0	8,274	9.2%	762	0%	0	15.0%	1,355	10,391	19
9.5	Make-up Water System	468	0	625	0	1,092	9.5%	104	0%	0	15.0%	179	1,375	3
9.6	Component Cooling Water System	420	0	334	0	754	9.4%	71	0%	0	15.0%	124	948	2
9.9	Circ. Water System Foundations	0	2,566	4,077	0	6,644	9.4%	625	0%	0	20.0%	1,454	8,723	16
	SUBTOTAL 9.	**$14,489**	**$6,768**	**$12,803**	**$0**	**$34,060**		**$3,184**		**$0**		**$5,004**	**$42,248**	**$77**

Exhibit 3-47 Case 1A Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & %	Eng'g CM H.O. & Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
10	ASH/SPENT SORBENT HANDLING SYS													
10.1	Ash Coolers	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.2	Cyclone Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.3	HGCU Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.4	High Temperature Ash Piping	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.5	Other Ash Recovery Equipment	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.6	Ash Storage Silos	586	0	1,806	0	2,393	9.7%	233	0%	0	10.0%	263	2,888	5
10.7	Ash Transport & Feed Equipment	3,795	0	3,888	0	7,683	9.5%	727	0%	0	10.0%	841	9,250	17
10.8	Misc. Ash Handling Equipment	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
10.9	Ash/Spent Sorbent Foundation	0	139	164	0	303	9.3%	28	0%	0	20.0%	66	398	1
	SUBTOTAL 10.	**$4,382**	**$139**	**$5,858**	**$0**	**$10,379**		**$988**		**$0**		**$1,170**	**$12,537**	**$23**
11	ACCESSORY ELECTRIC PLANT													
11.1	Generator Equipment	1,689	0	274	0	1,964	9.3%	182	0%	0	7.5%	161	2,306	4
11.2	Station Service Equipment	8,281	0	2,721	0	11,002	9.6%	1,052	0%	0	7.5%	904	12,958	24
11.3	Switchgear & Motor Control	9,520	0	1,618	0	11,138	9.3%	1,031	0%	0	10.0%	1,217	13,387	24
11.4	Conduit & Cable Tray	0	5,969	20,638	0	26,607	9.6%	2,546	0%	0	15.0%	4,373	33,526	61
11.5	Wire & Cable	0	11,263	21,742	0	33,005	8.4%	2,781	0%	0	15.0%	5,368	41,153	75
11.6	Protective Equipment	261	0	888	0	1,149	9.8%	112	0%	0	10.0%	126	1,388	3
11.7	Standby Equipment	1,336	0	30	0	1,366	9.5%	129	0%	0	10.0%	150	1,645	3
11.8	Main Power Transformers	7,634	0	128	0	7,762	7.6%	590	0%	0	10.0%	835	9,187	17
11.9	Electrical Foundations	0	332	815	0	1,147	9.5%	109	0%	0	20.0%	251	1,507	3
	SUBTOTAL 11.	**$28,721**	**$17,564**	**$48,855**	**$0**	**$95,140**		**$8,533**		**$0**		**$13,385**	**$117,058**	**$213**
12	INSTRUMENTATION & CONTROL													
12.1	PC Control Equipment	w/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.2	Combustion Turbine Control	N/A	0	N/A	0	0	0%	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%	0	0	0
12.4	Other Major Component Control	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
12.5	Signal Processing Equipment	W/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.6	Control Boards, Panels & Racks	600	0	360	0	960	9.6%	92	0%	0	15.0%	158	1,210	2
12.7	Computer Accessories	6,061	0	1,059	0	7,120	9.5%	678	0%	0	10.0%	780	8,578	16
12.8	Instrument Wiring & Tubing	3,286	0	6,519	0	9,806	8.5%	835	0%	0	15.0%	1,596	12,237	22
12.9	Other I & C Equipment	1,712	0	3,886	0	5,598	9.7%	545	0%	0	10.0%	614	6,758	12
	SUBTOTAL 12.	**$11,660**	**$0**	**$11,824**	**$0**	**$23,484**		**$2,151**		**$0**		**$3,148**	**$28,783**	**$52**
13	IMPROVEMENTS TO SITE													
13.1	Site Preparation	0	55	1,091	0	1,145	9.9%	113	0%	0	20.0%	252	1,510	3
13.2	Site Improvements	0	1,811	2,249	0	4,060	9.8%	399	0%	0	20.0%	892	5,350	10
13.3	Site Facilities	3,245	0	3,200	0	6,445	9.8%	633	0%	0	20.0%	1,416	8,493	15
	SUBTOTAL 13.	**$3,245**	**$1,865**	**$6,540**	**$0**	**$11,650**		**$1,144**		**$0**		**$2,559**	**$15,353**	**$28**
14	BUILDINGS & STRUCTURES													
14.1	Boiler Building	0	8,800	7,739	0	16,539	9.0%	1,485	0%	0	15.0%	2,704	20,728	38
14.2	Turbine Building	0	12,691	11,828	0	24,519	9.0%	2,208	0%	0	15.0%	4,009	30,736	56
14.3	Administration Building	0	636	672	0	1,308	9.1%	118	0%	0	15.0%	214	1,641	3
14.4	Circulation Water Pumphouse	0	122	97	0	219	8.9%	20	0%	0	15.0%	36	274	0
14.5	Water Treatment Buildings	0	627	572	0	1,199	9.0%	107	0%	0	15.0%	196	1,502	3
14.6	Machine Shop	0	425	286	0	711	8.9%	63	0%	0	15.0%	116	890	2
14.7	Warehouse	0	288	289	0	577	9.0%	52	0%	0	15.0%	94	724	1
14.8	Other Buildings & Structures	0	235	201	0	436	9.0%	39	0%	0	15.0%	71	546	1
14.9	Waste Treating Building & Str.	0	440	1,334	0	1,774	9.4%	168	0%	0	15.0%	291	2,233	4
	SUBTOTAL 14.	**$0**	**$24,265**	**$23,018**	**$0**	**$47,283**		**$4,260**		**$0**		**$7,731**	**$59,274**	**$108**
	Total Cost	**$657,726**	**$57,647**	**$387,303**	**$0**	**$1,102,676**		**$104,466**		**$8,061**		**$151,442**	**$1,366,646**	**$2,485**

Exhibit 3-48 Case 1A Owner's Costs

Owner's Costs	$1,000	$/kW
Preproduction Costs		
6 Months All Labor	$9,319	$17
1 Month Maintenance Materials	$1,380	$3
1 Month Non-fuel Consumables	$637	$1
1 Month Waste Disposal	$242	$0
25% of 1 Months Fuel Cost at 100% CF	$1,467	$3
2% of TPC	$27,333	$50
Total	**$40,379**	**$73**
Inventory Capital		
60 day supply of fuel and consumables at 100% CF	$12,668	$23
0.5% of TPC (spare parts)	$3	$0
Total	**$12,671**	**$23**
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$204,997	$373
Financing Costs	$36,899	$67
Total Overnight Costs (TOC)	**$1,662,491**	**$3,023**
TASC Multiplier	1.134	
Total As-Spent Cost (TASC)	**$1,885,265**	**$3,428**

Exhibit 3-49 Case 1A O&M Costs

INITIAL & ANNUAL O&M EXPENSES						
Case: Case 1A - Advanced O2 Membrane with Natural Gas Preheater						
Plant Size (MWe):	549.92			**Heat Rate (Btu/kWh):**		10,335
Primary/Secondary Fuel:	Illinois #6 Bituminous Coal			**Fuel Cost ($/MM Btu):**		1.64
Design/Construction	5 years			**Book Life (yrs):**		30
TPC (Plant Cost) Year:	June 2007			**TPI Year:**		2012
Capacity Factor (%):	85			**CO2** Captured (TPD):		12,002
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate (base):		$34.65	$/hour			
Operating Labor Burden:		30.00	% of base			
Labor Overhead Charge:		25.00	% of labor			
Operating Labor Requirements per Shift:		**units/mod.**		**Total Plant**		
Skilled Operator		2.0		2.0		
Operator		9.0		9.0		
Foreman		1.0		1.0		
Lab Tech's etc.		2.0		2.0		
TOTAL Operating Jobs		14.0		14.0		
					$	**$/kW-net**
Annual Operating Labor Cost (calc'd)					5,524,319	10.05
Maintenance Labor Cost (calc'd)					9,386,423	17.07
Administrative & Support Labor (calc'd)					3,727,686	6.78
Property Taxes and Insurance					27,332,915	49.70
TOTAL FIXED OPERATING COSTS					**45,971,342**	**83.60**
VARIABLE OPERATING COSTS						
					$	**$/kWh-net**
Maintenance Material Costs (calc'd)					**$14,079,745**	**0.00344**
Consumables	**Consumption**		**Unit**	**Initial**		
	Initial	**/Day**	**Cost**	**Cost**	**$**	**$/kWh-net**
Water (/1000 gallons)	0	5,174	1.08	$0	$1,736,356	0.00042
Chemicals						
MU & WT Chem. (lb)	0	25,046	0.17	$0	$1,344,812	0.00033
Limestone (ton)	0	510	21.63	$0	$3,419,982	0.00084
Carbon (Hg Removal) (lb)	0	0	1.05	$0	$0	0.00000
MEA Solvent (ton)	0	0	2249.89	$0	$0	0.00000
Caustic Soda, NaOH (ton)	0	0	433.68	$0	$0	0.00000
Sulfuric acid, H_2SO_4 (ton)	0	0	138.78	$0	$0	0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	0.00000
Activated C, MEA (lb)	0	0	1.05	$0	$0	0.00000
Ammonia, 19% soln (ton)	0	0	129.80	$0	$0	0.00000
Subtotal Chemicals				**$0**	**$4,764,794**	**0.00116**
Other						
Supplemental Fuel (MMBtu)	0	0	6.55	$0	$0	0.00000
SCR Catalyst Replacement (m3)	w/equip.	0.0	5775.94	$0	$0	0.00000
Emission Penalties	0	0	0.00	$0	$0	0.00000
Subtotal Other				**$0**	**$0**	**0.00000**
Waste Disposal						
Spent Mercury Catalyst (lb)	0	0	0.42	$0	$0	0.00000
Flyash (ton)	0	393	16.23	$0	$1,977,178	0.00048
Bottom Ash (ton)	0	98	16.23	$0	$494,295	0.00012
Subtotal Solid Waste Disposal				**$0**	**$2,471,473**	**0.00060**
By-products & Emissions						
Gypsum (tons)	0	0	0.00	$0	$0	0.00000
Sulfur (tons)	0	0	0.00	$0	$0	0.00000
Subtotal By-Products				**$0**	**$0**	**0.00000**
TOTAL VARIABLE OPERATING COSTS					**$23,052,368**	**0.00563**
Coal FUEL (tons)	**0**	**5,051**	**38.18**	**$0**	**$59,841,292**	**0.01461**
NATURAL GAS FUEL (Mscf)	**0**	**17,970**	**6.76**	**$0**	**$37,673,269**	**0.00920**

Exhibit 3-50 Equipment List for Case 1 and 1a

ACCOUNT 1 FUEL AND SORBENT HANDLING

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	Bottom Trestle Dumper and Receiving Hoppers	N/A	181 tonne (200 ton)	181 tonne (200 ton)	2 (0)
2	Feeder	Belt	572 tonne/hr (630 tph)	572 tonne/hr (630 tph)	2 (0)
3	Conveyor No. 1	Belt	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1 (0)
4	Transfer Tower No. 1	Enclosed	N/A	N/A	1 (0)
5	Conveyor No. 2	Belt	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1 (0)
6	As-Received Coal Sampling System	Two-stage	N/A	N/A	1 (0)
7	Stacker/Reclaimer	Traveling, linear	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1 (0)
8	Reclaim Hopper	N/A	45 tonne (50 ton)	36 tonne (40 ton)	2 (1)
9	Feeder	Vibratory	191 tonne/hr (210 tph)	154 tonne/hr (170 tph)	2 (1)
10	Conveyor No. 3	Belt w/ tripper	372 tonne/hr (410 tph)	318 tonne/hr (350 tph)	1 (0)
11	Crusher Tower	N/A	N/A	N/A	1 (0)
12	Coal Surge Bin w/ Vent Filter	Dual outlet	191 tonne (210 ton)	154 tonne (170 ton)	2 (0)
13	Crusher	Impactor reduction	8 cm x 0 - 3 cm x 0 (3 in x 0 - 1-1/4 in x 0)	8 cm x 0 - 3 cm x 0 (3 in x 0 - 1-1/4 in x 0)	2 (0)
14	As-Fired Coal Sampling System	Swing hammer	N/A	N/A	1 (1)

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
15	Conveyor No. 4	Belt w/tripper	372 tonne/hr (410 tph)	318 tonne/hr (350 tph)	1 (0)
16	Transfer Tower No. 2	Enclosed	N/A	N/A	1 (0)
17	Conveyor No. 5	Belt w/ tripper	372 tonne/hr (410 tph)	318 tonne/hr (350 tph)	1 (0)
18	Coal Silo w/ Vent Filter and Slide Gates	Field erected	816 tonne (900 ton)	726 tonne (800 ton)	3 (0)
19	Limestone Truck Unloading Hopper	N/A	36 tonne (40 ton)	36 tonne (40 ton)	1 (0)
20	Limestone Feeder	Belt	100 tonne/hr (110 tph)	82 tonne/hr (90 tph)	1 (0)
21	Limestone Conveyor No. L1	Belt	100 tonne/hr (110 tph)	82 tonne/hr (90 tph)	1 (0)
22	Limestone Reclaim Hopper	N/A	18 tonne (20 ton)	18 tonne (20 ton)	1 (0)
23	Limestone Reclaim Feeder	Belt	73 tonne/hr (80 tph)	64 tonne/hr (70 tph)	1 (0)
24	Limestone Conveyor No. L2	Belt	73 tonne/hr (80 tph)	64 tonne/hr (70 tph)	1 (0)
25	Limestone Day Bin	w/ actuator	299 tonne (330 ton)	254 tonne (280 ton)	2 (0)

ACCOUNT 2 COAL AND SORBENT PREPARATION AND FEED

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	Coal Feeder	Gravimetric	45 tonne/hr (50 tph)	36 tonne/hr (40 tph)	6 (0)
2	Coal Pulverizer	Ball type or equivalent	45 tonne/hr (50 tph)	36 tonne/hr (40 tph)	6 (0)
3	Limestone Weigh Feeder	Gravimetric	25 tonne/hr (28 tph)	21 tonne/hr (23 tph)	1 (1)

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
4	Limestone Ball Mill	Rotary	25 tonne/hr (28 tph)	21 tonne/hr (23 tph)	1 (1)
5	Limestone Mill Slurry Tank with Agitator	N/A	98,421 liters (26,000 gal)	83,279 liters (22,000 gal)	1 (1)
6	Limestone Mill Recycle Pumps	Horizontal centrifugal	1,628 lpm @ 12m H_2O (430 gpm @ 40 ft H_2O)	1,363 lpm @ 12m H_2O (360 gpm @ 40 ft H_2O)	1 (1)
7	Hydroclone Classifier	4 active cyclones in a 5-cyclone bank	416 lpm (110 gpm) per cyclone	341 lpm (90 gpm) per cyclone	1 (1)
8	Distribution Box	2-way	N/A	N/A	1 (1)
9	Limestone Slurry Storage Tank with Agitator	Field erected	545,099 liters (144,000 gal)	458,035 liters (121,000 gal)	1 (1)
10	Limestone Slurry Feed Pumps	Horizontal centrifugal	1,136 lpm @ 9m H_2O (300 gpm @ 30 ft H_2O)	946 lpm @ 9m H_2O (250 gpm @ 30 ft H_2O)	1 (1)

ACCOUNT 3 FEEDWATER AND MISCELLANEOUS SYSTEMS AND EQUIPMENT

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	995,563 liters (263,000 gal)	1,018,276 liters (269,000 gal)	2 (0)
2	Condensate Pumps	Vertical canned	23,470 lpm @ 213 m H_2O (6,200 gpm @ 700 ft H_2O)	23,848 lpm @ 213 m H_2O (6,300 gpm @ 700 ft H_2O)	1 (1)

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
3	Deaerator and Storage Tank	Horizontal spray type	1,658,787 kg/hr (3,657,000 lb/hr)	1,101,555 liters (291,000 gal)	1 (0)
4	Boiler Feed Pump/Turbine	Barrel type, multi-stage, centrifugal	28,012 lpm @ 3,444 m H_2O (7,400 gpm @ 11,300 ft H_2O)	25,741 lpm @ 213 m H_2O (6,800 gpm @ 700 ft H_2O)	1 (1)
5	Startup Boiler Feed Pump, Electric Motor Driven	Barrel type, multi-stage, centrifugal	8,328 lpm @ 3,444 m H_2O (2,200 gpm @ 11,300 ft H_2O)	1,832,060 kg/hr (4,039,000 lb/hr), 5 min. tank	1 (0)
6	LP Feedwater Heater 1A/1B	Horizontal U-tube	703,068 kg/hr (1,550,000 lb/hr)	30,662 lpm @ 3,444 m H_2O (8,100 gpm @ 11,300 ft H_2O)	2 (0)
7	LP Feedwater Heater 2A/2B	Horizontal U-tube	703,068 kg/hr (1,550,000 lb/hr)	9,085 lpm @ 3,444 m H_2O (2,400 gpm @ 11,300 ft H_2O)	2 (0)
8	LP Feedwater Heater 3A/3B	Horizontal U-tube	703,068 kg/hr (1,550,000 lb/hr)	766,571 kg/hr (1,690,000 lb/hr)	2 (0)
9	LP Feedwater Heater 4A/4B	Horizontal U-tube	703,068 kg/hr (1,550,000 lb/hr)	766,571 kg/hr (1,690,000 lb/hr)	2 (0)
10	HP Feedwater Heater 6	Horizontal U-tube	1,660,148 kg/hr (3,660,000 lb/hr)	766,571 kg/hr (1,690,000 lb/hr)	1 (0)
11	HP Feedwater Heater 7	Horizontal U-tube	1,660,148 kg/hr (3,660,000 lb/hr)	766,571 kg/hr (1,690,000 lb/hr)	1 (0)
12	HP Feedwater heater 8	Horizontal U-tube	1,660,148 kg/hr (3,660,000 lb/hr)	1,832,513 kg/hr (4,040,000 lb/hr)	1 (0)
13	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	1,832,513 kg/hr (4,040,000 lb/hr)	1 (0)
14	Fuel Oil System	No. 2 fuel oil for light off	1,135,624 liter (300,000 gal)	1,832,513 kg/hr (4,040,000 lb/hr)	1 (0)

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
15	Service Air Compressors	Flooded Screw	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	2 (1)
16	Instrument Air Dryers	Duplex, regenerative	28 m^3/min (1,000 scfm)	28 m^3/min (1,000 scfm)	2 (1)
17	Closed Cycle Cooling Heat Exchangers	Shell and tube	53 GJ/hr (50 MMBtu/hr) each	53 GJ/hr (50 MMBtu/hr) each	2 (0)
18	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	20,820 lpm @ 30 m H_2O (5,500 gpm @ 100 ft H_2O)	20,820 lpm @ 30 m H_2O (5,500 gpm @ 100 ft H_2O)	2 (1)
19	Engine-Driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 88 m H_2O (1,000 gpm @ 290 ft H_2O)	3,785 lpm @ 88 m H_2O (1,000 gpm @ 290 ft H_2O)	1 (1)
20	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 64 m H_2O (700 gpm @ 210 ft H_2O)	2,650 lpm @ 64 m H_2O (700 gpm @ 210 ft H_2O)	1 (1)
21	Raw Water Pumps	Stainless steel, single suction	16,996 lpm @ 43 m H_2O (4,490 gpm @ 140 ft H_2O)	16,050 lpm @ 43 m H_2O (4,240 gpm @ 140 ft H_2O)	2 (1)
22	Filtered Water Pumps	Stainless steel, single suction	568 lpm @ 49 m H_2O (150 gpm @ 160 ft H_2O)	568 lpm @ 49 m H_2O (150 gpm @ 160 ft H_2O)	2 (1)
23	Filtered Water Tank	Vertical, cylindrical	541,314 liter (143,000 gal)	541,314 liter (143,000 gal)	1 (0)
24	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly, electrodeionization unit	681 lpm (180 gpm)	719 lpm (190 gpm)	1 (1)
25	Liquid Waste Treatment System	--	10 years, 24-hour storm	10 years, 24-hour storm	1 (0)

ACCOUNT 4 BOILER AND ACCESSORIES

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	Boiler	Supercritical, drum, wall-fired, low NOx burners, overfire air	1,787,154 kg/hr steam @ 25.5 MPa/607°C/629°C (3,940,000 lb/hr steam @ 3,700 psig/1,125°F/1,165°F)	1,941,375 kg/hr steam @ 25.5 MPa/607°C/629°C (4,280,000 lb/hr steam @ 3,700 psig/1,125°F/1,165°F)	1 (0)
2	Primary Air Fan	Centrifugal	185,066 kg/hr, 2,223 m^3/min @ 47 cm WG (408,000 lb/hr, 78,500 acfm @ 19 in. WG)	156,036 kg/hr, 1,889 m^3/min @ 47 cm WG (344,000 lb/hr, 66,700 acfm @ 19 in. WG)	2 (0)
3	Forced Draft Fan	Centrifugal	602,371 kg/hr, 7,238 m^3/min @ 123 cm WG (1,328,000 lb/hr, 255,600 acfm @ 48 in. WG)	508,477 kg/hr, 6,145 m^3/min @ 123 cm WG (1,121,000 lb/hr, 217,000 acfm @ 48 in. WG)	2 (0)
4	Induced Draft Fan	Centrifugal	1,178,433 kg/hr, 20,252 m^3/min @ 95 cm WG (2,598,000 lb/hr, 715,200 acfm @ 37 in. WG)	998,357 kg/hr, 17,242 m^3/min @ 95 cm WG (2,201,000 lb/hr, 608,900 acfm @ 37 in. WG)	2 (0)
5	ASU Main Air Compressor	Centrifugal, multi-stage	21,323 m^3/min @ 1.5 MPa (753,000 scfm @ 215 psia)	20,020 m^3/min @ 1.5 MPa (707,000 scfm @ 215 psia)	2 (0)
6	Advanced Membrane ASU	Vendor design	5,987 tonne/day (6,600 tpd) of 100% purity oxygen	5,080 tonne/day (5,600 tpd) of 100% purity oxygen	2 (0)
7	Nitrogen Expander	Centrifugal, multi-stage	18,208 m^3/min @ 0.1 MPa (643,000 scfm @ 015 psia)	21,436 m^3/min @ 0.1 MPa (757,000 scfm @ 015 psia)	2 (0)
8	Recuperator	Single pass, multi-stage	1,023 GJ/hr (970 MMBtu/hr), Inlet N_2 temperature 330°C (625°F), Inlet O_2 temperature 802°C (1,475°F), N_2 temperature decrease 264°C (475°F), O_2 temperature decrease 736°C (1,325°F)	1,308 GJ/hr (1,240 MMBtu/hr), Inlet N_2 temperature 330°C (625°F), Inlet O_2 temperature 802°C (1,475°F), N_2 temperature decrease 270°C (485°F), O_2 temperature decrease 736°C (1,325°F)	2 (0)

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
9	PreHeater	Single pass, heat exchanger	N/A	528 GJ/hr (501 MMBtu/hr), Inlet air temperature 391°C (735°F), air temperature increase 181°C (326°F)	1 (0)
10	NG Combustor	Vendor design	N/A	823 GJ/hr (780 MMBtu/hr), Inlet air temperature 572°C (1,061°F), air temperature increase 230°C (414°F)	1 (0)

ACCOUNT 5 FLUE GAS CLEANUP

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	Fabric Filter	Single stage, high-ratio with pulse-jet online cleaning system	1,178,433 kg/hr (2,598,000 lb/hr) 99.8% efficiency	998,357 kg/hr (2,201,000 lb/hr) 99.8% efficiency	2 (0)
2	Absorber Module	Counter-current open spray	39,927 m^3/min (1,410,000 acfm)	34,009 m^3/min (1,201,000 acfm)	1 (0)
3	Recirculation Pumps	Horizontal centrifugal	140,060 lpm @ 64 m H2O (37,000 gpm @ 210 ft H2O)	117,348 lpm @ 64 m H_2O (31,000 gpm @ 210 ft H_2O)	5 (1)
4	Bleed Pumps	Horizontal centrifugal	4,959 lpm (1,310 gpm) at 20 wt% solids	4,164 lpm (1,100 gpm) at 20 wt% solids	2 (1)

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
5	Oxidation Air Blowers	Centrifugal	24 m^3/min @ 0.3 MPa (840 acfm @ 42 psia)	18 m^3/min @ 0.3 MPa (640 acfm @ 42 psia)	2 (1)
6	Agitators	Side entering	50 hp	50 hp	5 (1)
7	Dewatering Cyclones	Radial assembly, 5 units each	1,249 lpm (330 gpm) per cyclone	1,060 lpm (280 gpm) per cyclone	2 (0)
8	Vacuum Filter Belt	Horizontal belt	39 tonne/hr (43 tph) of 50 wt % slurry	33 tonne/hr (36 tph) of 50 wt % slurry	2 (1)
9	Filtrate Water Return Pumps	Horizontal centrifugal	757 lpm @ 12 m H_2O (200 gpm @ 40 ft H_2O)	644 lpm @ 12 m H_2O (170 gpm @ 40 ft H_2O)	1 (1)
10	Filtrate Water Return Storage Tank	Vertical, lined	492,104 lpm (130,000 gal)	416,395 lpm (110,000 gal)	1 (0)
11	Process Makeup Water Pumps	Horizontal centrifugal	454 lpm @ 21 m H_2O (120 gpm @ 70 ft H_2O)	379 lpm @ 21 m H_2O (100 gpm @ 70 ft H_2O)	1 (1)

ACCOUNT 5B CARBON DIOXIDE RECOVERY

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	CO_2 Compressor	Centrifugal	295,808 kg/h @ 15.3 MPa (652,146 lb/h @ 2,215 psia)	249,507 kg/h @ 15.3 MPa (550,069 lb/h @ 2,215 psia)	2 (0)

ACCOUNT 7 HRSG, DUCTING & STACK

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	Stack	Reinforced concrete with FRP liner	46 m (150 ft) high x 3.4 m (11 ft) diameter	46 m (150 ft) high x 3.2 m (10 ft) diameter	1 (0)

ACCOUNT 8 STEAM TURBINE GENERATOR AND AUXILIARIES

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	Steam Turbine	Commercially available advanced steam turbine	653 MW 24.1 MPa/599°C/621°C (3,500 psig/ 1,110°F/1,150°F)	697 MW 24.1 MPa/599°C/621°C (3,500 psig/ 1,110°F/1,150°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	730 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	770 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)
3	Surface Condenser	Single pass, divided waterbox including vacuum pumps	3,112 GJ/hr (2,950 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	31020 GJ/hr (2,940 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	776,000 lpm @ 30 m (205,000 gpm @ 100 ft)	734,400 lpm @ 30 m (194,000 gpm @ 100 ft)	2 (1)

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT / 4,326 GJ/hr (4,100 MMBtu/hr) heat duty	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT / 4,094 GJ/hr (3,880 MMBtu/hr) heat duty	1 (0)

ACCOUNT 10 ASH/SPENT SORBENT RECOVERY AND HANDLING

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	Economizer Hopper (part of boiler scope of supply)	--	--	--	4 (0)
2	Bottom Ash Hopper (part of boiler scope of supply)	--	--	--	2 (0)
3	Clinker Grinder	--	5.4 tonne/hr (6 tph)	4.5 tonne/hr (5 tph)	1 (1)
4	Pyrites Hopper (part of pulverizer scope of supply included with boiler)	--	--	--	6 (0)
5	Hydroejectors	--	--	--	12 (1)
6	Economizer /Pyrites Transfer Tank	--	--	--	1 (0)
7	Ash Sluice Pumps	Vertical, wet pit	189 lpm @ 17 m H_2O (50 gpm @ 56 ft H_2O)	151 lpm @ 17 m H_2O (40 gpm @ 56 ft H_2O)	1 (1)

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
8	Ash Seal Water Pumps	Vertical, wet pit	7,571 lpm @ 9 m H_2O (2000 gpm @ 28 ft H_2O)	7,571 lpm @ 9 m H_2O (2000 gpm @ 28 ft H_2O)	1 (1)
9	Hydrobins	--	189 lpm (50 gpm)	151 lpm (40 gpm)	1 (1)
10	Baghouse Hopper (part of baghouse scope of supply)	--	--	--	24 (0)
11	Air Heater Hopper (part of boiler scope of supply)	--	--	--	10 (0)
12	Air Blower	--	18 m^3/min @ 0.2 MPa (620 scfm @ 24 psi)	15 m^3/min @ 0.2 MPa (530 scfm @ 24 psi)	1 (1)
13	Fly Ash Silo	Reinforced concrete	590 tonne (1,300 ton)	499 tonne (1,100 ton)	2 (0)
14	Slide Gate Valves	--	--	--	2 (0)
15	Unloader	--	--	--	1 (0)
16	Telescoping Unloading Chute	--	109 tonne/hr (120 tph)	91 tonne/hr (100 tph)	1 (0)

ACCOUNT 11 ACCESSORY ELECTRIC PLANT

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a Design Condition	Operating Qty. (Spares)
1	STG Transformer	Oil-filled	24 kV/345 kV, 240 MVA, 3-ph, 60 Hz	24 kV/345 kV, 330 MVA, 3-ph, 60 Hz	1 (0)
2	Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 458 MVA, 3-ph, 60 Hz	24 kV/4.16 kV, 424 MVA, 3-ph, 60 Hz	1 (1)
3	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 69 MVA, 3-ph, 60 Hz	4.16 kV/480 V, 64 MVA, 3-ph, 60 Hz	1 (1)
4	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	24 kV, 3-ph, 60 Hz	1 (0)
5	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	4.16 kV, 3-ph, 60 Hz	1 (1)
6	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	480 V, 3-ph, 60 Hz	1 (1)
7	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

ACCOUNT 12 INSTRUMENTATION AND CONTROL

Equipment No.	Description	Type	Case 1 Design Condition	Case 1a 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	Operator stations/printers and engineering stations/printers	1 (0)
2	DCS - Processor	Microprocessor with redundant input/output	N/A	N/A	1 (0)
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	Fully redundant, 25% spare	1 (0)

3.4 CASE 4 – SUPERCRITICAL CO-SEQUESTRATION PROCESS

Case 4 does not use an FGD system, which means that the process is designed to capture CO_2 together with contaminants such as sulfur. This system is theoretically possible in an oxycombustion configuration due to the ability to co-sequester all flue gas constituents. However, since oxycombustion involves inert removal prior to firing, this causes the sulfur concentration in the flue gas stream to increase. For instance, for air-fired cases that utilize the same design fuel as this study, the boiler SO_2 concentrations are approximately 2,500 ppm. For Case 4, the sulfur concentrations in the boiler are approximately 8,400 ppm (a 3.36-fold increase in sulfur concentration from the air-fired case). Since current practical design limits for boiler materials to avoid excess corrosion is about a 3.5 percent sulfur coal (or approximately 3,500 ppm SO_2 in the flue gas), sulfur tolerant materials would be required for the boiler system, induced, forced, and primary air fans, and the baghouse for Case 4 of this study.

Similar to the current technology case (but without a wet FGD), major components for Case 4 include the following:

1. Conventional cryogenic ASU
2. PC boiler operating at supercritical steam conditions
3. Baghouse to remove particulates
4. CPU with compression to 15.3 MPa (2,215 psia)
5. Steam Turbine/generator

Block Flow Diagram and Stream Table

A process BFD for the supercritical CO_2 co-sequestration Case 4 is shown in Exhibit 3-51, and the corresponding stream tables are shown in Exhibit 3-52.

Heat and Mass Balance Diagram

Heat and mass balance diagrams are shown for the following subsystems in Exhibit 3-53 and Exhibit 3-54.

- Boiler and flue gas cleanup
- Steam cycle and feed water (power block)

Energy, Carbon, Sulfur, and Water Balances

An overall plant energy balance is provided in tabular form in Exhibit 3-55. The power out is the steam turbine power after generator losses.

Carbon, sulfur, and water balances are shown in Exhibit 3-56 through Exhibit 3-58.

Performance Summary

A performance summary is provided in Exhibit 3-59.

Costing Table

Tables of capital costs, owner's costs, and O&M costs are provided in Exhibit 3-60 through Exhibit 3-62, respectively.

Equipment List

In the interest of consolidation, the combined equipment list for Case 4 through Case 7 is shown in Exhibit 3-99.

Exhibit 3-51 Process Block Flow Diagram for Case 4

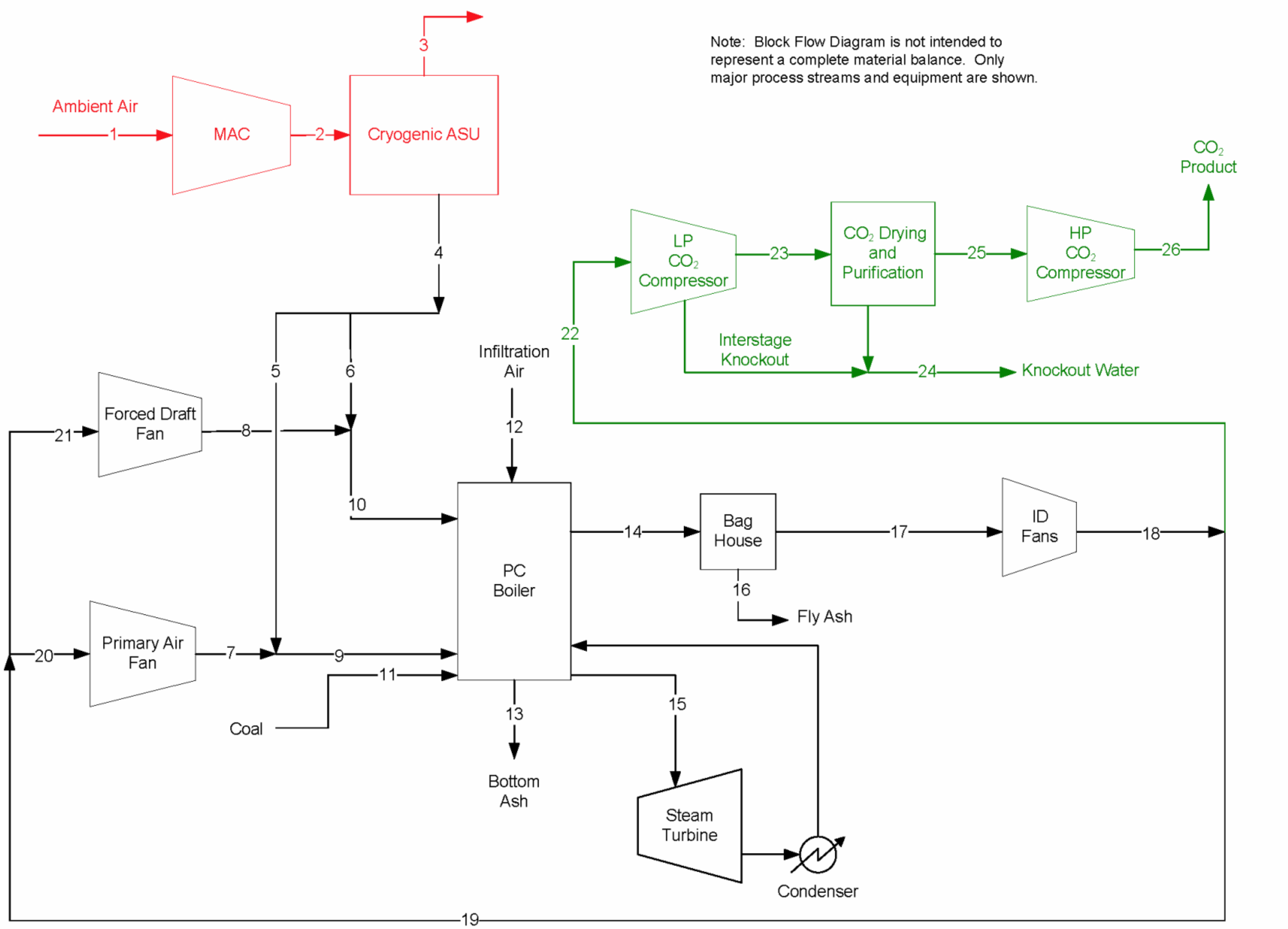


Exhibit 3-52 Stream Table for Case 4

	1	2	3	4	5	6	7	8	9	10	11	12	13
V-L Mole Fraction													
Ar	0.0092	0.0092	0.0024	0.0340	0.0340	0.0340	0.0251	0.0251	0.0275	0.0275	0.0000	0.0092	0.0000
CO_2	0.0005	0.0005	0.0006	0.0000	0.0000	0.0000	0.5692	0.5692	0.4139	0.4139	0.0000	0.0005	0.0000
H_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
H_2O	0.0101	0.0101	0.0128	0.0000	0.0000	0.0000	0.3047	0.3047	0.2215	0.2215	0.0000	0.0101	0.0000
N_2	0.7729	0.7729	0.9778	0.0162	0.0162	0.0162	0.0697	0.0697	0.0551	0.0551	0.0000	0.7729	0.0000
O_2	0.2074	0.2074	0.0063	0.9498	0.9498	0.9498	0.0230	0.0230	0.2758	0.2758	0.0000	0.2074	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0084	0.0084	0.0061	0.0061	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	0.0000	1.0000	0.0000
V-L Flowrate (kg_{mol}/hr)	72,546	72,546	57,084	15,462	3,634	11,829	9,685	31,527	13,318	43,355	0	1,451	0
V-L Flowrate (kg/hr)	2,093,396	2,093,396	1,595,430	497,966	117,022	380,944	336,687	1,096,022	453,709	1,476,966	0	41,868	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	229,991	0	4,471
Temperature (°C)	15	24	17	13	13	13	222	215	176	170	15	15	15
Pressure (MPa, abs)	0.10	0.59	0.10	0.16	0.16	0.16	0.11	0.11	0.11	0.11	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	30.57	32.03	38.64	11.49	11.49	11.49	632.51	623.68	472.33	465.78	---	30.57	---
Density (kg/m^3)	1.2	7.0	1.2	2.2	2.2	2.2	0.9	0.9	1.0	1.0	---	1.2	---
V-L Molecular Weight	28.856	28.856	27.949	32.205	32.205	32.205	34.765	34.765	34.066	34.066	---	28.856	---
V-L Flowrate (lb_{mol}/hr)	159,937	159,937	125,848	34,089	8,011	26,078	21,351	69,504	29,362	95,582	0	3,199	0
V-L Flowrate (lb/hr)	4,615,147	4,615,148	3,517,322	1,097,827	257,989	839,837	742,267	2,416,315	1,000,256	3,256,153	0	92,303	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	507,043	0	9,857
Temperature (°F)	59	75	63	55	56	56	432	418	349	338	59	59	59
Pressure (psia)	14.7	86.1	14.7	23.2	23.2	23.2	16.2	15.3	16.2	15.3	14.7	14.7	14.7
Enthalpy (Btu/lb)[A]	13.1	13.8	16.6	4.9	4.9	4.9	271.9	268.1	203.1	200.2	---	13.1	---
Density (lb/ft^3)	0.076	0.435	0.073	0.135	0.135	0.135	0.059	0.057	0.064	0.061	---	0.076	---

A - Reference conditions are 32.02 F & 0.089 PSIA

Exhibit 3-52 Stream Table for Case 4 (Continued)

	14	15	16	17	18	19	20	21	22	23	24	25	26
V-L Mole Fraction													
Ar	0.0251	0.0000	0.0000	0.0251	0.0251	0.0251	0.0251	0.0251	0.0304	0.0360	0.0000	0.0361	0.0361
CO_2	0.5692	0.0000	0.0000	0.5692	0.5692	0.5692	0.5692	0.5692	0.6905	0.8171	0.0000	0.8184	0.8184
H_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
H_2O	0.3047	1.0000	0.0000	0.3047	0.3047	0.3047	0.3047	0.3047	0.1564	0.0017	1.0000	0.0002	0.0002
N_2	0.0697	0.0000	0.0000	0.0697	0.0697	0.0697	0.0697	0.0697	0.0846	0.1001	0.0000	0.1003	0.1003
O_2	0.0230	0.0000	0.0000	0.0230	0.0230	0.0230	0.0230	0.0230	0.0279	0.0330	0.0000	0.0330	0.0330
SO_2	0.0084	0.0000	0.0000	0.0084	0.0084	0.0084	0.0084	0.0084	0.0102	0.0120	0.0000	0.0120	0.0120
Total	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	62,712	116,611	0	62,712	62,712	41,211	9,685	31,527	17,721	14,976	6,551	14,952	14,952
V-L Flowrate (kg/hr)	2,180,179	2,100,779	0	2,180,179	2,180,179	1,432,709	336,687	1,096,022	679,374	629,909	118,028	629,483	629,483
Solids Flowrate (kg/hr)	17,884	0	17,884	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	204	599	15	204	210	210	210	210	58	100	43	100	35
Pressure (MPa, abs)	0.10	24.23	0.10	0.10	0.10	0.10	0.10	0.10	0.10	3.33	0.10	3.33	15.27
Enthalpy (kJ/kg)[A]	682.04	3,493.92	---	612.21	617.96	617.96	617.96	617.96	236.31	69.77	178.39	68.06	-149.36
Density (kg/m^3)	0.9	68.5	---	0.9	0.9	0.9	0.9	0.9	1.4	48.5	970.0	48.5	576.2
V-L Molecular Weight	34.765	18.015	---	34.765	34.765	34.765	34.765	34.765	38.337	42.062	18.017	42.100	42.100
V-L Flowrate (lb_{mol}/hr)	138,256	257,083	0	138,256	138,256	90,855	21,351	69,504	39,068	33,016	14,442	32,964	32,964
V-L Flowrate (lb/hr)	4,806,471	4,631,426	0	4,806,471	4,806,471	3,158,582	742,267	2,416,315	1,497,764	1,388,712	260,207	1,387,771	1,387,771
Solids Flowrate (lb/hr)	39,426	0	39,426	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	400	1,110	59	400	409	409	409	409	136	212	109	212	95
Pressure (psia)	14.4	3,514.7	14.7	14.2	14.7	14.7	14.7	14.7	14.7	483.4	14.7	483.4	2,214.7
Enthalpy (Btu/lb)[A]	293.2	1,502.1	---	263.2	265.7	265.7	265.7	265.7	101.6	30.0	76.7	29.3	-64.2
Density (lb/ft^3)	0.054	4.274	---	0.054	0.055	0.055	0.055	0.055	0.089	3.028	60.553	3.030	35.971

Exhibit 3-53 Heat and Mass Balance, Boiler and Gas Cleanup Systems for Case 4

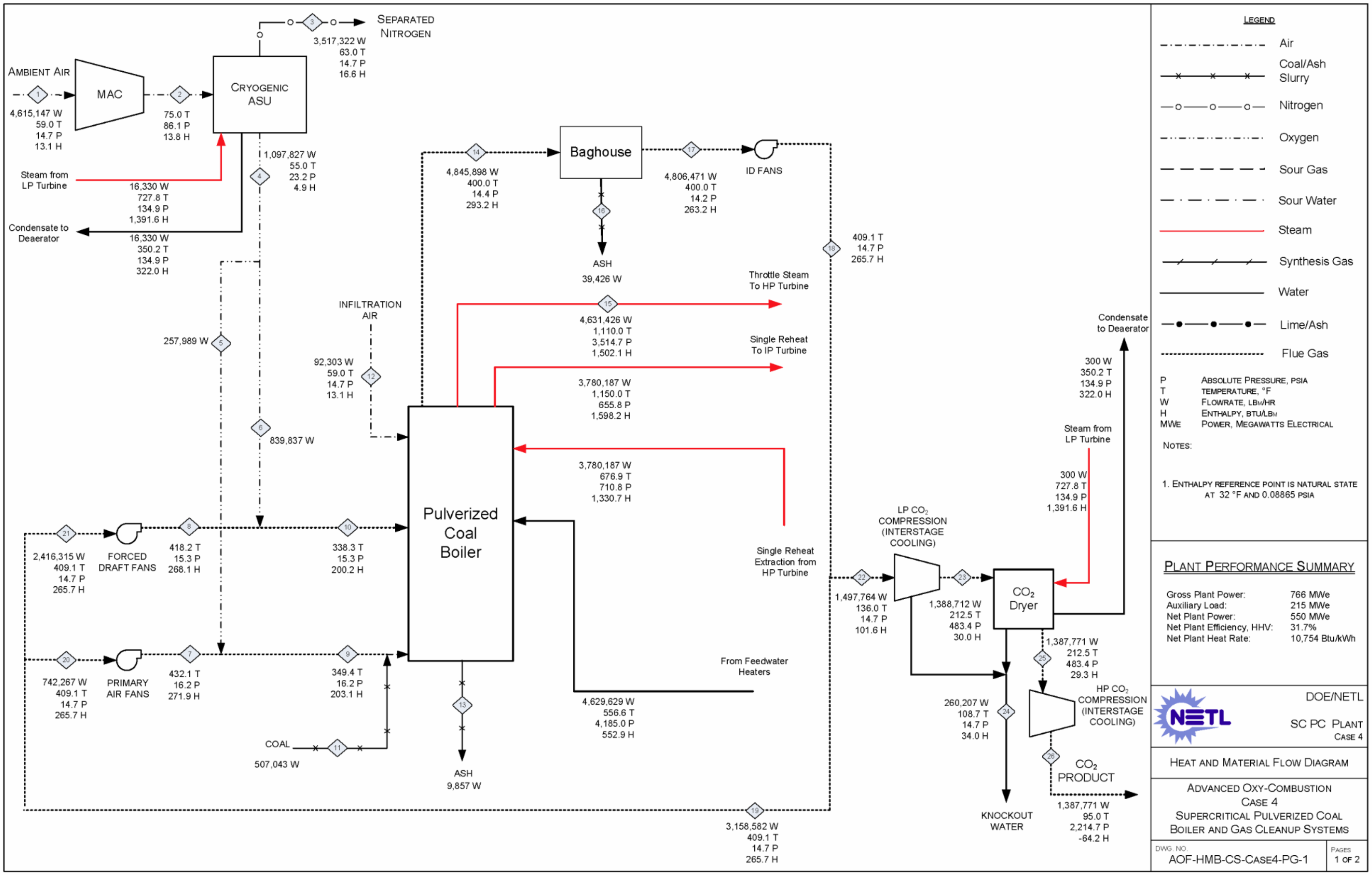


Exhibit 3-54 Heat and Mass Balance, Power Block Systems for Case 4

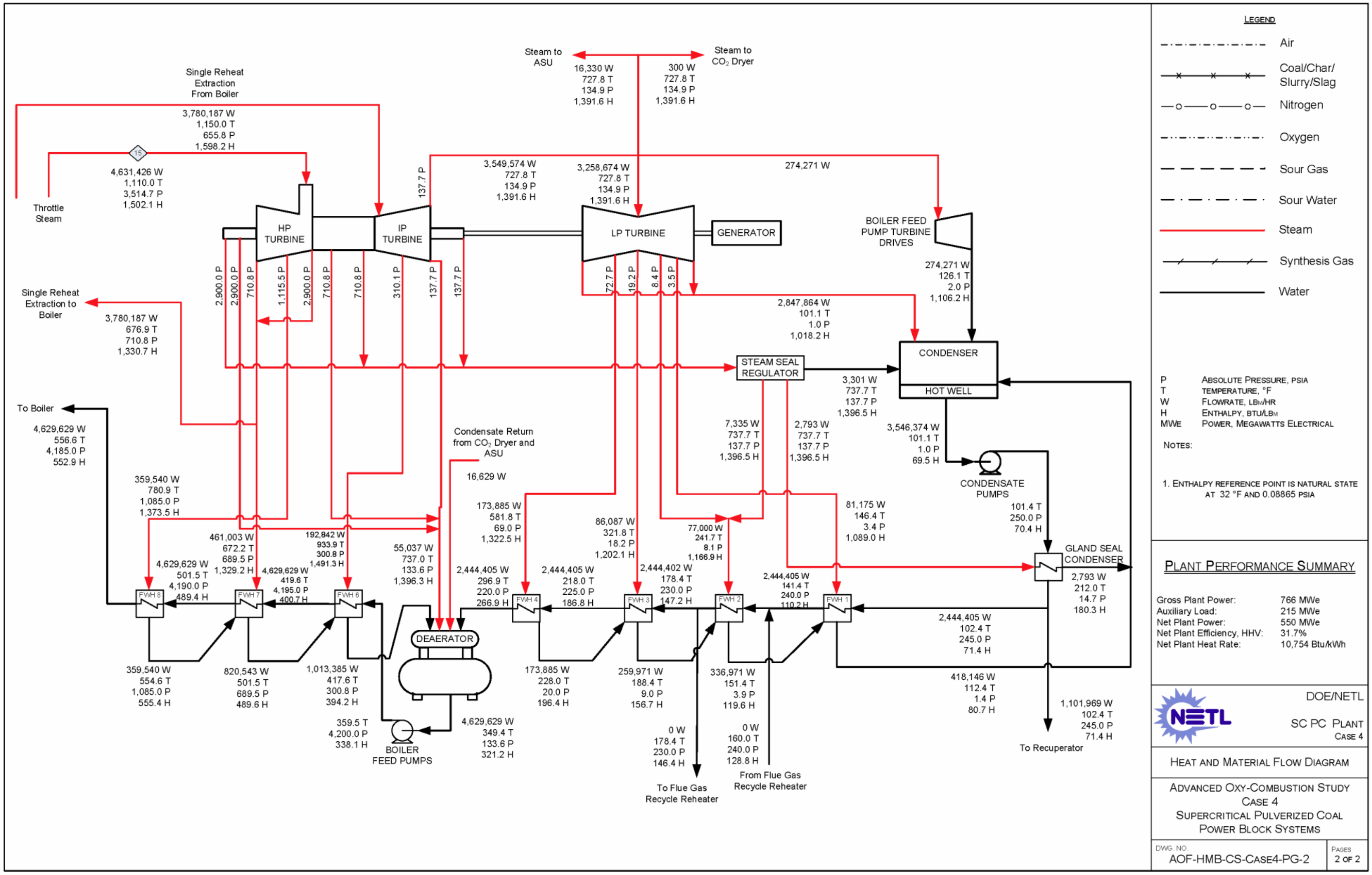


Exhibit 3-55 Cases 4 Energy Balance

	HHV	Sensible + Latent	Power	Total
Heat In GJ/hr (MMBtu/hr)				
Coal	6,241 (5,915)	5.2 (4.9)		6,246 (5,920)
Combustion Air		65.3 (61.9)		65.3 (61.9)
Raw Water Makeup		113.6 (107.7)		113.6 (107.7)
Limestone		0.00 (0.00)		0.00 (0.00)
Auxiliary Power			776 (735)	776 (735)
Totals	**6,241 (5,915)**	**184.1 (174.5)**	**776 (735)**	**7,201 (6,825)**
Heat Out GJ/hr (MMBtu/hr)				
Boiler Loss		57.8 (54.7)		57.8 (54.7)
Bottom Ash		0.7 (0.6)		0.7 (0.6)
Fly Ash + FGD Ash		2.7 (2.5)		2.7 (2.5)
MAC Cooling		401.6 (380.6)		401.6 (380.6)
ASU Vent		61.7 (58.4)		61.7 (58.4)
Condenser		3,160 (2,995)		3,160 (2,995)
CO_2 Cooling		486 (461)		486 (461)
CO_2		-94 (-89)		-94 (-89)
Wet FGD Cooling		0 (0)		0 (0)
Process Condensate		21 (20)		21 (20)
Cooling Tower Blowdown		53.2 (50.4)		53.2 (50.4)
Process Losses*		*351.5 (333.2)*		*351.5 (333.2)*
Power			2,756 (2,612)	2,756 (2,612)
Totals		**4,445 (4,213)**	**2,756 (2,612)**	**7,201 (6,825)**

Note: Italicized numbers are estimated
Reference conditions are 0°C (32.02°F) & 0.6 kPa (0.089 psia)
* Process losses are estimated to match the heat input to the plant and include losses from: steam turbine, combustion reactions, and gas cooling.

Exhibit 3-56 Case 4 Carbon Balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	146,974 (324,022)	CO_2 Product	146,980 (324,036)
Air (CO_2)	408 (899)	FGD Product	0 (0)
FGD Reagent	0 (0)	Separated Air	400 (882)
		Convergence Tolerance*	1 (3)
Total	147,382 (324,921)	Total	147,382 (324,921)

*by difference

Exhibit 3-57 Case 4 Sulfur Balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	5,778 (12,739)	CO_2 Compression Knockout	6 (14)
		CO_2 Product	5,772 (12,725)
		Convergence Tolerance*	0 (0)
Total	5,778 (12,739)	Total	5,778 (12,739)

*by difference

Exhibit 3-58 Case 4 Water Balance

Water Use	Water Demand	Internal Recycle	Raw Water Withdrawal	Process Water Discharge	Raw Water Consumption
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)
FGD Makeup	0.00 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
BFW Makeup	0.35 (93)	0.0 (0)	0.35 (93)	0.0 (0)	0.35 (93)
Cooling Tower	31.8 (8,403)	1.97 (520)	29.8 (7,883)	7.15 (1,890)	22.69 (5,993)
Total	**32.2 (8,496)**	**1.97 (520)**	**30.2 (7,976)**	**7.15 (1,890)**	**23.04 (6,086)**

Exhibit 3-59 Case 4 Performance Summary

Plant Output		
Steam Turbine Power	765,500	kW_e
Gross Power	**765,500**	kWe
Auxiliary Load		
Coal Handling and Conveying	480	kW_e
Limestone Handling & Reagent Preparation	0	kW_e
Pulverizers	3,450	kW_e
Ash Handling	660	kW_e
Primary Air Fans	1,410	kW_e
Forced Draft Fans	1,800	kW_e
Induced Draft Fans	3,610	kW_e
Air Separation Unit Main Air Compressor	115,970	kW_e
ASU Auxiliaries	1,000	kW_e
Baghouse	90	kW_e
FGD Pumps and Agitators	0	kWe
CO_2 Compression	67,770	kW_e
Condensate Pumps	1,020	kW_e
Boiler Feedwater Booster Pumps[2]	N/A	kW_e
Miscellaneous Balance of Plant[3]	2,000	kW_e
Steam Turbine Auxiliaries	400	kW_e
Circulating Water Pumps	8,170	kW_e
Cooling Tower Fans	4,770	kW_e
Transformer Losses	2,880	kW_e
Total	215,480	kW_e
Plant Performance		
Net Auxiliary Load	215,480	kW_e
Net Plant Power	550,020	kW_e
Net Plant Efficiency (HHV)	31.7%	
Net Plant Heat Rate (HHV)	11,347 (10,754)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	229,991 (507,043)	kg/hr (lb/hr)
Thermal Input[1]	1,733,562	kW_{th}
Condenser Duty	3,160 (2,995)	GJ/hr (MMBtu/hr)
Raw Water Usage	30.2 (7,976)	m^3/min (gpm)

1 - HHV of As Received Illinois No. 6 coal is 27,135 kJ/kg (11,666 Btu/lb)

2 - Boiler feed pumps are turbine driven

3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 3-60 Case 4 Capital Costs

	Department:	NETL Office of Program Planning and Analysis										**Cost Base:**	June 2007	
	Project:	Advancing Oxycombustion Technology										**Prepared:**	13-Apr-12	
	Case:	Case 4 - Co-sequestration											**x $1, 000**	
	Plant Size:	550	MW, net			Capital Charge Factor	0.158		Capacity Factor	0.85				
		Equipment	**Material**	**Labor**		**Bare**	**Eng'g CM H.O. &**		**Process Cont.**		**Project Cont.**		**TOTAL PLANT COST**	
Acct No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Erected**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**$**	**$/kW**
1	COAL HANDLING SYSTEM													
1.1	Coal Receive & Unload	3,759	0	1,717	0	5,477	8.9%	489	0%	0	15.0%	895	6,860	12
1.2	Coal Stackout & Reclaim	4,859	0	1,101	0	5,959	8.8%	522	0%	0	15.0%	972	7,453	14
1.3	Coal Conveyors & Yd Crus	4,517	0	1,089	0	5,606	8.8%	491	0%	0	15.0%	915	7,013	13
1.4	Other Coal Handling	1,182	0	252	0	1,434	8.7%	125	0%	0	15.0%	234	1,793	3
1.5	Sorbent Receive & Unload	0	0	0	0	0	8.8%	0	0%	0	15.0%	0	0	0
1.6	Sorbent Stackout & Reclaim	0	0	0	0	0	8.7%	0	0%	0	15.0%	0	0	0
1.7	Sorbent Conveyors	0	0	0	0	0	8.7%	0	0%	0	15.0%	0	0	0
1.8	Other Sorbent Handling	0	0	0	0	0	8.8%	0	0%	0	15.0%	0	0	0
1.9	Coal & Sorbent Hnd.Foundations	0	4,355	5,494	0	9,848	9.3%	921	0%	0	15.0%	1,615	12,384	23
	SUBTOTAL 1.	**$14,317**	**$4,355**	**$9,653**	**$0**	**$28,325**		**$2,548**		**$0**		**$4,631**	**$35,504**	**$65**
2	COAL PREP & FEED SYSTEMS													
2.1	Coal Crushing & Drying	2,169	0	423	0	2,591	8.7%	226	0%	0	15.0%	423	3,240	6
2.2	Prepared Coal Storage & Feed	5,552	0	1,212	0	6,764	8.7%	592	0%	0	15.0%	1,103	8,459	15
2.3	Slurry Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.4	Misc. Coal Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.5	Sorbent Prep Equipment	0	0	0	0	0	8.7%	0	0%	0	15.0%	0	0	0
2.6	Sorbent Storage & Feed	0	0	0	0	0	8.9%	0	0%	0	15.0%	0	0	0
2.7	Sorbent Injection System	0	0	0	0	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	0.0%	0	0	0
2.9	Coal & Sorbent Feed Foundation	0	512	430	0	942	9.2%	87	0%	0	15.0%	154	1,184	2
	SUBTOTAL 2.	**$7,721**	**$512**	**$2,065**	**$0**	**$10,298**		**$904**		**$0**		**$1,680**	**$12,883**	**$23**
3	FEEDWATER & MISC. BOP SYSTEMS													
3.1	Feedwater System	20,991	0	6,781	0	27,772	8.8%	2,432	0%	0	15.0%	4,531	34,734	63
3.2	Water Makeup & Pretreating	5,187	0	1,670	0	6,856	9.4%	643	0%	0	20.0%	1,500	8,999	16
3.3	Other Feedwater Subsystems	6,426	0	2,716	0	9,142	8.9%	815	0%	0	15.0%	1,494	11,451	21
3.4	Service Water Systems	1,017	0	553	0	1,570	9.3%	146	0%	0	20.0%	343	2,059	4
3.5	Other Boiler Plant Systems	7,907	0	7,807	0	15,714	9.4%	1,474	0%	0	15.0%	2,578	19,766	36
3.6	FO Supply Sys & Nat Gas	266	0	333	0	599	9.3%	56	0%	0	15.0%	98	752	1
3.7	Waste Treatment Equipment	1,085	0	619	0	1,704	9.7%	165	0%	0	20.0%	374	2,243	4
3.8	Misc. Power Plant Equipment	2,825	0	863	0	3,688	9.6%	354	0%	0	20.0%	808	4,850	9
	SUBTOTAL 3.	**$45,704**	**$0**	**$21,340**	**$0**	**$67,044**		**$6,084**		**$0**		**$11,725**	**$84,854**	**$154**
4	PC BOILER & ACCESSORIES													
4.1	PC Boiler	179,774	0	100,871	0	280,645	9.7%	27,183	15%	42,097	10.0%	34,993	384,918	700
4.2	ASU/Oxidant Compression	110,420	0	90,344	0	200,764	9.7%	19,446	0%	0	10.0%	22,021	242,231	440
4.3	Open	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.4	Boiler BoP (w/ID Fans)	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.5	Primary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.6	Secondary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.7	Major Component Rigging	0	w/4.1	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.8	PC Foundations	0	w/14.1	w/14.1	0	0	0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 4.	**$290,194**	**$0**	**$191,215**	**$0**	**$481,409**		**$46,630**		**$42,097**		**$57,014**	**$627,149**	**$1,140**

Exhibit 3-60 Case 4 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & %	Eng'g CM H.O. & Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
5A	FLUE GAS CLEANUP							*						
5.1	Absorber Vessels & Accessories	0	0	0	0	0	9.5%	0	0%	0	10.0%	0	0	0
5.2	Other FGD	0	0	0	0	0	9.6%	0	0%	0	10.0%	0	0	0
5.3	Bag House & Accessories	15,415	0	9,782	0	25,197	9.6%	2,410	0%	0	10.0%	2,761	30,368	55
5.4	Other Particulate Removal Materials	1,017	0	1,088	0	2,105	9.6%	203	0%	0	10.0%	231	2,538	5
5.5	Gypsum Dewatering System	0	0	0	0	0	9.4%	0	0%	0	10.0%	0	0	0
5.6	Mercury Removal System	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.7	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.8	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.9	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 5A.	**$16,431**	**$0**	**$10,870**	**$0**	**$27,302**		**$2,613**		**$0**		**$2,991**	**$32,906**	**$60**
5B	CO2 REMOVAL & COMPRESSION													
5B.1	CO2 Condensing Heat Exchanger	3,975	0	332	0	4,307	10%	431	0%	0	15.0%	711	5,449	10
5B.2	CO2 Compression & Drying	40,582	0	33,204	0	73,786	10%	7,379	0%	0	20.0%	16,233	97,398	177
5B.3	CO2 Pipeline											0	0	0
5B.4	CO2 Storage											0	0	0
5B.5	CO2 Monitoring											0	0	0
	SUBTOTAL 5B.	**$44,558**	**$0**	**$33,536**	**$0**	**$78,094**		**$7,809**		**$0**		**$16,944**	**$102,847**	**$187**
6	NITROGEN EXPANDER/GENERATOR													
6.1	Nitrogen Expander/Generator	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.2	Nitrogen Expander/Generator Accessories	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.3	Compressed Air Piping	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.4	Nitrogen Expander/Generator Foundations	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 6.	**$0**	**$0**	**$0**	**$0**	**$0**		**$0**		**$0**		**$0**	**$0**	**$0**
7	HRSG, DUCTING & STACK													
7.1	Flue Gas Recycle Heat Exchanger	0	0	0	0	0	10%	0	0%	0	15.0%	0	0	0
7.2	SCR System	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
7.3	Ductwork	9,062	0	5,822	0	14,884	8.7%	1,300	10%	1,488	15.0%	2,651	20,323	37
7.4	Stack	1,617	0	946	0	2,563	9.6%	245	0%	0	10.0%	281	3,088	6
7.9	HRSG, Duct & Stack Foundations	0	852	968	0	1,819	9.3%	170	0%	0	20.0%	398	2,386	4
	SUBTOTAL 7.	**$10,678**	**$852**	**$7,736**	**$0**	**$19,266**		**$1,714**		**$1,488**		**$3,329**	**$25,798**	**$47**
8	STEAM TURBINE GENERATOR													
8.1	Steam TG & Accessories	61,098	0	8,108	0	69,206	9.6%	6,626	0%	0	10.0%	7,583	83,416	152
8.2	Turbine Plant Auxiliaries	411	0	881	0	1,293	9.7%	125	0%	0	10.0%	142	1,560	3
8.3	Condenser & Auxiliaries	7,294	0	2,688	0	9,982	9.5%	949	0%	0	10.0%	1,093	12,024	22
8.4	Steam Piping	19,690	0	9,708	0	29,398	8.3%	2,454	0%	0	15.0%	4,778	36,630	67
8.9	TG Foundations	0	1,288	2,035	0	3,324	9.4%	313	0%	0	20.0%	727	4,364	8
	SUBTOTAL 8.	**$88,494**	**$1,288**	**$23,422**	**$0**	**$113,204**		**$10,467**		**$0**		**$14,323**	**$137,994**	**$251**
9	COOLING WATER SYSTEM													
9.1	Cooling Towers	12,056	0	3,754	0	15,810	9.5%	1,501	0%	0	10.0%	1,731	19,043	35
9.2	Circulating Water Pumps	2,097	0	161	0	2,258	8.6%	193	0%	0	10.0%	245	2,697	5
9.3	Circ. Water System Auxiliaries	570	0	76	0	646	9.4%	61	0%	0	10.0%	71	777	1
9.4	Circ. Water Piping	0	4,516	4,376	0	8,892	9.2%	819	0%	0	15.0%	1,457	11,168	20
9.5	Make-up Water System	498	0	665	0	1,163	9.5%	110	0%	0	15.0%	191	1,464	3
9.6	Component Cooling Water System	451	0	359	0	810	9.4%	76	0%	0	15.0%	133	1,019	2
9.9	Circ. Water System Foundations	0	2,743	4,358	0	7,100	9.4%	668	0%	0	20.0%	1,554	9,323	17
	SUBTOTAL 9.	**$15,672**	**$7,258**	**$13,750**	**$0**	**$36,680**		**$3,429**		**$0**		**$5,381**	**$45,490**	**$83**

Exhibit 3-60 Case 4 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
10	ASH/SPENT SORBENT HANDLING SYS													
10.1	Ash Coolers	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.2	Cyclone Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.3	HGCU Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.4	High Temperature Ash Piping	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.5	Other Ash Recovery Equipment	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.6	Ash Storage Silos	651	0	2,005	0	2,656	9.7%	259	0%	0	10.0%	291	3,206	6
10.7	Ash Transport & Feed Equipment	4,212	0	4,315	0	8,527	9.5%	806	0%	0	10.0%	933	10,266	19
10.8	Misc. Ash Handling Equipment	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
10.9	Ash/Spent Sorbent Foundation	0	155	182	0	337	9.3%	31	0%	0	20.0%	74	442	1
	SUBTOTAL 10.	**$4,863**	**$155**	**$6,502**	**$0**	**$11,519**		**$1,096**		**$0**		**$1,298**	**$13,914**	**$25**
11	ACCESSORY ELECTRIC PLANT													
11.1	Generator Equipment	1,829	0	297	0	2,126	9.3%	197	0%	0	7.5%	174	2,497	5
11.2	Station Service Equipment	6,444	0	2,117	0	8,562	9.6%	819	0%	0	7.5%	704	10,084	18
11.3	Switchgear & Motor Control	7,409	0	1,259	0	8,668	9.3%	802	0%	0	10.0%	947	10,418	19
11.4	Conduit & Cable Tray	0	4,645	16,061	0	20,706	9.6%	1,982	0%	0	15.0%	3,403	26,091	47
11.5	Wire & Cable	0	8,765	16,920	0	25,685	8.4%	2,164	0%	0	15.0%	4,177	32,026	58
11.6	Protective Equipment	261	0	888	0	1,149	9.8%	112	0%	0	10.0%	126	1,388	3
11.7	Standby Equipment	1,425	0	33	0	1,458	9.5%	138	0%	0	10.0%	160	1,756	3
11.8	Main Power Transformers	8,208	0	138	0	8,346	7.6%	634	0%	0	10.0%	898	9,879	18
11.9	Electrical Foundations	0	367	899	0	1,265	9.5%	120	0%	0	20.0%	277	1,663	3
	SUBTOTAL 11.	**$25,577**	**$13,777**	**$38,612**	**$0**	**$77,966**		**$6,969**		**$0**		**$10,866**	**$95,801**	**$174**
12	INSTRUMENTATION & CONTROL													
12.1	PC Control Equipment	w/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.2	Combustion Turbine Control	N/A	0	N/A	0	0	0%	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%	0	0	0
12.4	Other Major Component Control	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
12.5	Signal Processing Equipment	W/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.6	Control Boards, Panels & Racks	557	0	334	0	891	9.6%	86	0%	0	15.0%	147	1,124	2
12.7	Computer Accessories	5,627	0	984	0	6,611	9.5%	630	0%	0	10.0%	724	7,965	14
12.8	Instrument Wiring & Tubing	3,051	0	6,052	0	9,103	8.5%	775	0%	0	15.0%	1,482	11,361	21
12.9	Other I & C Equipment	1,590	0	3,608	0	5,198	9.7%	506	0%	0	10.0%	570	6,275	11
	SUBTOTAL 12.	**$10,826**	**$0**	**$10,978**	**$0**	**$21,804**		**$1,997**		**$0**		**$2,923**	**$26,724**	**$49**
13	IMPROVEMENTS TO SITE													
13.1	Site Preparation	0	54	1,076	0	1,129	9.9%	111	0%	0	20.0%	248	1,489	3
13.2	Site Improvements	0	1,786	2,218	0	4,003	9.8%	393	0%	0	20.0%	879	5,275	10
13.3	Site Facilities	3,200	0	3,155	0	6,355	9.8%	624	0%	0	20.0%	1,396	8,375	15
	SUBTOTAL 13.	**$3,200**	**$1,839**	**$6,448**	**$0**	**$11,488**		**$1,128**		**$0**		**$2,523**	**$15,139**	**$28**
14	BUILDINGS & STRUCTURES													
14.1	Boiler Building	0	8,769	7,712	0	16,481	9.0%	1,480	0%	0	15.0%	2,694	20,655	38
14.2	Turbine Building	0	12,620	11,762	0	24,382	9.0%	2,195	0%	0	15.0%	3,987	30,564	56
14.3	Administration Building	0	631	668	0	1,299	9.1%	118	0%	0	15.0%	213	1,629	3
14.4	Circulation Water Pumphouse	0	130	103	0	234	8.9%	21	0%	0	15.0%	38	293	1
14.5	Water Treatment Buildings	0	672	613	0	1,285	9.0%	115	0%	0	15.0%	210	1,609	3
14.6	Machine Shop	0	422	284	0	706	8.9%	63	0%	0	15.0%	115	884	2
14.7	Warehouse	0	286	287	0	573	9.0%	52	0%	0	15.0%	94	719	1
14.8	Other Buildings & Structures	0	234	199	0	433	9.0%	39	0%	0	15.0%	71	543	1
14.9	Waste Treating Building & Str.	0	443	1,344	0	1,787	9.4%	169	0%	0	15.0%	293	2,249	4
	SUBTOTAL 14.	**$0**	**$24,208**	**$22,971**	**$0**	**$47,179**		**$4,251**		**$0**		**$7,715**	**$59,145**	**$108**
	Total Cost	**$578,235**	**$54,244**	**$399,098**	**$0**	**$1,031,577**		**$97,639**		**$43,585**		**$143,345**	**$1,316,146**	**$2,393**

Exhibit 3-61 Case 4 Owner's Costs

Owner's Costs	$1,000	$/kW
Preproduction Costs		
6 Months All Labor	$8,941	$16
1 Month Maintenance Materials	$1,291	$2
1 Month Non-fuel Consumables	$335	$1
1 Month Waste Disposal	$292	$1
25% of 1 Months Fuel Cost at 100% CF	$1,767	$3
2% of TPC	$26,323	$48
Total	**$38,949**	**$71**
Inventory Capital		
60 day supply of fuel and consumables at 100% CF	$14,426	$26
0.5% of TPC (spare parts)	$6,581	$12
Total	**$21,007**	**$38**
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$197,422	$359
Financing Costs	$35,536	$65
Total Overnight Costs (TOC)	**$1,609,960**	**$2,927**
TASC Multiplier	1.134	
Total As-Spent Cost (TASC)	**$1,825,694**	**$3,319**

Exhibit 3-62 Case 4 O&M Costs

INITIAL & ANNUAL O&M EXPENSES						
Case:	Case 4 - Co-sequestration					
Plant Size (MWe):	550.02			**Heat Rate (Btu/kWh):**		10,754
Primary/Secondary Fuel:	Illinois #6 Bituminous Coal			**Fuel Cost ($/MM Btu):**		1.64
Design/Construction	5 years			**Book Life (yrs):**		30
TPC (Plant Cost) Year:	June 2007			**TPI Year:**		2012
Capacity Factor (%):	85			**CO2** Captured (TPD):		14,248
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate (base):		$34.65	$/hour			
Operating Labor Burden:		30.00	% of base			
Labor Overhead Charge:		25.00	% of labor			
Operating Labor Requirements per Shift:		**units/mod.**		**Total Plant**		
Skilled Operator		2.0		2.0		
Operator		9.0		9.0		
Foreman		1.0		1.0		
Lab Tech's etc.		2.0		2.0		
TOTAL Operating Jobs		14.0		14.0		
					$	**$/kW-net**
Annual Operating Labor Cost (calc'd)					5,524,319	10.04
Maintenance Labor Cost (calc'd)					8,781,199	15.97
Administrative & Support Labor (calc'd)					3,576,379	6.50
Property Taxes and Insurance					26,322,917	47.86
TOTAL FIXED OPERATING COSTS					**44,204,814**	**80.37**
VARIABLE OPERATING COSTS						
					$	**$/kWh-net**
Maintenance Material Costs (calc'd)					**$13,171,902**	**0.00322**
Consumables	**Consumption**		**Unit**	**Initial**		
	Initial	**/Day**	**Cost**	**Cost**	**$**	**$/kWh-net**
Water (/1000 gallons)	0	5,743	1.08	$0	$1,927,199	0.00047
Chemicals						
MU & WT Chem. (lb)	0	27,798	0.17	$0	$1,492,621	0.00036
Limestone (ton)	0	0	21.63	$0	$0	0.00000
Carbon (Hg Removal) (lb)	0	0	1.05	$0	$0	0.00000
MEA Solvent (ton)	0	0	2249.89	$0	$0	0.00000
Caustic Soda, NaOH (ton)	0	0	433.68	$0	$0	0.00000
Sulfuric acid, H_2SO_4 (ton)	0	0	138.78	$0	$0	0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	0.00000
Activated C, MEA (lb)	0	0	1.05	$0	$0	0.00000
Ammonia, 19% soln (ton)	0	0	129.80	$0	$0	0.00000
Subtotal Chemicals				**$0**	**$1,492,621**	**0.00036**
Other						
Supplemental Fuel (MMBtu)	0	0	6.55	$0	$0	0.00000
SCR Catalyst Replacement	w/equip.	0.0	5775.94	$0	$0	0.00000
Emission Penalties	0	0	0.00	$0	$0	0.00000
Subtotal Other				**$0**	**$0**	**0.00000**
Waste Disposal						
Spent Mercury Catalyst (lb)	0	0	0.42	$0	$0	0.00000
Flyash (ton)	0	473	16.23	$0	$2,381,574	0.00058
Bottom Ash (ton)	0	118	16.23	$0	$595,424	0.00015
Subtotal Solid Waste Disposal				**$0**	**$2,976,997**	**0.00073**
By-products & Emissions						
Gypsum (tons)	0	0	0.00	$0	$0	0.00000
Sulfur (tons)	0	0	0.00	$0	$0	0.00000
Subtotal By-Products				**$0**	**$0**	**0.00000**
TOTAL VARIABLE OPERATING COSTS					**$19,568,718**	**0.00478**
Coal FUEL (tons)	**0**	**6,085**	**38.18**	**$0**	**$72,081,686**	**0.01760**
NATURAL GAS FUEL (Mscf)	**0**	**0**	**6.76**	**$0**	**$0**	**0.00000**

3.5 CASE 5 – ADVANCED FLUE GAS RECYCLE PROCESS

The advanced FGR system eliminates the FGR superheating system used in the current technology case. The current technology case integrates the low pressure feedwater heating system with the FGR stream to superheat the recycle stream by 8°C (15°F). The primary reason to superheat the recycle stream is to ensure that primary or secondary air streams do not produce condensate in the ducts or enter the air fans at saturated conditions. This case assumes that these problems can be mitigated without the superheating system and upgraded fan, and that burner and coal drying system designs will not be affected by the saturated conditions of the FGR stream.

Similar to the current technology case (but without flue gas recycle superheater), major components for Case 5 include the following:

1. Conventional cryogenic ASU
2. PC boiler operating at supercritical steam conditions
3. Baghouse to remove particulates
4. Wet FGD to reduce sulfur emissions
5. CPU with compression to 15.3 MPa (2,215 psia)
6. Steam Turbine/generator

Block Flow Diagram and Stream Table

A process BFD for Case 5 is shown in Exhibit 3-63, and the corresponding stream tables are shown in Exhibit 3-64.

Heat and Mass Balance Diagram

Heat and mass balance diagrams are shown for the following subsystems in Exhibit 3-65 and Exhibit 3-66:

- Boiler and flue gas cleanup
- Steam cycle and feed water (power block)

Energy, Carbon, Sulfur, and Water Balances

An overall plant energy balance is provided in tabular form in Exhibit 3-67. The power out is the steam turbine power after generator losses.

Carbon, sulfur, and water balances are shown in Exhibit 3-68 through Exhibit 3-70.

Performance Summary

A performance summary is provided in Exhibit 3-71.

Costing Table

Tables of capital costs, owner's costs, and O&M costs are provided in Exhibit 3-72 through Exhibit 3-74, respectively.

Equipment List

The combined equipment list for Case 4 through Case 7 is shown in Exhibit 3-99.

Exhibit 3-63 Process Block Flow Diagram for Case 5

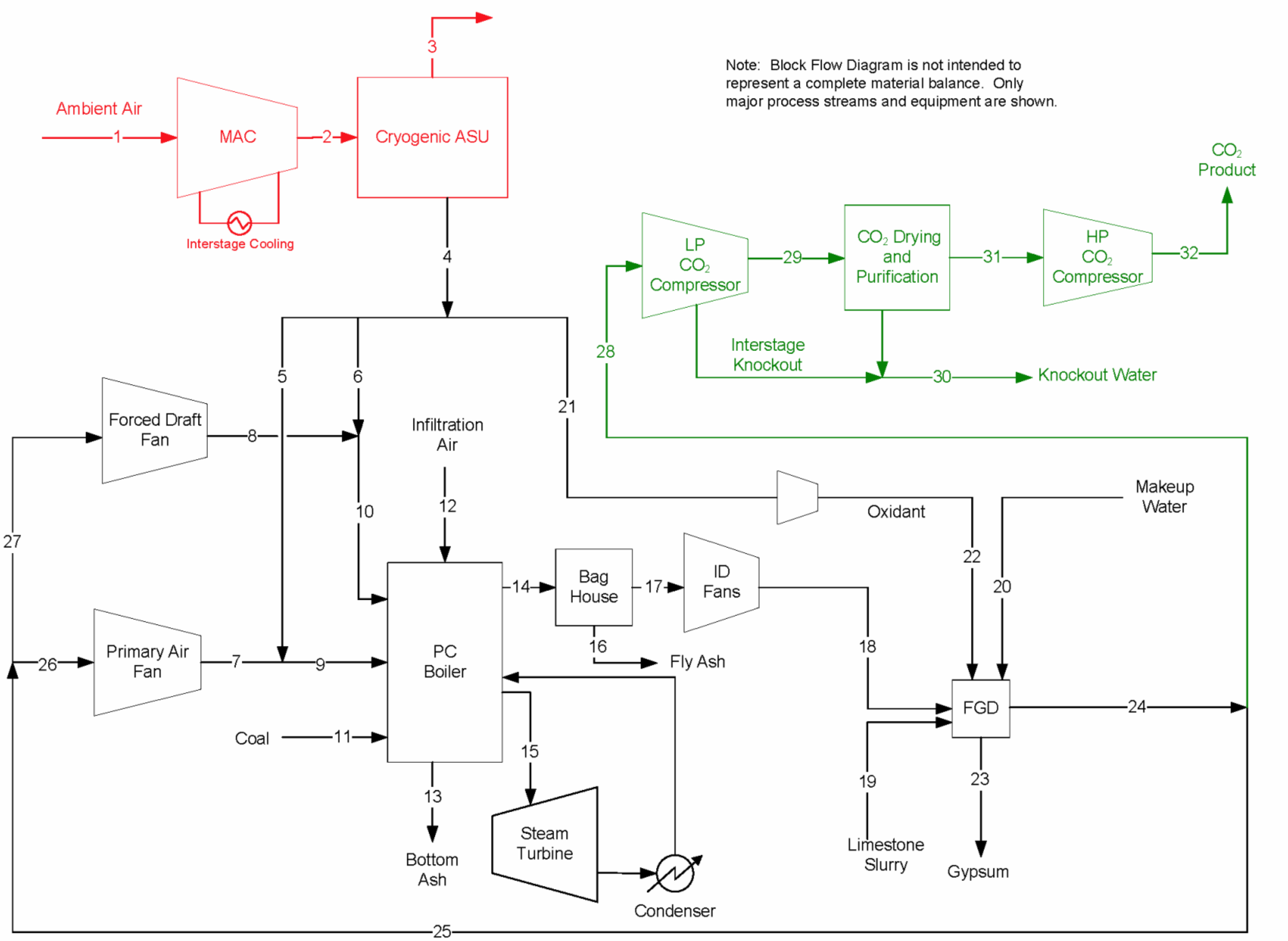


Exhibit 3-64 Stream Table for Case 5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
V-L Mole Fraction																
Ar	0.0092	0.0092	0.0024	0.0340	0.0340	0.0340	0.0308	0.0308	0.0317	0.0317	0.0000	0.0092	0.0000	0.0287	0.0000	0.0000
CO_2	0.0005	0.0005	0.0006	0.0000	0.0000	0.0000	0.7084	0.7084	0.5063	0.5063	0.0000	0.0005	0.0000	0.6606	0.0000	0.0000
H_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	0.0000	0.0000
H_2O	0.0101	0.0101	0.0128	0.0000	0.0000	0.0000	0.1522	0.1522	0.1088	0.1088	0.0000	0.0101	0.0000	0.2079	1.0000	0.0000
N_2	0.7729	0.7729	0.9778	0.0162	0.0162	0.0162	0.0855	0.0855	0.0657	0.0657	0.0000	0.7729	0.0000	0.0801	0.0000	0.0000
O_2	0.2074	0.2074	0.0063	0.9498	0.9498	0.9498	0.0231	0.0231	0.2874	0.2874	0.0000	0.2074	0.0000	0.0197	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0031	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	0.0000	1.0000	0.0000	1.0000	1.0000	0.0000
V-L Flowrate (kg_{mol}/hr)	78,744	78,744	61,961	16,783	3,889	12,659	9,743	31,717	13,632	44,377	0	1,575	0	64,563	123,001	0
V-L Flowrate (kg/hr)	2,272,242	2,272,237	1,731,730	540,508	125,240	407,696	373,017	1,214,289	498,257	1,621,985	0	45,445	0	2,391,062	2,215,890	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	249,640	0	4,853	19,411	0	19,411
Temperature (°C)	15	24	17	13	13	13	67	61	54	51	15	15	15	177	599	15
Pressure (MPa, abs)	0.10	0.59	0.10	0.16	0.16	0.16	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	24.23	0.10
Enthalpy (kJ/kg)[A]	30.57	32.03	38.64	11.49	11.49	11.49	240.24	234.76	182.74	178.64	---	30.57	---	496.90	3,493.92	---
Density (kg/m^3)	1.2	7.0	1.2	2.2	2.2	2.2	1.5	1.5	1.5	1.4	---	1.2	---	1.0	68.5	---
V-L Molecular Weight	28.856	28.856	27.949	32.205	32.205	32.205	38.285	38.285	36.550	36.550	---	28.856	---	37.035	18.015	---
V-L Flowrate (lb_{mol}/hr)	173,601	173,601	136,600	37,001	8,573	27,909	21,480	69,924	30,054	97,834	0	3,472	0	142,336	271,170	0
V-L Flowrate (lb/hr)	5,009,436	5,009,426	3,817,810	1,191,615	276,107	898,816	822,361	2,677,048	1,098,468	3,575,864	0	100,189	0	5,271,388	4,885,202	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	550,361	0	10,699	42,795	0	42,795
Temperature (°F)	59	75	63	55	56	56	152	142	129	124	59	59	59	350	1,110	59
Pressure (psia)	14.7	86.1	14.7	23.2	23.2	23.2	16.2	15.3	16.2	15.3	14.7	14.7	14.7	14.4	3,514.7	14.7
Enthalpy (Btu/lb)[A]	13.1	13.8	16.6	4.9	4.9	4.9	103.3	100.9	78.6	76.8	---	13.1	---	213.6	1,502.1	---
Density (lb/ft^3)	0.076	0.435	0.073	0.135	0.135	0.135	0.095	0.091	0.094	0.090	---	0.076	---	0.061	4.274	---

A - Reference conditions are 32.02 F & 0.089 PSIA

Exhibit 3-64 Stream Table for Case 5 (Continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
V-L Mole Fraction																
Ar	0.0287	0.0287	0.0000	0.0000	0.0340	0.0340	0.0000	0.0308	0.0308	0.0308	0.0308	0.0308	0.0362	0.0000	0.0363	0.0363
CO_2	0.6606	0.6606	0.0000	0.0000	0.0000	0.0000	0.0011	0.7084	0.7084	0.7084	0.7084	0.7084	0.8337	0.0000	0.8354	0.8354
H_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	0.0000	0.0000
H_2O	0.2079	0.2079	1.0000	1.0000	0.0000	0.0000	0.9989	0.1522	0.1522	0.1522	0.1522	0.1522	0.0021	1.0000	0.0001	0.0001
N_2	0.0801	0.0801	0.0000	0.0000	0.0162	0.0162	0.0000	0.0855	0.0855	0.0855	0.0855	0.0855	0.1007	0.0000	0.1009	0.1009
O_2	0.0197	0.0197	0.0000	0.0000	0.9498	0.9498	0.0000	0.0231	0.0231	0.0231	0.0231	0.0231	0.0272	0.0000	0.0272	0.0272
SO_2	0.0031	0.0031	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
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	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	64,563	64,563	3,143	1,725	235	235	242	60,485	41,460	9,743	31,717	19,026	16,165	2,895	16,133	16,133
V-L Flowrate (kg/hr)	2,391,062	2,391,062	56,629	31,075	7,572	7,572	4,363	2,315,681	1,587,305	373,017	1,214,289	728,406	676,860	52,165	676,284	676,284
Solids Flowrate (kg/hr)	0	0	25,150	0	0	0	39,159	0	0	0	0	0	0	0	0	0
Temperature (°C)	177	186	15	15	13	95	57	57	57	57	57	58	104	22	104	21
Pressure (MPa, abs)	0.10	0.11	0.11	0.10	0.16	0.31	0.10	0.10	0.10	0.10	0.10	0.10	3.33	0.24	3.33	15.27
Enthalpy (kJ/kg)[A]	429.52	439.12	---	62.80	11.49	85.68	---	231.21	231.21	231.21	231.21	231.74	74.58	93.20	72.43	-188.93
Density (kg/m^3)	1.0	1.0	---	1,003.1	2.2	3.3	---	1.4	1.4	1.4	1.4	1.4	47.6	996.0	47.7	691.1
V-L Molecular Weight	37.035	37.035	---	18.015	32.205	32.205	---	38.285	38.285	38.285	38.285	38.285	41.872	18.016	41.920	41.920
V-L Flowrate (lb_{mol}/hr)	142,336	142,336	6,930	3,803	518	518	533	133,348	91,405	21,480	69,924	41,945	35,637	6,383	35,567	35,567
V-L Flowrate (lb/hr)	5,271,388	5,271,388	124,846	68,510	16,692	16,692	9,619	5,105,203	3,499,409	822,361	2,677,048	1,605,859	1,492,220	115,004	1,490,951	1,490,951
Solids Flowrate (lb/hr)	0	0	55,446	0	0	0	86,331	0	0	0	0	0	0	0	0	0
Temperature (°F)	350	366	59	59	56	203	135	135	135	135	135	136	219	72	219	70
Pressure (psia)	14.2	15.2	15.5	14.7	23.2	45.0	14.7	14.7	14.7	14.7	14.7	14.7	483.4	35.0	483.4	2,214.7
Enthalpy (Btu/lb)[A]	184.7	188.8	---	27.0	4.9	36.8	---	99.4	99.4	99.4	99.4	99.6	32.1	40.1	31.1	-81.2
Density (lb/ft^3)	0.061	0.064	---	62.622	0.135	0.204	---	0.089	0.089	0.089	0.089	0.089	2.973	62.179	2.976	43.147

Exhibit 3-65 Heat and Mass Balance, Boiler and Gas Cleanup Systems for Case 5

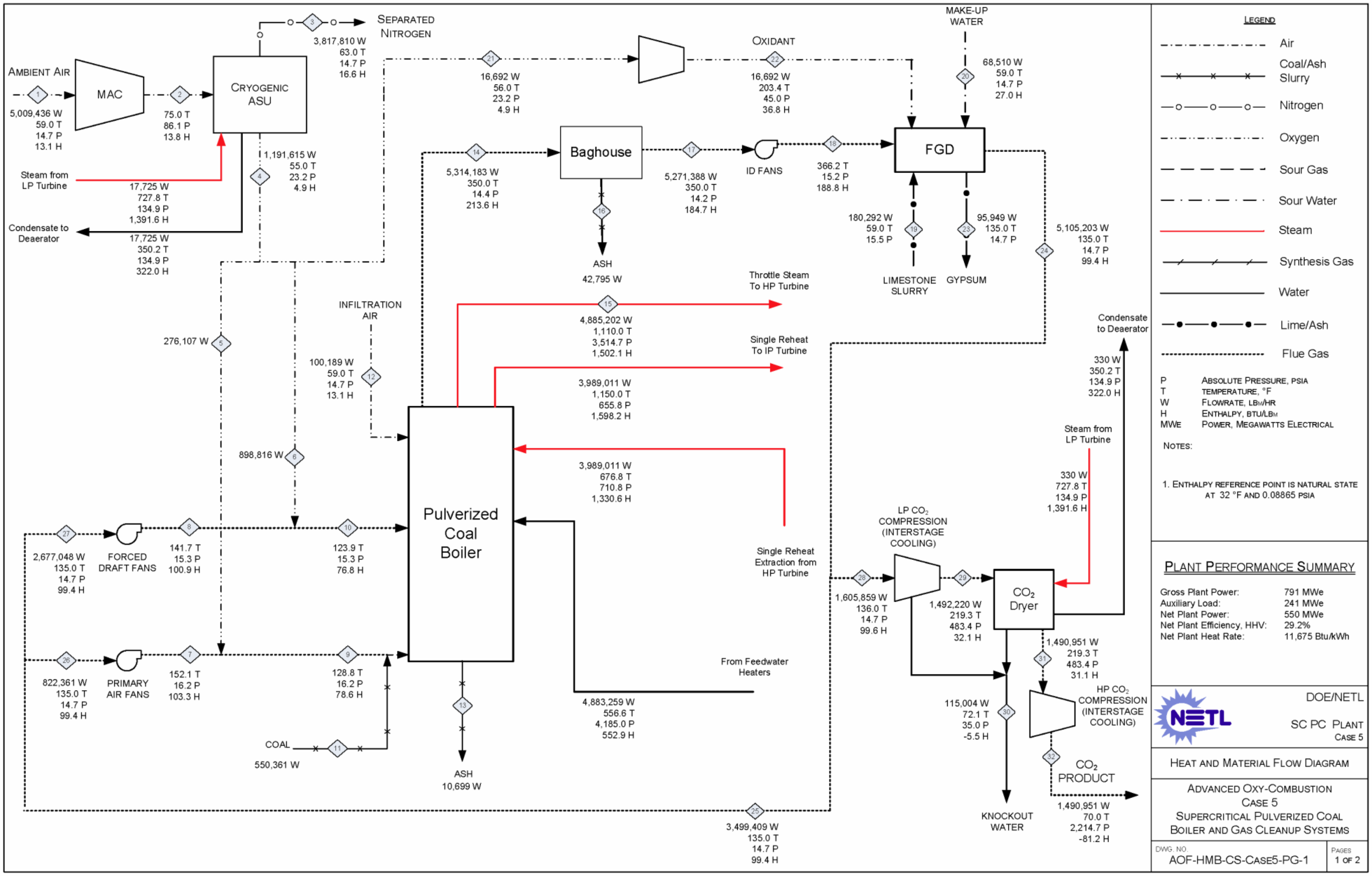


Exhibit 3-66 Heat and Mass Balance, Power Block Systems for Case 5

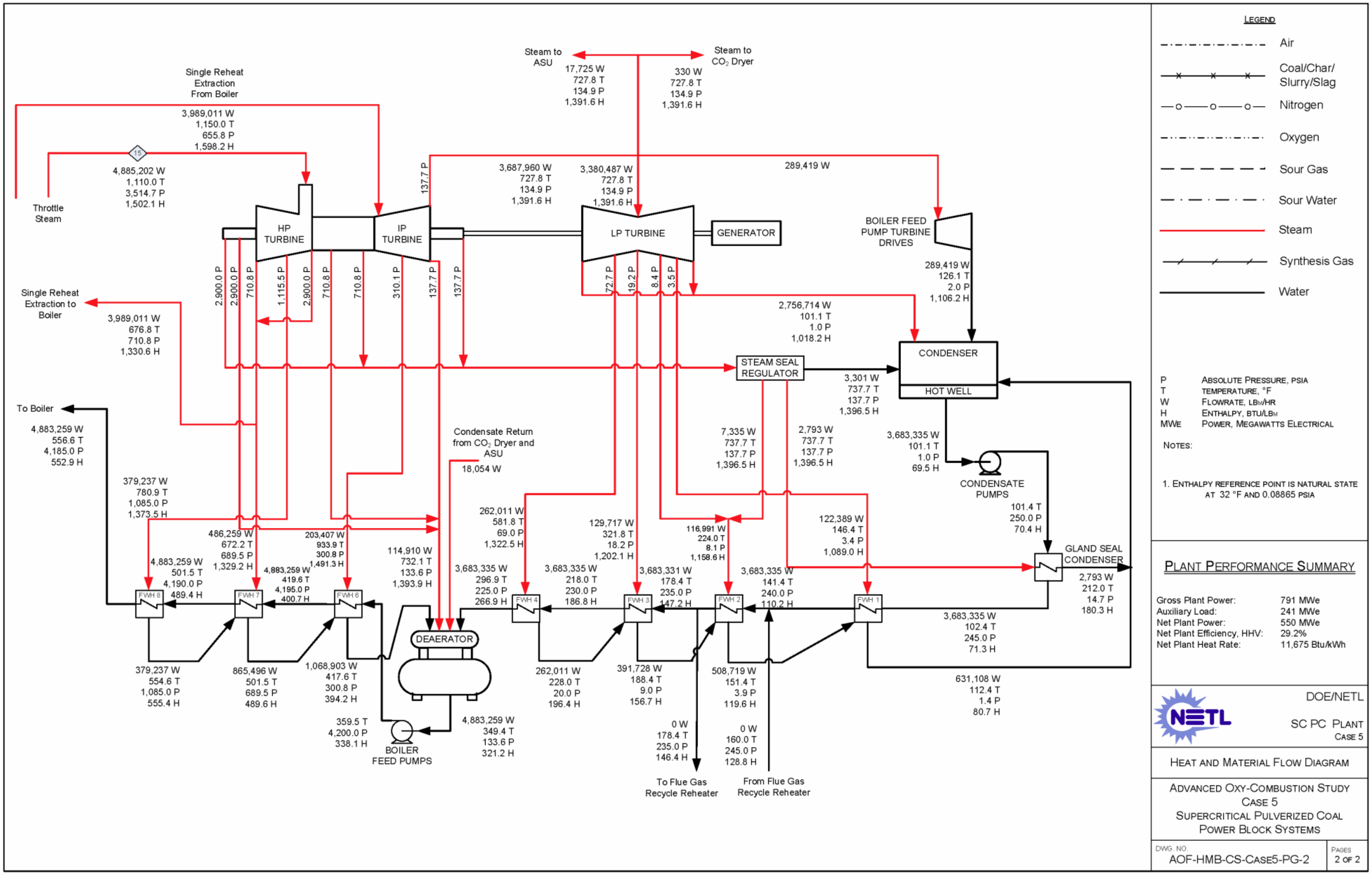


Exhibit 3-67 Cases 5 Energy Balance

	HHV	Sensible + Latent	Power	Total
Heat In GJ/hr (MMBtu/hr)				
Coal	6,774 (6,421)	*5.7 (5.4)*		6,780 (6,426)
Combustion Air		70.9 (67.2)		70.9 (67.2)
Raw Water Makeup		125.0 (118.5)		125.0 (118.5)
Limestone		0.55 (0.52)		0.55 (0.52)
Auxiliary Power			866 (821)	866 (821)
Totals	**6,774 (6,421)**	**202.1 (191.5)**	**866 (821)**	**7,842 (7,433)**
Heat Out GJ/hr (MMBtu/hr)				
Boiler Loss		60.9 (57.8)		60.9 (57.8)
Bottom Ash		0.6 (0.6)		0.6 (0.6)
Fly Ash + FGD Ash		2.5 (2.3)		2.5 (2.3)
MAC Cooling		435.9 (413.1)		435.9 (413.1)
ASU Vent		66.9 (63.4)		66.9 (63.4)
Condenser		3,088 (2,927)		3,088 (2,927)
CO_2 Cooling		548 (519)		548 (519)
CO_2		-128 (-121)		-128 (-121)
Wet FGD Cooling		513 (486)		513 (486)
Process Condensate		4.9 (4.6)		4.9 (4.6)
Cooling Tower Blowdown		59.7 (56.6)		59.7 (56.6)
Process Losses*		*404.3 (383.2)*		*404.3 (383.2)*
Power			2,846 (2,698)	2,846 (2,698)
Totals		**4,996 (4,736)**	**2,846 (2,698)**	**7,842 (7,433)**

Note: Italicized numbers are estimated

Reference conditions are 0°C (32.02°F) & 0.6 kPa (0.089 psia)

* Process losses are estimated to match the heat input to the plant and include losses from: steam turbine, combustion reactions, and gas cooling.

Exhibit 3-68 Case 5 Carbon Balance

Carbon In		**Carbon Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	159,530 (351,704)	CO_2 Product	161,875 (356,874)
Air (CO_2)	443 (976)	FGD Product	221 (487)
FGD Reagent	2,552 (5,626)	Separated Air	434 (957)
		Convergence Tolerance*	-5 (-11)
Total	162,525 (358,306)	Total	162,525 (358,306)

*by difference

Exhibit 3-69 Case 5 Sulfur Balance

Sulfur In		**Sulfur Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	6,272 (13,827)	Gypsum	6,232 (13,739)
		CO_2 Product	40 (88)
		Convergence Tolerance*	0 (0)
Total	6,272 (13,827)	Total	6,272 (13,827)

*by difference

Exhibit 3-70 Case 5 Water Balance

Water Use	**Water Demand**	**Internal Recycle**	**Raw Water Withdrawal**	**Process Water Discharge**	**Raw Water Consumption**
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)
FGD Makeup	0.52 (137)	0.0 (0)	0.52 (137)	0.0 (0)	0.52 (137)
BFW Makeup	0.37 (98)	0.0 (0)	0.37 (98)	0.0(0)	0.37 (98)
Cooling Tower	35.7 (9,444)	3.41 (901)	32.3 (8,542)	8.04 (2124)	24.30 (6418)
Total	**36.6 (9,678)**	**3.41 (901)**	**33.2 (8,777)**	**8.04 (2,124)**	**25.18 (6,653)**

Exhibit 3-71 Case 5 Performance Summary

Plant Output		
Steam Turbine Power	790,600	kW_e
Gross Power	**790,600**	kWe
Auxiliary Load		
Coal Handling and Conveying	500	kW_e
Limestone Handling & Reagent Preparation	1,210	kW_e
Pulverizers	3,740	kW_e
Ash Handling	720	kW_e
Primary Air Fans	980	kW_e
Forced Draft Fans	1,240	kW_e
Induced Draft Fans	6,610	kW_e
Air Separation Unit Main Air Compressor	125,880	kW_e
ASU Auxiliaries	1,000	kW_e
Baghouse	90	kW_e
FGD Pumps and Agitators	4,050	kWe
CO_2 Compression	73,620	kW_e
Condensate Pumps	1,040	kW_e
Boiler Feedwater Booster Pumps[2]	N/A	kW_e
Miscellaneous Balance of Plant[3]	2,000	kW_e
Steam Turbine Auxiliaries	400	kW_e
Circulating Water Pumps	9,180	kW_e
Cooling Tower Fans	5,360	kW_e
Transformer Losses	3,030	kW_e
Total	240,650	kW_e
Plant Performance		
Net Auxiliary Load	240,650	kW_e
Net Plant Power	549,950	kW_e
Net Plant Efficiency (HHV)	29.2%	
Net Plant Heat Rate (HHV)	12,317 (11,675)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	249,640 (550,361)	kg/hr (lb/hr)
Thermal Input[1]	1,881,666	kW_{th}
Condenser Duty	3,088 (2,927)	GJ/hr (MMBtu/hr)
Raw Water Usage	33.2 (8,777)	m^3/min (gpm)

1 - HHV of As Received Illinois No. 6 coal is 27,135 kJ/kg (11,666 Btu/lb)

2 - Boiler feed pumps are turbine driven

3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 3-72 Case 5 Capital Costs

	Department:	NETL Office of Program Planning and Analysis										**Cost Base:**	June 2007	
	Project:	Advancing Oxycombustion Technology										**Prepared:**	13-Apr-12	
	Case:	Case 5 - Advanced Recycle											**x $1, 000**	
	Plant Size:	550	MW, net			Capital Charge Factor	0.158		Capacity Factor	0.85				
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Bare Erected**	**Eng'g CM H.O. & Fee %**	**Eng'g CM H.O. & Fee Total**	**Process Cont. %**	**Process Cont. Total**	**Project Cont. %**	**Project Cont. Total**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**
1	COAL HANDLING SYSTEM													
1.1	Coal Receive & Unload	3,955	0	1,807	0	5,762	8.9%	515	0%	0	15.0%	941	7,218	13
1.2	Coal Stackout & Reclaim	5,112	0	1,158	0	6,270	8.8%	549	0%	0	15.0%	1,023	7,842	14
1.3	Coal Conveyors & Yd Crus	4,753	0	1,146	0	5,899	8.8%	517	0%	0	15.0%	962	7,378	13
1.4	Other Coal Handling	1,243	0	265	0	1,509	8.7%	132	0%	0	15.0%	246	1,887	3
1.5	Sorbent Receive & Unload	163	0	49	0	212	8.8%	19	0%	0	15.0%	35	265	0
1.6	Sorbent Stackout & Reclaim	2,630	0	482	0	3,112	8.7%	271	0%	0	15.0%	508	3,891	7
1.7	Sorbent Conveyors	939	203	230	0	1,372	8.7%	119	0%	0	15.0%	224	1,714	3
1.8	Other Sorbent Handling	567	133	297	0	997	8.8%	88	0%	0	15.0%	163	1,248	2
1.9	Coal & Sorbent Hnd.Foundations	0	4,863	6,135	0	10,997	9.3%	1,028	0%	0	15.0%	1,804	13,829	25
	SUBTOTAL 1.	**$19,362**	**$5,199**	**$11,569**	**$0**	**$36,130**		**$3,237**		**$0**		**$5,905**	**$45,272**	**$82**
2	COAL PREP & FEED SYSTEMS													
2.1	Coal Crushing & Drying	2,289	0	446	0	2,735	8.7%	239	0%	0	15.0%	446	3,420	6
2.2	Prepared Coal Storage & Feed	5,861	0	1,279	0	7,140	8.7%	624	0%	0	15.0%	1,165	8,930	16
2.3	Slurry Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.4	Misc. Coal Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.5	Sorbent Prep Equipment	4,481	193	931	0	5,604	8.7%	488	0%	0	15.0%	914	7,007	13
2.6	Sorbent Storage & Feed	540	0	207	0	747	8.9%	66	0%	0	15.0%	122	935	2
2.7	Sorbent Injection System	0	0	0	0	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	0.0%	0	0	0
2.9	Coal & Sorbent Feed Foundation	0	574	482	0	1,056	9.2%	97	0%	0	15.0%	173	1,326	2
	SUBTOTAL 2.	**$13,171**	**$767**	**$3,345**	**$0**	**$17,282**		**$1,515**		**$0**		**$2,820**	**$21,617**	**$39**
3	FEEDWATER & MISC. BOP SYSTEMS													
3.1	Feedwater System	21,778	0	7,035	0	28,813	8.8%	2,523	0%	0	15.0%	4,700	36,037	66
3.2	Water Makeup & Pretreating	5,551	0	1,787	0	7,338	9.4%	688	0%	0	20.0%	1,605	9,632	18
3.3	Other Feedwater Subsystems	6,667	0	2,818	0	9,485	8.9%	845	0%	0	15.0%	1,550	11,880	22
3.4	Service Water Systems	1,088	0	592	0	1,680	9.3%	156	0%	0	20.0%	367	2,204	4
3.5	Other Boiler Plant Systems	8,230	0	8,125	0	16,355	9.4%	1,534	0%	0	15.0%	2,683	20,573	37
3.6	FO Supply Sys & Nat Gas	272	0	339	0	611	9.3%	57	0%	0	15.0%	100	768	1
3.7	Waste Treatment Equipment	2,975	0	1,696	0	4,670	9.7%	452	0%	0	20.0%	1,025	6,147	11
3.8	Misc. Power Plant Equipment	2,883	0	881	0	3,764	9.6%	361	0%	0	20.0%	825	4,951	9
	SUBTOTAL 3.	**$49,445**	**$0**	**$23,273**	**$0**	**$72,718**		**$6,617**		**$0**		**$12,856**	**$92,190**	**$168**
4	PC BOILER & ACCESSORIES													
4.1	PC Boiler	186,567	0	104,683	0	291,250	9.7%	28,211	0%	0	10.0%	31,946	351,406	639
4.2	ASU/Oxidant Compression	115,985	0	94,897	0	210,882	9.7%	20,426	0%	0	10.0%	23,131	254,439	463
4.3	Open	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.4	Boiler BoP (w/ID Fans)	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.5	Primary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.6	Secondary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.7	Major Component Rigging	0	w/4.1	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.8	PC Foundations	0	w/14.1	w/14.1	0	0	0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 4.	**$302,552**	**$0**	**$199,580**	**$0**	**$502,131**		**$48,637**		**$0**		**$55,077**	**$605,845**	**$1,102**

Exhibit 3-72 Case 5 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
5A	FLUE GAS CLEANUP							*						
5.1	Absorber Vessels & Accessories	60,351	0	12,992	0	73,343	9.5%	6,942	0%	0	10.0%	8,028	88,313	161
5.2	Other FGD	3,152	0	3,572	0	6,723	9.6%	648	0%	0	10.0%	737	8,108	15
5.3	Bag House & Accessories	15,048	0	9,550	0	24,597	9.6%	2,353	0%	0	10.0%	2,695	29,645	54
5.4	Other Particulate Removal Materials	993	0	1,062	0	2,055	9.6%	198	0%	0	10.0%	225	2,478	5
5.5	Gypsum Dewatering System	5,463	0	928	0	6,391	9.4%	604	0%	0	10.0%	699	7,694	14
5.6	Mercury Removal System	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.7	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.8	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.9	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 5A.	**$85,006**	**$0**	**$28,104**	**$0**	**$113,110**		**$10,744**		**$0**		**$12,385**	**$136,239**	**$248**
5B	CO2 REMOVAL & COMPRESSION													
5B.1	CO2 Condensing Heat Exchanger	6,032	0	504	0	6,536	10%	654	0%	0	15.0%	1,078	8,268	15
5B.2	CO2 Compression & Drying	43,041	0	35,216	0	78,257	10%	7,826	0%	0	20.0%	17,217	103,299	188
5B.3	CO2 Pipeline											0	0	0
5B.4	CO2 Storage											0	0	0
5B.5	CO2 Monitoring											0	0	0
	SUBTOTAL 5B.	**$49,074**	**$0**	**$35,719**	**$0**	**$84,793**		**$8,479**		**$0**		**$18,295**	**$111,567**	**$203**
6	NITROGEN EXPANDER/GENERATOR													
6.1	Nitrogen Expander/Generator	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.2	Nitrogen Expander/Generator Accessories	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.3	Compressed Air Piping	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.4	Nitrogen Expander/Generator Foundations	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 6.	**$0**	**$0**	**$0**	**$0**	**$0**		**$0**		**$0**		**$0**	**$0**	**$0**
7	HRSG, DUCTING & STACK													
7.1	Flue Gas Recycle Heat Exchanger	0	0	0	0	0	10%	0	0%	0	15.0%	0	0	0
7.2	SCR System	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
7.3	Ductwork	9,349	0	6,006	0	15,355	8.7%	1,341	0%	0	15.0%	2,504	19,200	35
7.4	Stack	1,593	0	932	0	2,525	9.6%	241	0%	0	10.0%	277	3,043	6
7.9	HRSG, Duct & Stack Foundations	0	861	978	0	1,840	9.3%	171	0%	0	20.0%	402	2,413	4
	SUBTOTAL 7.	**$10,941**	**$861**	**$7,917**	**$0**	**$19,719**		**$1,754**		**$0**		**$3,183**	**$24,656**	**$45**
8	STEAM TURBINE GENERATOR													
8.1	Steam TG & Accessories	62,506	0	8,295	0	70,801	9.6%	6,779	0%	0	10.0%	7,758	85,338	155
8.2	Turbine Plant Auxiliaries	421	0	902	0	1,323	9.7%	128	0%	0	10.0%	145	1,596	3
8.3	Condenser & Auxiliaries	7,183	0	2,647	0	9,830	9.5%	934	0%	0	10.0%	1,076	11,840	22
8.4	Steam Piping	20,439	0	10,078	0	30,517	8.3%	2,547	0%	0	15.0%	4,960	38,023	69
8.9	TG Foundations	0	1,317	2,081	0	3,398	9.4%	320	0%	0	20.0%	744	4,462	8
	SUBTOTAL 8.	**$90,548**	**$1,317**	**$24,003**	**$0**	**$115,868**		**$10,708**		**$0**		**$14,683**	**$141,259**	**$257**
9	COOLING WATER SYSTEM													
9.1	Cooling Towers	13,090	0	4,076	0	17,167	9.5%	1,630	0%	0	10.0%	1,880	20,676	38
9.2	Circulating Water Pumps	2,318	0	178	0	2,497	8.6%	213	0%	0	10.0%	271	2,981	5
9.3	Circ. Water System Auxiliaries	614	0	82	0	696	9.4%	66	0%	0	10.0%	76	838	2
9.4	Circ. Water Piping	0	4,871	4,721	0	9,593	9.2%	884	0%	0	15.0%	1,571	12,048	22
9.5	Make-up Water System	527	0	704	0	1,232	9.5%	117	0%	0	15.0%	202	1,551	3
9.6	Component Cooling Water System	487	0	387	0	874	9.4%	82	0%	0	15.0%	143	1,099	2
9.9	Circ. Water System Foundations	0	2,942	4,674	0	7,615	9.4%	717	0%	0	20.0%	1,666	9,999	18
	SUBTOTAL 9.	**$17,037**	**$7,813**	**$14,823**	**$0**	**$39,674**		**$3,708**		**$0**		**$5,810**	**$49,192**	**$89**

Exhibit 3-72 Case 5 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor		Bare Erected	Eng'g CM H.O. &		Process Cont.		Project Cont.		TOTAL PLANT COST	
				Direct	Indirect		%	Total	%	Total	%	Total	$	$/kW
10	ASH/SPENT SORBENT HANDLING SYS													
10.1	Ash Coolers	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.2	Cyclone Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.3	HGCU Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.4	High Temperature Ash Piping	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.5	Other Ash Recovery Equipment	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.6	Ash Storage Silos	681	0	2,099	0	2,780	9.7%	271	0%	0	10.0%	305	3,356	6
10.7	Ash Transport & Feed Equipment	4,410	0	4,517	0	8,927	9.5%	844	0%	0	10.0%	977	10,749	20
10.8	Misc. Ash Handling Equipment	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
10.9	Ash/Spent Sorbent Foundation	0	162	191	0	353	9.3%	33	0%	0	20.0%	77	463	1
	SUBTOTAL 10.	**$5,091**	**$162**	**$6,807**	**$0**	**$12,060**		**$1,148**		**$0**		**$1,359**	**$14,568**	**$26**
11	ACCESSORY ELECTRIC PLANT													
11.1	Generator Equipment	1,862	0	302	0	2,165	9.3%	200	0%	0	7.5%	177	2,542	5
11.2	Station Service Equipment	6,760	0	2,221	0	8,981	9.6%	859	0%	0	7.5%	738	10,578	19
11.3	Switchgear & Motor Control	7,771	0	1,321	0	9,092	9.3%	842	0%	0	10.0%	993	10,927	20
11.4	Conduit & Cable Tray	0	4,872	16,847	0	21,719	9.6%	2,079	0%	0	15.0%	3,570	27,368	50
11.5	Wire & Cable	0	9,194	17,748	0	26,942	8.4%	2,270	0%	0	15.0%	4,382	33,593	61
11.6	Protective Equipment	261	0	888	0	1,149	9.8%	112	0%	0	10.0%	126	1,388	3
11.7	Standby Equipment	1,446	0	33	0	1,479	9.5%	140	0%	0	10.0%	162	1,781	3
11.8	Main Power Transformers	8,293	0	140	0	8,432	7.6%	641	0%	0	10.0%	907	9,980	18
11.9	Electrical Foundations	0	375	919	0	1,294	9.5%	123	0%	0	20.0%	283	1,700	3
	SUBTOTAL 11.	**$26,394**	**$14,441**	**$40,419**	**$0**	**$81,254**		**$7,266**		**$0**		**$11,339**	**$99,858**	**$182**
12	INSTRUMENTATION & CONTROL													
12.1	PC Control Equipment	w/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.2	Combustion Turbine Control	N/A	0	N/A	0	0	0%	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%	0	0	0
12.4	Other Major Component Control	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
12.5	Signal Processing Equipment	W/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.6	Control Boards, Panels & Racks	565	0	339	0	904	9.6%	87	0%	0	15.0%	149	1,140	2
12.7	Computer Accessories	5,708	0	998	0	6,705	9.5%	639	0%	0	10.0%	734	8,078	15
12.8	Instrument Wiring & Tubing	3,095	0	6,139	0	9,233	8.5%	786	0%	0	15.0%	1,503	11,523	21
12.9	Other I & C Equipment	1,613	0	3,660	0	5,272	9.7%	513	0%	0	10.0%	579	6,364	12
	SUBTOTAL 12.	**$10,980**	**$0**	**$11,134**	**$0**	**$22,114**		**$2,025**		**$0**		**$2,965**	**$27,104**	**$49**
13	IMPROVEMENTS TO SITE													
13.1	Site Preparation	0	55	1,106	0	1,161	9.9%	114	0%	0	20.0%	255	1,530	3
13.2	Site Improvements	0	1,835	2,280	0	4,115	9.8%	404	0%	0	20.0%	904	5,423	10
13.3	Site Facilities	3,289	0	3,244	0	6,533	9.8%	641	0%	0	20.0%	1,435	8,609	16
	SUBTOTAL 13.	**$3,289**	**$1,891**	**$6,629**	**$0**	**$11,809**		**$1,160**		**$0**		**$2,594**	**$15,562**	**$28**
14	BUILDINGS & STRUCTURES													
14.1	Boiler Building	0	8,830	7,765	0	16,595	9.0%	1,490	0%	0	15.0%	2,713	20,798	38
14.2	Turbine Building	0	12,760	11,892	0	24,652	9.0%	2,220	0%	0	15.0%	4,031	30,903	56
14.3	Administration Building	0	640	677	0	1,317	9.1%	119	0%	0	15.0%	215	1,652	3
14.4	Circulation Water Pumphouse	0	140	111	0	251	8.9%	22	0%	0	15.0%	41	314	1
14.5	Water Treatment Buildings	0	716	653	0	1,368	9.0%	123	0%	0	15.0%	224	1,714	3
14.6	Machine Shop	0	428	288	0	716	8.9%	64	0%	0	15.0%	117	896	2
14.7	Warehouse	0	290	291	0	581	9.0%	53	0%	0	15.0%	95	729	1
14.8	Other Buildings & Structures	0	237	202	0	439	9.0%	39	0%	0	15.0%	72	550	1
14.9	Waste Treating Building & Str.	0	446	1,353	0	1,799	9.4%	170	0%	0	15.0%	295	2,264	4
	SUBTOTAL 14.	**$0**	**$24,487**	**$23,232**	**$0**	**$47,719**		**$4,300**		**$0**		**$7,803**	**$59,821**	**$109**
	Total Cost	**$682,890**	**$56,938**	**$436,553**	**$0**	**$1,176,382**		**$111,297**		**$0**		**$157,073**	**$1,444,752**	**$2,627**

Exhibit 3-73 Case 5 Owner's Costs

Owner's Costs	$1,000	$/kW
Preproduction Costs		
6 Months All Labor	$9,711	$18
1 Month Maintenance Materials	$1,473	$3
1 Month Non-fuel Consumables	$807	$1
1 Month Waste Disposal	$317	$1
25% of 1 Months Fuel Cost at 100% CF	$1,918	$3
2% of TPC	$28,895	$53
Total	**$43,120**	**$78**
Inventory Capital		
60 day supply of fuel and consumables at 100% CF	$16,539	$30
0.5% of TPC (spare parts)	$7,224	$13
Total	**$23,763**	**$43**
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$216,713	$394
Financing Costs	$39,008	$71
Total Overnight Costs (TOC)	**$1,768,256**	**$3,215**
TASC Multiplier	1.134	
Total As-Spent Cost (TASC)	**$2,005,202**	**$3,646**

Exhibit 3-74 Case 5 O&M Costs

INITIAL & ANNUAL O&M EXPENSES						
Case:	Case 5 - Advanced Recycle					
Plant Size (MWe):	549.95			**Heat Rate (Btu/kWh):**		11,675
Primary/Secondary Fuel:	Illinois #6 Bituminous Coal			**Fuel Cost ($/MM Btu):**		1.64
Design/Construction	5 years			**Book Life (yrs):**		30
TPC (Plant Cost) Year:	June 2007			**TPI Year:**		2012
Capacity Factor (%):	85			**CO2 Captured (TPD):**		15,692

OPERATING & MAINTENANCE LABOR					
Operating Labor					
Operating Labor Rate (base):	$34.65	$/hour			
Operating Labor Burden:	30.00	% of base			
Labor Overhead Charge:	25.00	% of labor			
Operating Labor Requirements per Shift:	**units/mod.**		**Total Plant**		
Skilled Operator	2.0		2.0		
Operator	9.0		9.0		
Foreman	1.0		1.0		
Lab Tech's etc.	2.0		2.0		
TOTAL Operating Jobs	14.0		14.0		
				$	**$/kW-net**
Annual Operating Labor Cost (calc'd)				5,524,319	10.05
Maintenance Labor Cost (calc'd)				10,013,832	18.21
Administrative & Support Labor (calc'd)				3,884,538	7.06
Property Taxes and Insurance				28,895,034	52.54
TOTAL FIXED OPERATING COSTS				**48,317,723**	**87.86**

VARIABLE OPERATING COSTS						
					$	**$/kWh-net**
Maintenance Material Costs (calc'd)					**$15,020,866**	**0.00367**
Consumables	**Consumption**		**Unit**	**Initial**		
	Initial	**/Day**	**Cost**	**Cost**	**$**	**$/kWh-net**
Water (/1000 gallons)	0	6,319	1.08	$0	$2,120,740	0.00052
Chemicals						
MU & WT Chem. (lb)	0	30,590	0.17	$0	$1,642,519	0.00040
Limestone (ton)	0	665	21.63	$0	$4,465,708	0.00109
Carbon (Hg Removal) (lb)	0	0	1.05	$0	$0	0.00000
MEA Solvent (ton)	0	0	2249.89	$0	$0	0.00000
Caustic Soda, NaOH (ton)	0	0	433.68	$0	$0	0.00000
Sulfuric acid, H_2SO_4 (ton)	0	0	138.78	$0	$0	0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	0.00000
Activated C, MEA (lb)	0	0	1.05	$0	$0	0.00000
Ammonia, 19% soln (ton)	0	0	129.80	$0	$0	0.00000
Subtotal Chemicals				**$0**	**$6,108,226**	**0.00149**
Other						
Supplemental Fuel (MMBtu)	0	0	6.55	$0	$0	0.00000
SCR Catalyst Replacement	w/equip.	0.0	5775.94	$0	$0	0.00000
Emission Penalties	0	0	0.00	$0	$0	0.00000
Subtotal Other				**$0**	**$0**	**0.00000**
Waste Disposal						
Spent Mercury Catalyst (lb)	0	0	0.42	$0	$0	0.00000
Flyash (ton)	0	514	16.23	$0	$2,585,082	0.00063
Bottom Ash (ton)	0	128	16.23	$0	$646,286	0.00016
Subtotal Solid Waste Disposal				**$0**	**$3,231,368**	**0.00079**
By-products & Emissions						
Gypsum (tons)	0	0	0.00	$0	$0	0.00000
Sulfur (tons)	0	0	0.00	$0	$0	0.00000
Subtotal By-Products				**$0**	**$0**	**0.00000**
TOTAL VARIABLE OPERATING COSTS					**$26,481,200**	**0.00647**
Coal FUEL (tons)	**0**	**6,604**	**38.18**	**$0**	**$78,239,812**	**0.01911**
NATURAL GAS FUEL (Mscf)	**0**	**0**	**6.76**	**$0**	**$0**	**0.00000**

3.6 CASE 6 – ADVANCED CO_2 COMPRESSION PROCESS

The advanced CO_2 compression system employs "shock wave compression" technology for product CO_2 compression. The major advantages of shock wave technology are reported to be (1) its ability to produce higher single stage compression efficiencies; (2) its simplicity and small size, which make it less expensive to manufacture; and (3) its higher single stage compression ratio, which causes the compressed stream to have a higher temperature and offers an opportunity for waste heat recovery. This is in contrast to a conventional system, where in each compression stage the CO_2 stream temperature reaches about 99°C (210°F) and the stream is cooled using cooling water without useful heat recovery. The main reason for not recovering the heat in a conventional system is that the temperature is too low and to recover it is likely economically prohibitive. A review of the shock wave compression technology and the relevant assumptions used in this study are given in Section 2.5.6.

Similar to the current technology case (with the exception of advanced compression system for CO_2 compression), major components for Case 6 include the following:

1. Conventional cryogenic ASU
2. PC boiler operating at supercritical steam conditions
3. Baghouse to remove particulates
4. Wet FGD to reduce sulfur emission
5. Shock wave system to compress CO_2 to 15.3 MPa (2215 psia)
6. Steam turbine/generator

Block Flow Diagram and Stream Table

A process BFD for Case 6 is shown in Exhibit 3-75, and the corresponding stream tables are shown in Exhibit 3-76.

Heat and Mass Balance Diagram

Heat and mass balance diagrams are shown for the following subsystems in Exhibit 3-77 and Exhibit 3-78:

- Boiler and flue gas cleanup
- Steam cycle and feed water (power block)

Energy, Carbon, Sulfur, and Water Balances

An overall plant energy balance is provided in tabular form in Exhibit 3-79. The power out is the steam turbine power after generator losses.

Carbon, sulfur and water balances are shown in Exhibit 3-80 through Exhibit 3-82.

Performance Summary

A performance summary is provided in Exhibit 3-83.

Costing Table

Tables of capital costs, owner's costs, and O&M costs are provided in Exhibit 3-84 through Exhibit 3-86, respectively.

Equipment List

The combined equipment list for Case 4 through Case 7 is shown in Exhibit 3-99.

Exhibit 3-75 Process Block Flow Diagram for Case 6

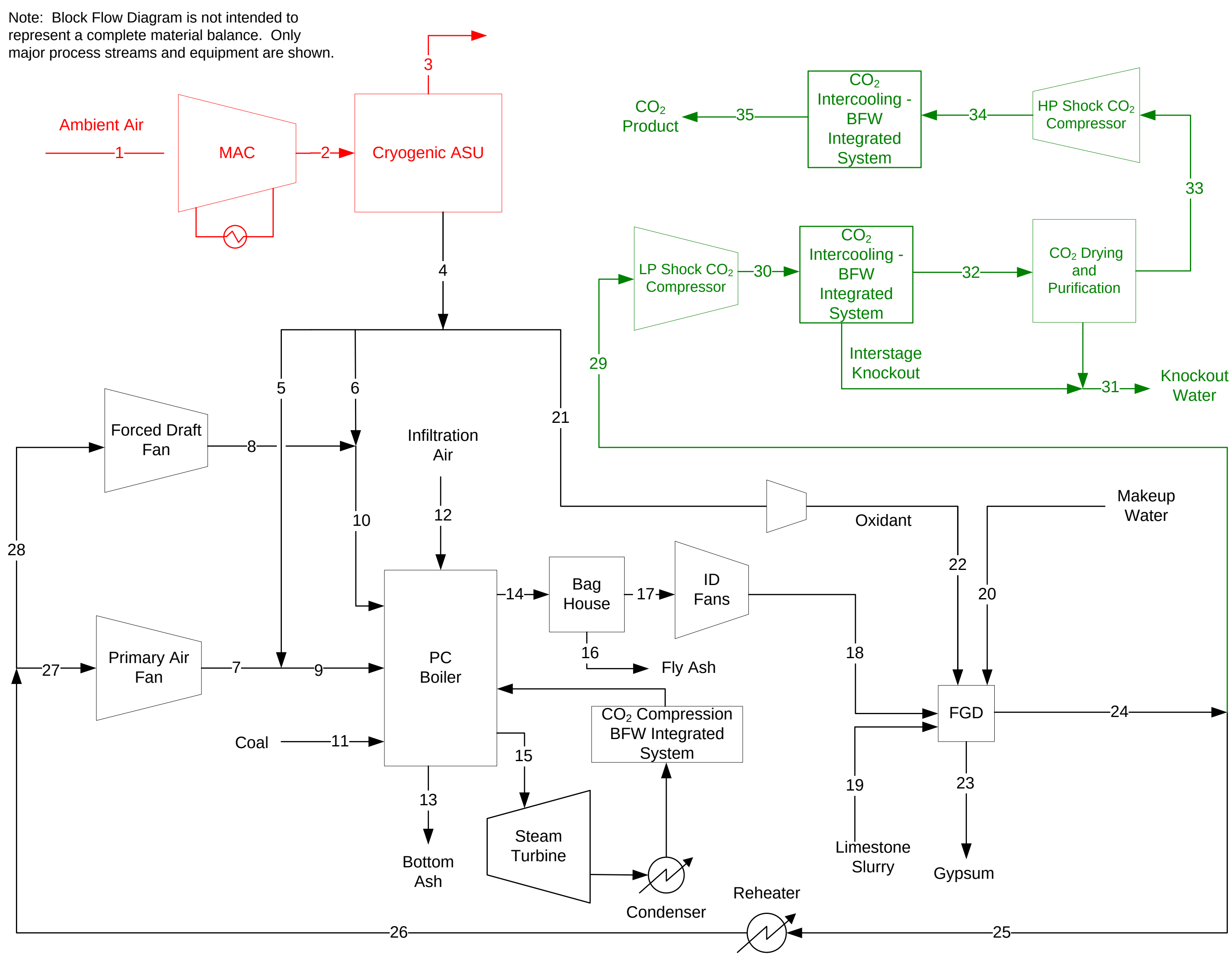


Exhibit 3-76 Stream Table for Case 6

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
V-L Mole Fraction																		
Ar	0.0092	0.0092	0.0024	0.0340	0.0340	0.0340	0.0308	0.0308	0.0317	0.0317	0.0000	0.0092	0.0000	0.0288	0.0000	0.0000	0.0288	0.0288
CO_2	0.0005	0.0005	0.0006	0.0000	0.0000	0.0000	0.7090	0.7090	0.5086	0.5086	0.0000	0.0005	0.0000	0.6614	0.0000	0.0000	0.6614	0.6614
H_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	0.0000	0.0000	0.0000	0.0000
H_2O	0.0101	0.0101	0.0128	0.0000	0.0000	0.0000	0.1514	0.1514	0.1087	0.1087	0.0000	0.0101	0.0000	0.2069	1.0000	0.0000	0.2069	0.2069
N_2	0.7729	0.7729	0.9778	0.0162	0.0162	0.0162	0.0856	0.0856	0.0660	0.0660	0.0000	0.7729	0.0000	0.0802	0.0000	0.0000	0.0802	0.0802
O_2	0.2074	0.2074	0.0063	0.9498	0.9498	0.9498	0.0231	0.0231	0.2849	0.2849	0.0000	0.2074	0.0000	0.0197	0.0000	0.0000	0.0197	0.0197
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0030	0.0000	0.0000	0.0030	0.0030
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	77,534	77,534	61,009	16,526	3,829	12,465	9,722	31,648	13,551	44,113	0	1,551	0	64,117	120,752	0	64,117	64,117
V-L Flowrate (kg/hr)	2,237,330	2,237,330	1,705,126	532,204	123,316	401,434	372,369	1,212,179	495,685	1,613,613	0	44,747	0	2,375,957	2,175,381	0	2,375,957	2,375,957
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	245,804	0	4,778	19,113	0	19,113	0	0
Temperature (°C)	15	24	17	13	13	13	75	69	60	56	15	15	15	177	599	15	177	186
Pressure (MPa, abs)	0.10	0.59	0.10	0.16	0.16	0.16	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	24.23	0.10	0.10	0.11
Enthalpy (kJ/kg)[A]	30.57	32.03	38.64	11.49	11.49	11.49	247.49	241.88	188.78	184.56	---	30.57	---	494.88	3,493.92	---	428.12	438.37
Density (kg/m^3)	1.2	7.0	1.2	2.2	2.2	2.2	1.5	1.4	1.5	1.4	---	1.2	---	1.0	68.5	---	1.0	1.0
V-L Molecular Weight	28.856	28.856	27.949	32.205	32.205	32.205	38.302	38.302	36.579	36.579	---	28.856	---	37.057	18.015	---	37.057	37.057
V-L Flowrate (lb_{mol}/hr)	170,934	170,934	134,501	36,433	8,442	27,481	21,433	69,771	29,875	97,252	0	3,419	0	141,353	266,213	0	141,353	141,353
V-L Flowrate (lb/hr)	4,932,468	4,932,468	3,759,159	1,173,309	271,866	885,010	820,932	2,672,397	1,092,798	3,557,407	0	98,649	0	5,238,088	4,795,895	0	5,238,088	5,238,088
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	541,905	0	10,534	42,137	0	42,137	0	0
Temperature (°F)	59	75	63	55	56	56	167	157	141	133	59	59	59	350	1,110	59	350	367
Pressure (psia)	14.7	86.1	14.7	23.2	23.2	23.2	16.2	15.3	16.2	15.3	14.7	14.7	14.7	14.4	3,514.7	14.7	14.2	15.3
Enthalpy (Btu/lb)[A]	13.1	13.8	16.6	4.9	4.9	4.9	106.4	104.0	81.2	79.3	---	13.1	---	212.8	1,502.1	---	184.1	188.5
Density (lb/ft^3)	0.076	0.435	0.073	0.135	0.135	0.135	0.092	0.089	0.092	0.088	---	0.076	---	0.062	4.274	---	0.061	0.064

A - Reference conditions are 32.02 F & 0.089 PSIA

Exhibit 3-76 Stream Table for Case 6 (Continued)

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
V-L Mole Fraction																	
Ar	0.0000	0.0000	0.0340	0.0340	0.0099	0.0308	0.0308	0.0308	0.0308	0.0308	0.0308	0.0308	0.0000	0.0355	0.0363	0.0363	0.0363
CO_2	0.0000	0.0000	0.0000	0.0000	0.9704	0.7090	0.7090	0.7090	0.7090	0.7090	0.7090	0.7090	0.0000	0.8164	0.8355	0.8355	0.8355
H_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	0.0000	0.0000	0.0000
H_2O	1.0000	1.0000	0.0000	0.0000	0.0029	0.1514	0.1514	0.1514	0.1514	0.1514	0.1514	0.1514	1.0000	0.0228	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0162	0.0162	0.0019	0.0856	0.0856	0.0856	0.0856	0.0856	0.0856	0.0856	0.0000	0.0986	0.1009	0.1009	0.1009
O_2	0.0000	0.0000	0.9498	0.9498	0.0086	0.0231	0.0231	0.0231	0.0231	0.0231	0.0231	0.0231	0.0000	0.0266	0.0272	0.0272	0.0272
SO_2	0.0000	0.0000	0.0000	0.0000	0.0063	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001
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	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	3,352	1,427	231	231	0	60,086	41,369	41,369	9,722	31,648	18,717	18,717	2,835	16,253	15,882	15,882	15,882
V-L Flowrate (kg/hr)	60,382	25,704	7,454	7,454	11	2,301,442	1,584,543	1,584,548	372,369	1,212,179	716,899	716,899	51,066	672,517	665,833	665,833	665,833
Solids Flowrate (kg/hr)	24,768	0	0	0	38,562	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	15	13	95	57	57	57	66	66	66	58	321	78	21	21	274	21
Pressure (MPa, abs)	0.11	0.10	0.16	0.31	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.25	0.10	1.24	1.24	15.27	15.26
Enthalpy (kJ/kg)[A]	---	62.80	11.49	85.68	---	230.24	230.24	238.24	238.24	238.24	230.77	502.50	324.69	8.64	6.84	221.55	-188.96
Density (kg/m^3)	---	1,003.1	2.2	3.3	---	1.4	1.4	1.4	1.4	1.4	1.4	9.7	941.3	22.7	22.6	144.2	690.8
V-L Molecular Weight	---	18.015	32.205	32.205	---	38.302	38.302	38.302	38.302	38.302	38.302	38.302	18.015	41.378	41.923	41.923	41.923
V-L Flowrate (lb_{mol}/hr)	7,389	3,146	510	510	1	132,467	91,204	91,204	21,433	69,771	41,263	41,263	6,249	35,832	35,014	35,014	35,014
V-L Flowrate (lb/hr)	133,120	56,668	16,433	16,433	23	5,073,812	3,493,320	3,493,329	820,932	2,672,397	1,580,492	1,580,492	112,582	1,482,645	1,467,910	1,467,910	1,467,910
Solids Flowrate (lb/hr)	54,603	0	0	0	85,015	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	59	56	203	135	135	135	150	150	150	136	610	172	70	70	525	70
Pressure (psia)	15.5	14.7	23.2	45.0	14.8	14.8	14.8	14.7	14.7	14.7	14.8	180.8	14.7	179.8	179.8	2,214.7	2,213.7
Enthalpy (Btu/lb)[A]	---	27.0	4.9	36.8	---	99.0	99.0	102.4	102.4	102.4	99.2	216.0	139.6	3.7	2.9	95.2	-81.2
Density (lb/ft^3)	---	62.622	0.135	0.204	---	0.089	0.089	0.087	0.087	0.087	0.089	0.606	58.763	1.420	1.408	9.002	43.124

Exhibit 3-77 Heat and Mass Balance, Boiler and Gas Cleanup Systems for Case 6

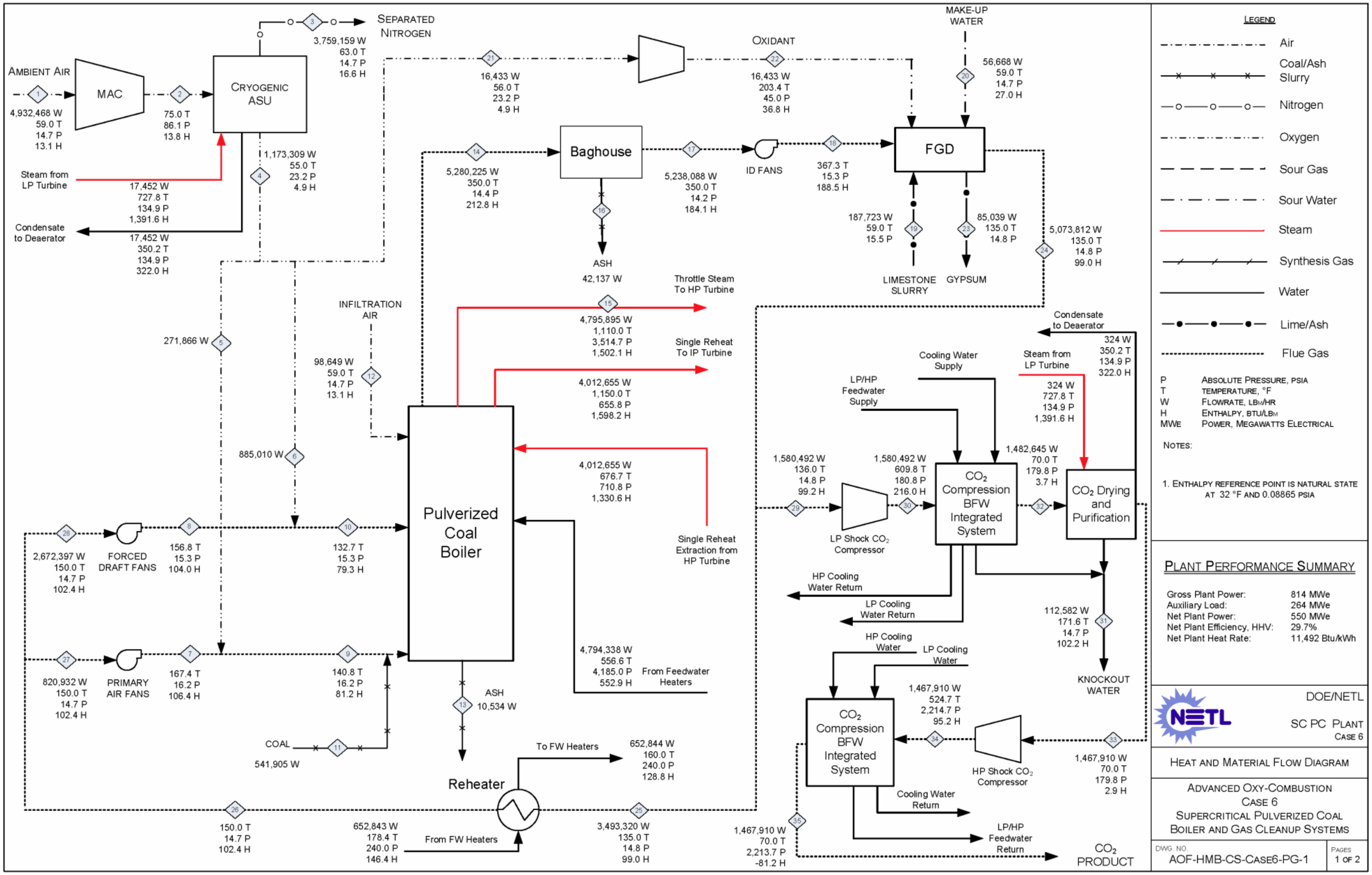


Exhibit 3-78 Heat and Mass Balance, Power Block Systems for Case 6

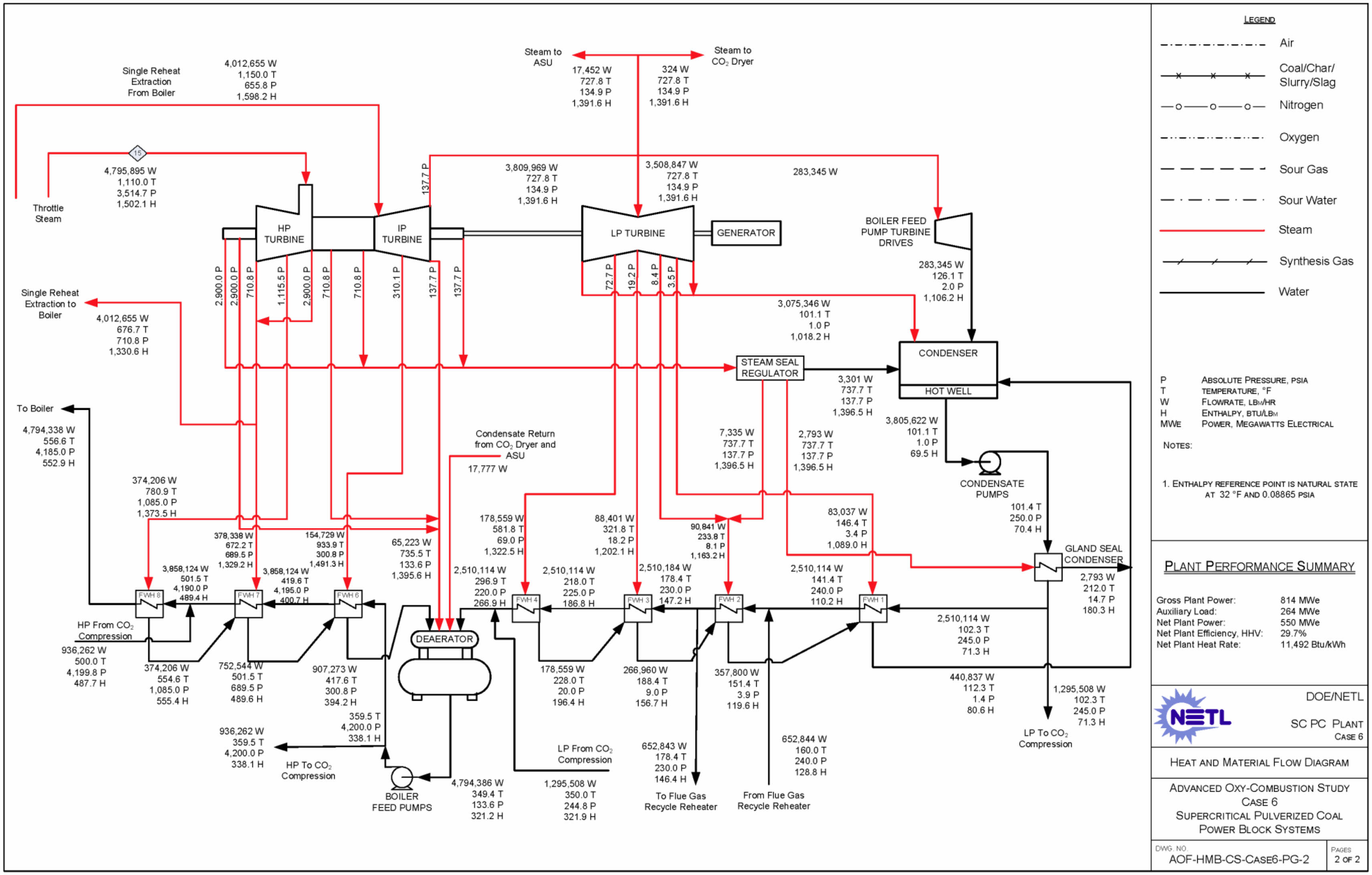


Exhibit 3-79 Cases 6 Energy Balance

	HHV	Sensible + Latent	Power	Total
Heat In GJ/hr (MMBtu/hr)				
Coal	6,670 (6,322)	*5.6 (5.3)*		6,675 (6,327)
Combustion Air		69.8 (66.1)		69.8 (66.1)
Raw Water Makeup		121.0 (114.7)		121.0 (114.7)
Limestone		0.54 (0.51)		0.54 (0.51)
Auxiliary Power			950 (900)	950 (900)
Totals	**6,670 (6,322)**	**196.9 (186.7)**	**950 (900)**	**7,817 (7,409)**
Heat Out GJ/hr (MMBtu/hr)				
Boiler Loss		60.1 (57.0)		60.1 (57.0)
Bottom Ash		0.6 (0.6)		0.6 (0.6)
Fly Ash + FGD Ash		2.4 (2.3)		2.4 (2.3)
MAC Cooling		429.2 (406.8)		429.2 (406.8)
ASU Vent		65.9 (62.5)		65.9 (62.5)
Condenser		3,398 (3,221)		3,398 (3,221)
CO_2 Cooling		125 (119)		125 (119)
CO_2		-126 (-119)		-126 (-119)
Wet FGD Cooling		505 (478)		505 (478)
Process Condensate		54 (51)		54 (51)
Cooling Tower Blowdown		58.2 (55.1)		58.2 (55.1)
Process Losses*		*374.4 (354.9)*		*374.4 (354.9)*
Power			2,930 (2,777)	2,930 (2,777)
Totals		**4,886 (4,631)**	**2,930 (2,777)**	**7,817 (7,409)**

Note: Italicized numbers are estimated
Reference conditions are 0°C (32.02°F) & 0.6 kPa (0.089 psia)
* Process losses are estimated to match the heat input to the plant and include losses from: steam turbine, combustion reactions, and gas cooling.

Exhibit 3-80 Case 6 Carbon Balance

Carbon In		**Carbon Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	157,079 (346,300)	CO_2 Product	159,384 (351,382)
Air (CO2)	436 (961)	FGD Product	217 (479)
FGD Reagent	2,513 (5,541)	Separated Air	427 (942)
		Convergence Tolerance*	-1 (-2)
Total	160,028 (352,802)	Total	160,028 (352,802)

*by difference

Exhibit 3-81 Case 6 Sulfur Balance

Sulfur In		**Sulfur Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	6,175 (13,614)	Gypsum	6,136 (13,528)
		CO_2 Product	39 (86)
		Convergence Tolerance*	0 (0)
Total	6,175 (13,614)	Total	6,175 (13,614)

*by difference

Exhibit 3-82 Case 6 Water Balance

Water Use	**Water Demand**	**Internal Recycle**	**Raw Water Withdrawal**	**Process Water Discharge**	**Raw Water Consumption**
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	gpm (m^3/min)	m^3/min (gpm)
FGD Makeup	0.43 (113)	0.0 (0)	0.43 (113)	0.0 (0)	0.43 (113)
BFW Makeup	0.36 (96)	0.0 (0)	0.36 (96)	0.0 (0)	0.36 (96)
Cooling Tower	34.8 (9,195)	3.43 (905)	31.4 (8,289)	7.83 (2068)	23.55 (6222)
Total	**35.6 (9,404)**	**3.43 (905)**	**32.2 (8,499)**	**7.83 (2,068)**	**24.34 (6,431)**

Exhibit 3-83 Case 6 Performance Summary

Plant Output		
Steam Turbine Power	814,000	kW_e
Gross Power	**814,000**	kWe
Auxiliary Load		
Coal Handling and Conveying	500	kW_e
Limestone Handling & Reagent Preparation	1,190	kW_e
Pulverizers	3,680	kW_e
Ash Handling	710	kW_e
Primary Air Fans	1,010	kW_e
Forced Draft Fans	1,270	kW_e
Induced Draft Fans	7,010	kW_e
Air Separation Unit Main Air Compressor	123,950	kW_e
ASU Auxiliaries	1,000	kW_e
Baghouse	90	kW_e
FGD Pumps and Agitators	3,990	kWe
CO_2 Compression	98,700	kW_e
Condensate Pumps	1,070	kW_e
Boiler Feedwater Booster Pumps[2]	N/A	kW_e
Miscellaneous Balance of Plant[3]	2,000	kW_e
Steam Turbine Auxiliaries	400	kW_e
Circulating Water Pumps	8,930	kW_e
Cooling Tower Fans	5,220	kW_e
Transformer Losses	3,160	kW_e
Total	263,880	kW_e
Plant Performance		
Net Auxiliary Load	263,880	kW_e
Net Plant Power	550,120	kW_e
Net Plant Efficiency (HHV)	29.7%	
Net Plant Heat Rate (HHV)	12,124 (11,492)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	245,804 (541,905)	kg/hr (lb/hr)
Thermal Input[1]	1,852,755	kW_{th}
Condenser Duty	3,398 (3,221)	GJ/hr (MMBtu/hr)
Raw Water Usage	32.2 (8,499)	m^3/min (gpm)

1 - HHV of As Received Illinois No. 6 coal is 27,135 kJ/kg (11,666 Btu/lb)

2 - Boiler feed pumps are turbine driven

3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 3-84 Case 6 Capital Costs

	Department:	NETL Office of Program Planning and Analysis										**Cost Base:**	June 2007	
	Project:	Advancing Oxycombustion Technology										**Prepared:**	13-Apr-12	
	Case:	Case 6 - Advanced CO2 Compression											**x $1, 000**	
	Plant Size:	550	MW, net		Capital Charge Factor	0.158		Capacity Factor	0.85					
		Equipment	**Material**	**Labor**		**Bare**	**Eng'g CM H.O. &**		**Process Cont.**		**Project Cont.**		**TOTAL PLANT COST**	
Acct No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Erected**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**$**	**$/kW**
1	COAL HANDLING SYSTEM													
1.1	Coal Receive & Unload	3,918	0	1,789	0	5,707	8.9%	510	0%	0	15.0%	932	7,149	13
1.2	Coal Stackout & Reclaim	5,063	0	1,147	0	6,210	8.8%	544	0%	0	15.0%	1,013	7,767	14
1.3	Coal Conveyors & Yd Crus	4,707	0	1,135	0	5,842	8.8%	512	0%	0	15.0%	953	7,308	13
1.4	Other Coal Handling	1,232	0	263	0	1,494	8.7%	131	0%	0	15.0%	244	1,869	3
1.5	Sorbent Receive & Unload	161	0	49	0	210	8.8%	19	0%	0	15.0%	34	263	0
1.6	Sorbent Stackout & Reclaim	2,605	0	477	0	3,082	8.7%	269	0%	0	15.0%	503	3,853	7
1.7	Sorbent Conveyors	929	201	228	0	1,358	8.7%	118	0%	0	15.0%	221	1,697	3
1.8	Other Sorbent Handling	561	132	294	0	987	8.8%	87	0%	0	15.0%	161	1,236	2
1.9	Coal & Sorbent Hnd.Foundations	0	4,816	6,076	0	10,892	9.3%	1,018	0%	0	15.0%	1,787	13,697	25
	SUBTOTAL 1.	**$19,176**	**$5,149**	**$11,458**	**$0**	**$35,784**		**$3,206**		**$0**		**$5,848**	**$44,838**	**$82**
2	COAL PREP & FEED SYSTEMS													
2.1	Coal Crushing & Drying	2,266	0	442	0	2,707	8.7%	236	0%	0	15.0%	442	3,385	6
2.2	Prepared Coal Storage & Feed	5,801	0	1,266	0	7,068	8.7%	618	0%	0	15.0%	1,153	8,839	16
2.3	Slurry Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.4	Misc. Coal Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.5	Sorbent Prep Equipment	4,436	191	921	0	5,549	8.7%	483	0%	0	15.0%	905	6,937	13
2.6	Sorbent Storage & Feed	534	0	205	0	739	8.9%	66	0%	0	15.0%	121	926	2
2.7	Sorbent Injection System	0	0	0	0	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	0.0%	0	0	0
2.9	Coal & Sorbent Feed Foundation	0	568	477	0	1,045	9.2%	96	0%	0	15.0%	171	1,313	2
	SUBTOTAL 2.	**$13,038**	**$760**	**$3,311**	**$0**	**$17,109**		**$1,500**		**$0**		**$2,791**	**$21,399**	**$39**
3	FEEDWATER & MISC. BOP SYSTEMS													
3.1	Feedwater System	21,503	0	6,946	0	28,449	8.8%	2,491	0%	0	15.0%	4,641	35,581	65
3.2	Water Makeup & Pretreating	5,426	0	1,747	0	7,173	9.4%	672	0%	0	20.0%	1,569	9,414	17
3.3	Other Feedwater Subsystems	6,583	0	2,782	0	9,365	8.9%	835	0%	0	15.0%	1,530	11,730	21
3.4	Service Water Systems	1,064	0	579	0	1,642	9.3%	152	0%	0	20.0%	359	2,154	4
3.5	Other Boiler Plant Systems	8,117	0	8,014	0	16,130	9.4%	1,513	0%	0	15.0%	2,647	20,290	37
3.6	FO Supply Sys & Nat Gas	271	0	338	0	609	9.3%	57	0%	0	15.0%	100	765	1
3.7	Waste Treatment Equipment	2,950	0	1,682	0	4,632	9.7%	449	0%	0	20.0%	1,016	6,097	11
3.8	Misc. Power Plant Equipment	2,872	0	877	0	3,750	9.6%	360	0%	0	20.0%	822	4,931	9
	SUBTOTAL 3.	**$48,785**	**$0**	**$22,964**	**$0**	**$71,749**		**$6,529**		**$0**		**$12,683**	**$90,962**	**$165**
4	PC BOILER & ACCESSORIES													
4.1	PC Boiler	184,189	0	103,349	0	287,537	9.7%	27,851	0%	0	10.0%	31,539	346,927	631
4.2	ASU/Oxidant Compression	114,916	0	94,022	0	208,938	9.7%	20,238	0%	0	10.0%	22,918	252,093	458
4.3	Open	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.4	Boiler BoP (w/ID Fans)	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.5	Primary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.6	Secondary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.7	Major Component Rigging	0	w/4.1	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.8	PC Foundations	0	w/14.1	w/14.1	0	0	0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 4.	**$299,105**	**$0**	**$197,371**	**$0**	**$496,475**		**$48,089**		**$0**		**$54,456**	**$599,021**	**$1,089**

Exhibit 3-84 Case 6 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
5A	FLUE GAS CLEANUP							*						
5.1	Absorber Vessels & Accessories	59,900	0	12,895	0	72,795	9.5%	6,890	0%	0	10.0%	7,968	87,653	159
5.2	Other FGD	3,128	0	3,545	0	6,673	9.6%	643	0%	0	10.0%	732	8,047	15
5.3	Bag House & Accessories	14,967	0	9,498	0	24,465	9.6%	2,340	0%	0	10.0%	2,680	29,485	54
5.4	Other Particulate Removal Materials	988	0	1,057	0	2,044	9.6%	197	0%	0	10.0%	224	2,465	4
5.5	Gypsum Dewatering System	5,411	0	919	0	6,330	9.4%	598	0%	0	10.0%	693	7,621	14
5.6	Mercury Removal System	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.7	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.8	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.9	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 5A.	**$84,393**	**$0**	**$27,914**	**$0**	**$112,307**		**$10,668**		**$0**		**$12,297**	**$135,272**	**$246**
5B	CO2 REMOVAL & COMPRESSION													
5B.1	CO2 Condensing Heat Exchanger	5,997	0	501	0	6,498	10%	650	0%	0	15.0%	1,072	8,219	15
5B.2	CO2 Compression & Drying	41,386	0	12,984	0	54,370	10%	5,200	0%	0	20.0%	11,914	71,483	130
5B.3	CO2 Additional BFW Heat Exchanger	4,653	0	389	0	5,042	10%	504	0%	0	15.0%	832	6,378	12
5B.4	CO2 Pipeline											0	0	0
5B.5	CO2 Storage											0	0	0
5B.6	CO2 Monitoring											0	0	0
	SUBTOTAL 5B.	**$52,036**	**$0**	**$13,873**	**$0**	**$65,909**		**$6,354**		**$0**		**$13,818**	**$86,080**	**$156**
6	NITROGEN EXPANDER/GENERATOR													
6.1	Nitrogen Expander/Generator	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.2	Nitrogen Expander/Generator Accessories	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.3	Compressed Air Piping	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.4	Nitrogen Expander/Generator Foundations	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 6.	**$0**	**$0**	**$0**	**$0**	**$0**		**$0**		**$0**		**$0**	**$0**	**$0**
7	HRSG, DUCTING & STACK													
7.1	Flue Gas Recycle Heat Exchanger	1,402	0	117	0	1,519	10%	152	0%	0	15.0%	251	1,921	3
7.2	SCR System	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
7.3	Ductwork	9,294	0	5,971	0	15,265	8.7%	1,333	0%	0	15.0%	2,490	19,088	35
7.4	Stack	1,587	0	929	0	2,516	9.6%	240	0%	0	10.0%	276	3,032	6
7.9	HRSG, Duct & Stack Foundations	0	859	976	0	1,836	9.3%	171	0%	0	20.0%	401	2,408	4
	SUBTOTAL 7.	**$12,283**	**$859**	**$7,993**	**$0**	**$21,136**		**$1,897**		**$0**		**$3,417**	**$26,450**	**$48**
8	STEAM TURBINE GENERATOR													
8.1	Steam TG & Accessories	63,770	0	8,463	0	72,233	9.6%	6,916	0%	0	10.0%	7,915	87,064	158
8.2	Turbine Plant Auxiliaries	429	0	920	0	1,349	9.7%	131	0%	0	10.0%	148	1,628	3
8.3	Condenser & Auxiliaries	7,658	0	2,823	0	10,481	9.5%	996	0%	0	10.0%	1,148	12,625	23
8.4	Steam Piping	20,177	0	9,948	0	30,125	8.3%	2,514	0%	0	15.0%	4,896	37,535	68
8.9	TG Foundations	0	1,343	2,122	0	3,465	9.4%	326	0%	0	20.0%	758	4,549	8
	SUBTOTAL 8.	**$92,035**	**$1,343**	**$24,276**	**$0**	**$117,654**		**$10,883**		**$0**		**$14,865**	**$143,402**	**$261**
9	COOLING WATER SYSTEM													
9.1	Cooling Towers	12,845	0	4,000	0	16,845	9.5%	1,599	0%	0	10.0%	1,844	20,288	37
9.2	Circulating Water Pumps	2,266	0	174	0	2,440	8.6%	209	0%	0	10.0%	265	2,914	5
9.3	Circ. Water System Auxiliaries	604	0	81	0	684	9.4%	65	0%	0	10.0%	75	824	1
9.4	Circ. Water Piping	0	4,788	4,640	0	9,428	9.2%	868	0%	0	15.0%	1,544	11,840	22
9.5	Make-up Water System	517	0	691	0	1,208	9.5%	114	0%	0	15.0%	198	1,521	3
9.6	Component Cooling Water System	478	0	381	0	859	9.4%	81	0%	0	15.0%	141	1,081	2
9.9	Circ. Water System Foundations	0	2,895	4,599	0	7,494	9.4%	705	0%	0	20.0%	1,640	9,840	18
	SUBTOTAL 9.	**$16,710**	**$7,683**	**$14,566**	**$0**	**$38,959**		**$3,641**		**$0**		**$5,708**	**$48,308**	**$88**

Exhibit 3-84 Case 6 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
10	ASH/SPENT SORBENT HANDLING SYS													
10.1	Ash Coolers	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.2	Cyclone Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.3	HGCU Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.4	High Temperature Ash Piping	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.5	Other Ash Recovery Equipment	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.6	Ash Storage Silos	675	0	2,081	0	2,756	9.7%	268	0%	0	10.0%	302	3,327	6
10.7	Ash Transport & Feed Equipment	4,372	0	4,478	0	8,850	9.5%	837	0%	0	10.0%	969	10,656	19
10.8	Misc. Ash Handling Equipment	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
10.9	Ash/Spent Sorbent Foundation	0	161	189	0	349	9.3%	33	0%	0	20.0%	76	459	1
	SUBTOTAL 10.	**$5,047**	**$161**	**$6,748**	**$0**	**$11,956**		**$1,138**		**$0**		**$1,348**	**$14,442**	**$26**
11	ACCESSORY ELECTRIC PLANT													
11.1	Generator Equipment	1,892	0	307	0	2,199	9.3%	204	0%	0	7.5%	180	2,583	5
11.2	Station Service Equipment	7,035	0	2,311	0	9,346	9.6%	894	0%	0	7.5%	768	11,008	20
11.3	Switchgear & Motor Control	8,087	0	1,375	0	9,462	9.3%	876	0%	0	10.0%	1,034	11,372	21
11.4	Conduit & Cable Tray	0	5,070	17,532	0	22,602	9.6%	2,163	0%	0	15.0%	3,715	28,480	52
11.5	Wire & Cable	0	9,568	18,470	0	28,037	8.4%	2,362	0%	0	15.0%	4,560	34,959	64
11.6	Protective Equipment	261	0	888	0	1,149	9.8%	112	0%	0	10.0%	126	1,388	3
11.7	Standby Equipment	1,465	0	33	0	1,499	9.5%	142	0%	0	10.0%	164	1,805	3
11.8	Main Power Transformers	8,417	0	142	0	8,559	7.6%	650	0%	0	10.0%	921	10,130	18
11.9	Electrical Foundations	0	382	937	0	1,319	9.5%	125	0%	0	20.0%	289	1,733	3
	SUBTOTAL 11.	**$27,157**	**$15,020**	**$41,995**	**$0**	**$84,173**		**$7,529**		**$0**		**$11,757**	**$103,458**	**$188**
12	INSTRUMENTATION & CONTROL													
12.1	PC Control Equipment	w/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.2	Combustion Turbine Control	N/A	0	N/A	0	0	0%	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%	0	0	0
12.4	Other Major Component Control	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
12.5	Signal Processing Equipment	W/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.6	Control Boards, Panels & Racks	572	0	343	0	915	9.6%	88	0%	0	15.0%	150	1,153	2
12.7	Computer Accessories	5,775	0	1,009	0	6,785	9.5%	646	0%	0	10.0%	743	8,174	15
12.8	Instrument Wiring & Tubing	3,131	0	6,212	0	9,343	8.5%	796	0%	0	15.0%	1,521	11,659	21
12.9	Other I & C Equipment	1,632	0	3,703	0	5,335	9.7%	520	0%	0	10.0%	585	6,440	12
	SUBTOTAL 12.	**$11,110**	**$0**	**$11,267**	**$0**	**$22,377**		**$2,049**		**$0**		**$3,000**	**$27,426**	**$50**
13	IMPROVEMENTS TO SITE													
13.1	Site Preparation	0	55	1,101	0	1,157	9.9%	114	0%	0	20.0%	254	1,525	3
13.2	Site Improvements	0	1,828	2,271	0	4,099	9.8%	403	0%	0	20.0%	900	5,402	10
13.3	Site Facilities	3,277	0	3,231	0	6,508	9.8%	639	0%	0	20.0%	1,429	8,576	16
	SUBTOTAL 13.	**$3,277**	**$1,884**	**$6,603**	**$0**	**$11,764**		**$1,155**		**$0**		**$2,584**	**$15,503**	**$28**
14	BUILDINGS & STRUCTURES													
14.1	Boiler Building	0	8,822	7,758	0	16,579	9.0%	1,489	0%	0	15.0%	2,710	20,778	38
14.2	Turbine Building	0	12,740	11,874	0	24,614	9.0%	2,216	0%	0	15.0%	4,025	30,855	56
14.3	Administration Building	0	639	676	0	1,315	9.1%	119	0%	0	15.0%	215	1,649	3
14.4	Circulation Water Pumphouse	0	137	109	0	247	8.9%	22	0%	0	15.0%	40	309	1
14.5	Water Treatment Buildings	0	701	639	0	1,340	9.0%	120	0%	0	15.0%	219	1,678	3
14.6	Machine Shop	0	427	287	0	715	8.9%	63	0%	0	15.0%	117	895	2
14.7	Warehouse	0	290	291	0	580	9.0%	52	0%	0	15.0%	95	727	1
14.8	Other Buildings & Structures	0	237	201	0	438	9.0%	39	0%	0	15.0%	72	549	1
14.9	Waste Treating Building & Str.	0	445	1,350	0	1,795	9.4%	170	0%	0	15.0%	295	2,259	4
	SUBTOTAL 14.	**$0**	**$24,438**	**$23,185**	**$0**	**$47,622**		**$4,291**		**$0**		**$7,787**	**$59,700**	**$109**
	Total Cost	**$684,153**	**$57,296**	**$413,524**	**$0**	**$1,154,973**		**$108,928**		**$0**		**$152,360**	**$1,416,260**	**$2,574**

Exhibit 3-85 Case 6 Owner's Costs

Owner's Costs	$1,000	$/kW
Preproduction Costs		
6 Months All Labor	$9,597	$17
1 Month Maintenance Materials	$1,446	$3
1 Month Non-fuel Consumables	$788	$1
1 Month Waste Disposal	$312	$1
25% of 1 Months Fuel Cost at 100% CF	$1,888	$3
2% of TPC	$28,325	$51
Total	**$42,357**	**$77**
Inventory Capital		
60 day supply of fuel and consumables at 100% CF	$16,280	$30
0.5% of TPC (spare parts)	$7,081	$13
Total	**$23,361**	**$42**
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$212,439	$386
Financing Costs	$38,239	$70
Total Overnight Costs (TOC)	**$1,733,556**	**$3,151**
TASC Multiplier	1.134	
Total As-Spent Cost (TASC)	**$1,965,853**	**$3,573**

Exhibit 3-86 Case 6 O&M Costs

INITIAL & ANNUAL O&M EXPENSES						
Case:	Case 6 - Advanced CO2 Compression					
Plant Size (MWe):	550.12			**Heat Rate (Btu/kWh):**		11,492
Primary/Secondary Fuel:	Illinois #6 Bituminous Coal			**Fuel Cost ($/MM Btu):**		1.64
Design/Construction	5 years			**Book Life (yrs):**		30
TPC (Plant Cost) Year:	June 2007			**TPI Year:**		2012
Capacity Factor (%):	85			**CO2** Captured (TPD):		15,450
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate (base):		$34.65	$/hour			
Operating Labor Burden:		30.00	% of base			
Labor Overhead Charge:		25.00	% of labor			
Operating Labor Requirements per Shift:		**units/mod.**		**Total Plant**		
Skilled Operator		2.0		2.0		
Operator		9.0		9.0		
Foreman		1.0		1.0		
Lab Tech's etc.		2.0		2.0		
TOTAL Operating Jobs		14.0		14.0		
					$	**$/kW-net**
Annual Operating Labor Cost (calc'd)					5,524,319	10.04
Maintenance Labor Cost (calc'd)					9,831,588	17.87
Administrative & Support Labor (calc'd)					3,838,977	6.98
Property Taxes and Insurance					28,325,203	51.49
TOTAL FIXED OPERATING COSTS					**47,520,088**	**86.38**
VARIABLE OPERATING COSTS						
					$	**$/kWh-net**
Maintenance Material Costs (calc'd)					**$14,747,498**	**0.00360**
Consumables	**Consumption**		**Unit**	**Initial**		
	Initial	**/Day**	**Cost**	**Cost**	**$**	**$/kWh-net**
Water (/1000 gallons)	0	6,119	1.08	$0	$2,053,568	0.00050
Chemicals						
MU & WT Chem. (lb)	0	29,621	0.17	$0	$1,590,494	0.00039
Limestone (ton)	0	655	21.63	$0	$4,397,811	0.00107
Carbon (Hg Removal) (lb)	0	0	1.05	$0	$0	0.00000
MEA Solvent (ton)	0	0	2249.89	$0	$0	0.00000
Caustic Soda, NaOH (ton)	0	0	433.68	$0	$0	0.00000
Sulfuric acid, H_2SO_4 (ton)	0	0	138.78	$0	$0	0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	0.00000
Activated C, MEA (lb)	0	0	1.05	$0	$0	0.00000
Ammonia, 19% soln (ton)	0	0	129.80	$0	$0	0.00000
Subtotal Chemicals				**$0**	**$5,988,305**	**0.00146**
Other						
Supplemental Fuel (MMBtu)	0	0	6.55	$0	$0	0.00000
SCR Catalyst Replacement	w/equip.	0.0	5775.94	$0	$0	0.00000
Emission Penalties	0	0	0.00	$0	$0	0.00000
Subtotal Other				**$0**	**$0**	**0.00000**
Waste Disposal						
Spent Mercury Catalyst (lb)	0	0	0.42	$0	$0	0.00000
Flyash (ton)	0	506	16.23	$0	$2,545,335	0.00062
Bottom Ash (ton)	0	126	16.23	$0	$636,319	0.00016
Subtotal Solid Waste Disposal				**$0**	**$3,181,654**	**0.00078**
By-products & Emissions						
Gypsum (tons)	0	0	0.00	$0	$0	0.00000
Sulfur (tons)	0	0	0.00	$0	$0	0.00000
Subtotal By-Products				**$0**	**$0**	**0.00000**
TOTAL VARIABLE OPERATING COSTS					**$25,971,025**	**0.00634**
Coal FUEL (tons)	**0**	**6,503**	**38.18**	**$0**	**$77,037,699**	**0.01881**
NATURAL GAS FUEL (Mscf)	**0**	**0**	**6.76**	**$0**	**$0**	**0.00000**

3.7 CASE 7 – OXYCOMBUSTION BOILER DEVELOPMENT

This case uses an oxycombustion boiler system designed specifically for coal combustion in a highly concentrated O_2 environment. Conceptually, an oxycombustion-specific boiler is designed to accommodate a smaller flue gas flow, which results in reduced equipment size. It is also designed to accommodate increased temperatures by increasing heat transfer rates above those of conventional boilers. Furthermore, fan loads required for flue gas recycle are reduced, increasing system efficiency. More information on oxycombustion boilers is in Section 2.5.7.

With the exception of the higher adiabatic flame temperature, the major features for Case 7 are similar to the current technology case, which include the following:

1. Conventional cryogenic ASU
2. Advanced oxycombustion boiler with an adiabatic flame temperature of 4,187°F
3. Baghouse to remove particulates
4. Wet FGD to reduce sulfur emissions
5. CPU with compression to 15.3 MPa (2,215 psia)
6. FGR superheater
7. Steam turbine/generator

A process BFD for Case 7 is shown in Exhibit 3-87, and the corresponding stream tables are shown in Exhibit 3-88.

Heat and Mass Balance Diagram

Heat and mass balance diagrams are shown for the following subsystems in Exhibit 3-89 and Exhibit 3-90:

- Boiler and flue gas cleanup
- Steam cycle and feed water (power block)

Energy, Carbon, Sulfur, and Water Balances

An overall plant energy balance is provided in tabular form in Exhibit 3-91. The power out is the steam turbine power after generator losses.

Carbon, sulfur, and water balances are shown in Exhibit 3-92 through Exhibit 3-94.

Performance Summary

A performance summary is provided in Exhibit 3-95.

Costing Table

Tables of capital costs, owner's costs, and O&M costs are provided in Exhibit 3-96 through Exhibit 3-98, respectively.

Equipment List

In an attempt to condense the content of the report, the combined equipment list for Case 4 through Case 7 is shown in Exhibit 3-99.

Exhibit 3-87 Process Block Flow Diagram for Case 7

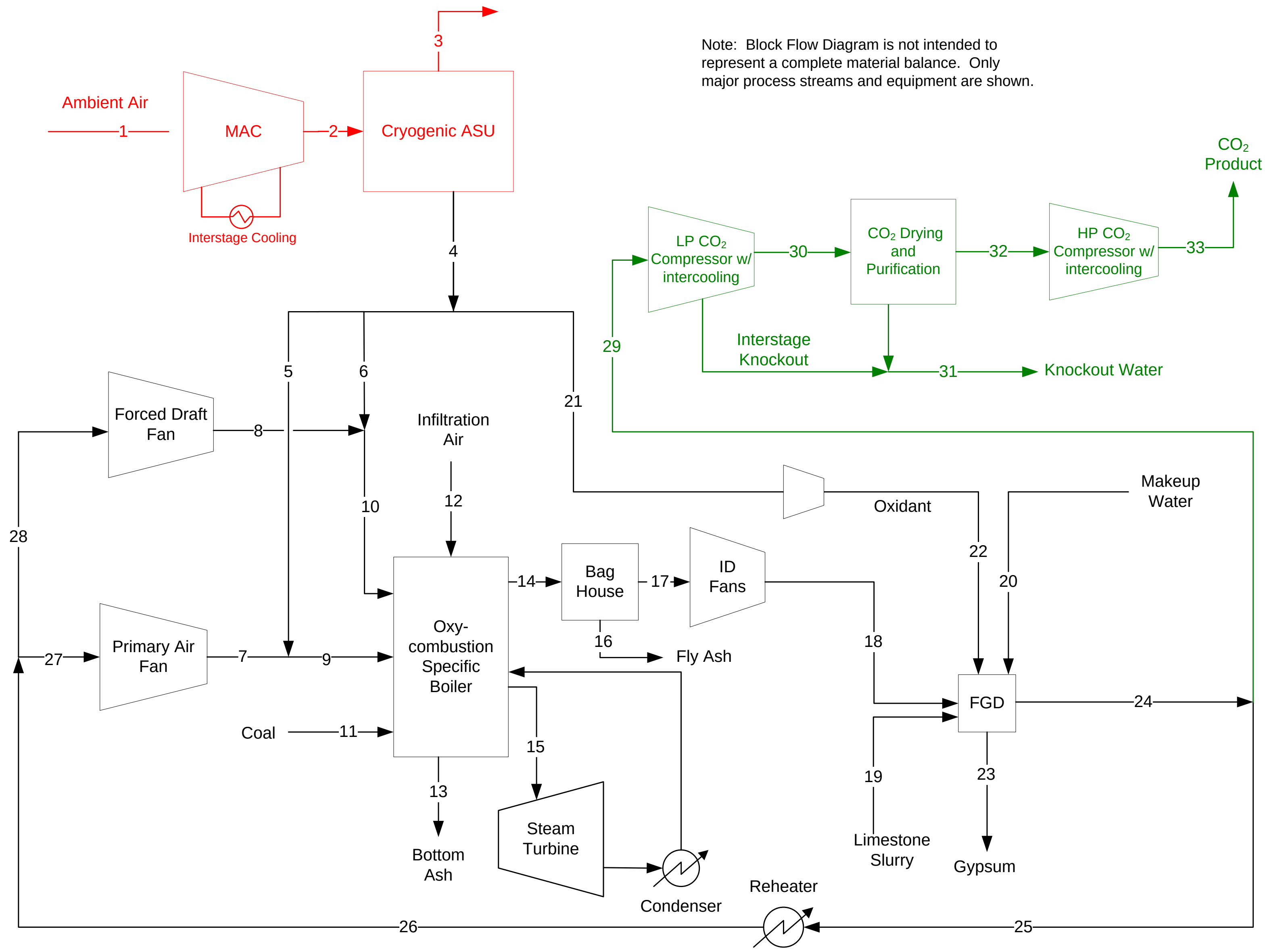


Exhibit 3-88 Stream Table for Case 7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
V-L Mole Fraction																	
Ar	0.0092	0.0092	0.0024	0.0340	0.0340	0.0340	0.0308	0.0308	0.0319	0.0319	0.0000	0.0092	0.0000	0.0284	0.0000	0.0000	0.0284
CO_2	0.0005	0.0005	0.0006	0.0000	0.0000	0.0000	0.7090	0.7090	0.4711	0.4711	0.0000	0.0005	0.0000	0.6536	0.0000	0.0000	0.6536
H_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	0.0000	0.0000	0.0000
H_2O	0.0101	0.0101	0.0128	0.0000	0.0000	0.0000	0.1514	0.1514	0.1006	0.1006	0.0000	0.0101	0.0000	0.2161	1.0000	0.0000	0.2161
N_2	0.7729	0.7729	0.9778	0.0162	0.0162	0.0162	0.0856	0.0856	0.0623	0.0623	0.0000	0.7729	0.0000	0.0793	0.0000	0.0000	0.0793
O_2	0.2074	0.2074	0.0063	0.9498	0.9498	0.9498	0.0231	0.0231	0.3340	0.3340	0.0000	0.2074	0.0000	0.0191	0.0000	0.0000	0.0191
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0035	0.0000	0.0000	0.0035
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	77,685	77,685	61,127	16,558	3,836	12,489	7,598	24,735	11,435	37,224	0	1,554	0	55,125	122,311	0	55,125
V-L Flowrate (kg/hr)	2,241,685	2,241,687	1,708,446	533,240	123,554	402,206	291,040	947,427	414,593	1,349,633	0	44,834	0	2,031,404	2,203,471	0	2,031,404
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	246,282	0	4,788	19,150	0	19,150	0
Temperature (°C)	15	24	17	13	13	13	75	69	57	53	15	15	15	177	599	15	177
Pressure (MPa, abs)	0.10	0.59	0.10	0.16	0.16	0.16	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	24.23	0.10	0.10
Enthalpy (kJ/kg)[A]	30.57	32.03	38.64	11.49	11.49	11.49	247.49	241.87	177.16	173.22	---	30.57	---	519.94	3,493.92	---	441.58
Density (kg/m^3)	1.2	7.0	1.2	2.2	2.2	2.2	1.5	1.4	1.5	1.4	---	1.2	---	1.0	68.5	---	1.0
V-L Molecular Weight	28.856	28.856	27.949	32.205	32.205	32.205	38.303	38.303	36.257	36.257	---	28.856	---	36.851	18.015	---	36.851
V-L Flowrate (lb_{mol}/hr)	171,267	171,267	134,763	36,504	8,458	27,534	16,752	54,532	25,210	82,066	0	3,425	0	121,530	269,650	0	121,530
V-L Flowrate (lb/hr)	4,942,070	4,942,073	3,766,479	1,175,594	272,389	886,713	641,632	2,088,718	914,021	2,975,431	0	98,841	0	4,478,480	4,857,822	0	4,478,480
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	542,960	0	10,555	42,219	0	42,219	0
Temperature (°F)	59	75	63	55	56	56	167	157	135	128	59	59	59	350	1,110	59	350
Pressure (psia)	14.7	86.1	14.7	23.2	23.2	23.2	16.2	15.3	16.2	15.3	14.7	14.7	14.7	14.4	3,514.7	14.7	14.2
Enthalpy (Btu/lb)[A]	13.1	13.8	16.6	4.9	4.9	4.9	106.4	104.0	76.2	74.5	---	13.1	---	223.5	1,502.1	---	189.8
Density (lb/ft^3)	0.076	0.435	0.073	0.135	0.135	0.135	0.092	0.089	0.092	0.088	---	0.076	---	0.061	4.274	---	0.060

A - Reference conditions are 32.02 F & 0.089 PSIA

Exhibit 3-88 Stream Table for Case 7 (Continued)

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
V-L Mole Fraction																
Ar	0.0284	0.0000	0.0000	0.0340	0.0340	0.0099	0.0308	0.0308	0.0308	0.0308	0.0308	0.0308	0.0362	0.0000	0.0363	0.0363
CO_2	0.6536	0.0000	0.0000	0.0000	0.0000	0.9695	0.7090	0.7090	0.7090	0.7090	0.7090	0.7090	0.8337	0.0000	0.8354	0.8354
H_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	0.0000	0.0000
H_2O	0.2161	1.0000	1.0000	0.0000	0.0000	0.0026	0.1514	0.1514	0.1514	0.1514	0.1514	0.1514	0.0021	1.0000	0.0001	0.0001
N_2	0.0793	0.0000	0.0000	0.0162	0.0162	0.0019	0.0856	0.0856	0.0856	0.0856	0.0856	0.0856	0.1007	0.0000	0.1009	0.1009
O_2	0.0191	0.0000	0.0000	0.9498	0.9498	0.0086	0.0231	0.0231	0.0231	0.0231	0.0231	0.0231	0.0272	0.0000	0.0272	0.0272
SO_2	0.0035	0.0000	0.0000	0.0000	0.0000	0.0074	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
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	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	55,125	3,174	1,618	232	232	0	51,087	32,334	32,334	7,598	24,735	18,753	15,947	2,840	15,915	15,915
V-L Flowrate (kg/hr)	2,031,404	57,185	29,145	7,481	7,481	12	1,956,764	1,238,464	1,238,470	291,040	947,427	718,302	667,740	51,169	667,176	667,176
Solids Flowrate (kg/hr)	0	24,852	0	0	0	38,658	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	186	15	15	13	95	57	57	57	66	66	66	58	104	22	104	21
Pressure (MPa, abs)	0.11	0.11	0.10	0.16	0.31	0.10	0.10	0.10	0.10	0.10	0.10	0.10	3.35	0.24	3.35	15.27
Enthalpy (kJ/kg)[A]	451.88	---	62.80	11.49	85.68	---	230.24	230.24	238.24	238.24	238.24	230.78	74.45	93.20	72.32	-188.93
Density (kg/m^3)	1.0	---	1,003.1	2.2	3.3	---	1.4	1.4	1.4	1.4	1.4	1.4	47.9	996.0	47.9	691.2
V-L Molecular Weight	36.851	---	18.015	32.205	32.205	---	38.303	38.303	38.303	38.303	38.303	38.303	41.873	18.016	41.920	41.920
V-L Flowrate (lb_{mol}/hr)	121,530	6,998	3,567	512	512	1	112,627	71,283	71,284	16,752	54,532	41,344	35,157	6,262	35,088	35,088
V-L Flowrate (lb/hr)	4,478,480	126,072	64,254	16,492	16,492	26	4,313,927	2,730,345	2,730,359	641,632	2,088,718	1,583,585	1,472,115	112,809	1,470,870	1,470,870
Solids Flowrate (lb/hr)	0	54,790	0	0	0	85,227	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	367	59	59	56	203	135	135	135	150	150	150	136	219	72	219	70
Pressure (psia)	15.3	15.5	14.7	23.2	45.0	14.8	14.8	14.8	14.7	14.7	14.7	14.8	485.8	35.2	485.8	2,214.7
Enthalpy (Btu/lb)[A]	194.3	---	27.0	4.9	36.8	---	99.0	99.0	102.4	102.4	102.4	99.2	32.0	40.1	31.1	-81.2
Density (lb/ft^3)	0.064	---	62.622	0.135	0.204	---	0.089	0.089	0.087	0.087	0.087	0.089	2.989	62.179	2.992	43.148

Exhibit 3-89 Heat and Mass Balance, Boiler and Gas Cleanup Systems for Case 7

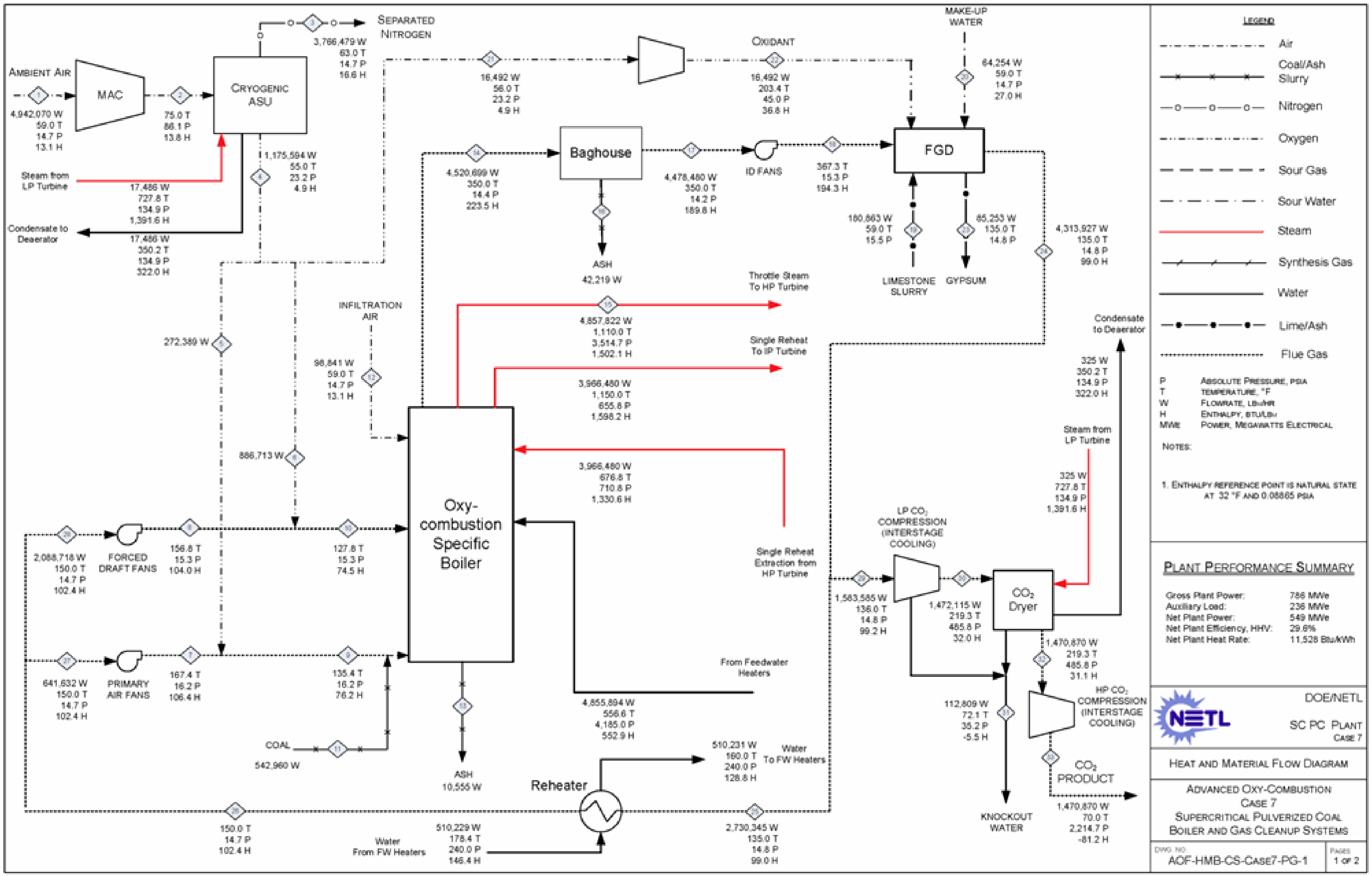


Exhibit 3-90 Heat and Mass Balance, Power Block Systems for Case 7

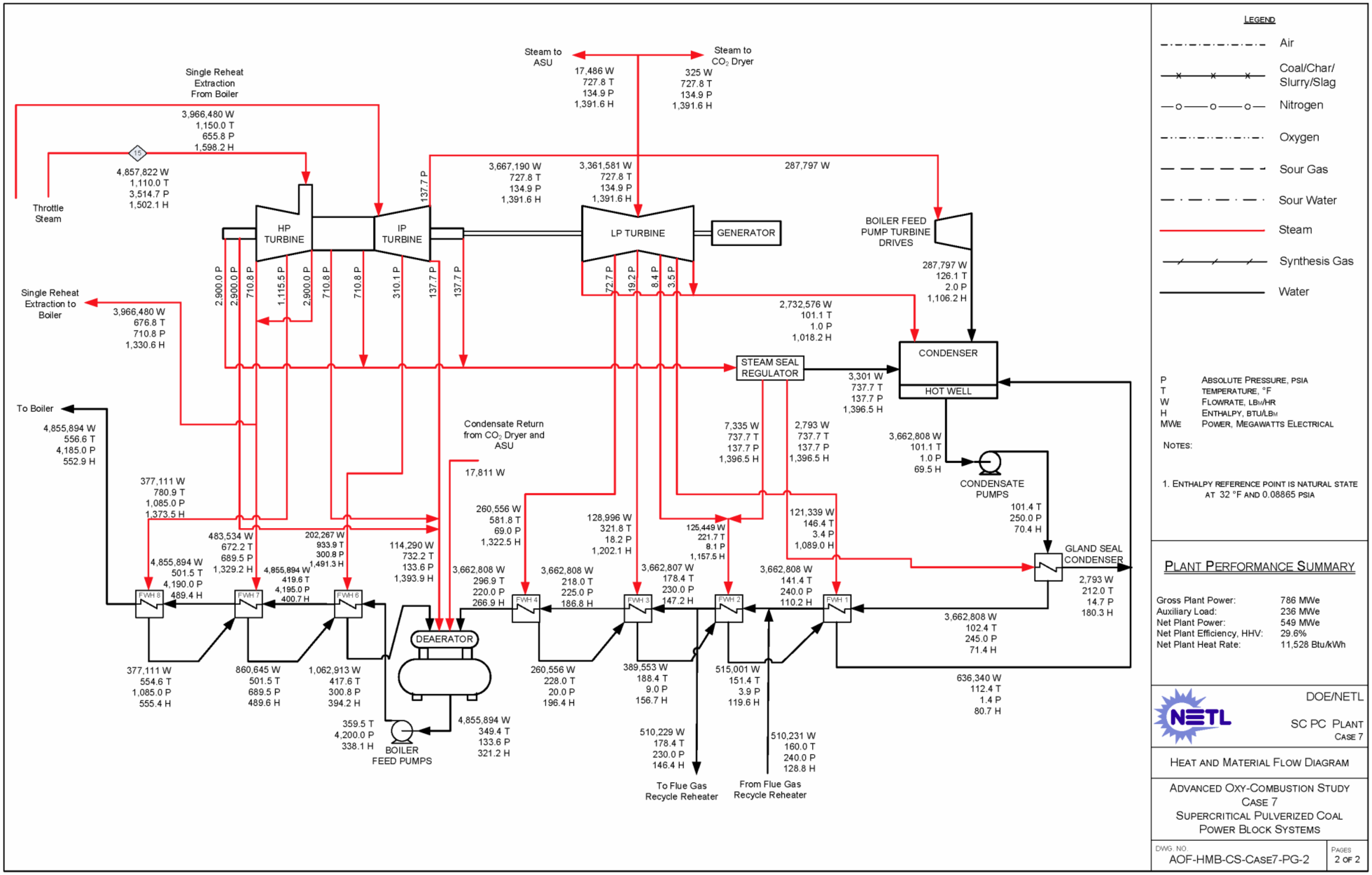


Exhibit 3-91 Cases 7 Energy Balance

	HHV	Sensible + Latent	Power	Total
Heat In GJ/hr (MMBtu/hr)				
Coal	6,683 (6,334)	*5.6 (5.3)*		6,688 (6,339)
Combustion Air		69.9 (66.3)		69.9 (66.3)
Raw Water Makeup		122.3 (115.9)		122.3 (115.9)
Limestone		0.54 (0.51)		0.54 (0.51)
Auxiliary Power			851 (807)	851 (807)
Totals	**6,683 (6,334)**	**198.3 (188.0)**	**851 (807)**	**7,732 (7,329)**
Heat Out GJ/hr (MMBtu/hr)				
Boiler Loss		60.6 (57.4)		60.6 (57.4)
Bottom Ash		0.6 (0.6)		0.6 (0.6)
Fly Ash + FGD Ash		2.4 (2.3)		2.4 (2.3)
MAC Cooling		430.0 (407.6)		430.0 (407.6)
ASU Vent		66.0 (62.6)		66.0 (62.6)
Condenser		3,062 (2,902)		3,062 (2,902)
CO_2 Cooling		539 (511)		539 (511)
CO_2		-126 (-119)		-126 (-119)
Wet FGD Cooling		466 (442)		466 (442)
Process Condensate		42 (40)		42 (40)
Cooling Tower Blowdown		58.6 (55.6)		58.6 (55.6)
Process Losses*		*362.1 (343.2)*		*362.1 (343.2)*
Power			2,829 (2,682)	2,829 (2,682)
Totals		**4,903 (4,647)**	**2,829 (2,682)**	**7,732 (7,329)**

Note: Italicized numbers are estimated
Reference conditions are 0°C (32.02°F) & 0.6 kPa (0.089 psia)
* Process losses are estimated to match the heat input to the plant and include losses from: steam turbine, combustion reactions, and gas cooling.

Exhibit 3-92 Case 7 Carbon Balance

Carbon In		**Carbon Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	157,385 (346,974)	CO_2 Product	159,691 (352,058)
Air (CO_2)	437 (963)	FGD Product	224 (495)
FGD Reagent	2,522 (5,560)	Separated Air	428 (944)
		Convergence Tolerance*	0 (0)
Total	160,344 (353,497)	Total	160,344 (353,497)

*by difference

Exhibit 3-93 Case 7 Sulfur Balance

Sulfur In		**Sulfur Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	6,187 (13,641)	Gypsum	6,141 (13,539)
		CO_2 Product	46 (101)
		Convergence Tolerance*	0 (0)
Total	6,187 (13,641)	Total	6,187 (13,641)

*by difference

Exhibit 3-94 Case 7 Water Balance

Water Use	**Water Demand**	**Internal Recycle**	**Raw Water Withdrawal**	**Process Water Discharge**	**Raw Water Consumption**
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)
FGD Makeup	0.49 (129)	0.0 (0)	0.49 (129)	0.0 (0)	0.49 (129)
BFW Makeup	0.37 (97)	0.0 (0)	0.37 (97)	0.0 (0)	0.37 (97)
Cooling Tower	35.1 (9,269)	3.44 (907)	31.7 (8,362)	7.89 (2,085)	23.76 (6,277)
Total	**35.9 (9,495)**	**3.44 (907)**	**32.5 (8,587)**	**7.89 (2,085)**	**24.62 (6,503)**

Exhibit 3-95 Case 7 Performance Summary

Plant Output		
Steam Turbine Power	785,900	kW_e
Gross Power	**785,900**	kWe
Auxiliary Load		
Coal Handling and Conveying	500	kW_e
Limestone Handling & Reagent Preparation	1,200	kW_e
Pulverizers	3,690	kW_e
Ash Handling	710	kW_e
Primary Air Fans	790	kW_e
Forced Draft Fans	1,010	kW_e
Induced Draft Fans	6,030	kW_e
Air Separation Unit Main Air Compressor	124,190	kW_e
ASU Auxiliaries	1,000	kW_e
Baghouse	90	kW_e
FGD Pumps and Agitators	4,000	kWe
CO_2 Compression	72,520	kW_e
Condensate Pumps	1,050	kW_e
Boiler Feedwater Booster Pumps[2]	N/A	kW_e
Miscellaneous Balance of Plant[3]	2,000	kW_e
Steam Turbine Auxiliaries	400	kW_e
Circulating Water Pumps	9,010	kW_e
Cooling Tower Fans	5,260	kW_e
Transformer Losses	3,000	kW_e
Total	236,450	kW_e
Plant Performance		
Net Auxiliary Load	236,450	kW_e
Net Plant Power	549,450	kW_e
Net Plant Efficiency (HHV)	29.6%	
Net Plant Heat Rate (HHV)	12,163 (11,528)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	246,282 (542,960)	kg/hr (lb/hr)
Thermal Input[1]	1,856,362	kW_{th}
Condenser Duty	3,062 (2,902)	GJ/hr (MMBtu/hr)
Raw Water Usage	32.5 (8,587)	m^3/min (gpm)

1 - HHV of As Received Illinois No. 6 coal is 27,135 kJ/kg (11,666 Btu/lb)
2 - Boiler feed pumps are turbine driven
3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 3-96 Case 7 Capital Costs

	Department:	NETL Office of Program Planning and Analysis										**Cost Base:**	June 2007	
	Project:	Advancing Oxycombustion Technology										**Prepared:**	13-Apr-12	
	Case:	Case 7 - Oxycombustion Boiler											**x $1, 000**	
	Plant Size:	549	MW, net			Capital Charge Factor	0.158	Capacity Factor		0.85				
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Bare Erected**	**Eng'g CM H.O. & Fee %**	**Eng'g CM H.O. & Fee Total**	**Process Cont. %**	**Process Cont. Total**	**Project Cont. %**	**Project Cont. Total**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**
1	COAL HANDLING SYSTEM													
1.1	Coal Receive & Unload	3,922	0	1,792	0	5,714	8.9%	510	0%	0	15.0%	934	7,158	13
1.2	Coal Stackout & Reclaim	5,069	0	1,149	0	6,218	8.8%	544	0%	0	15.0%	1,014	7,776	14
1.3	Coal Conveyors & Yd Crus	4,713	0	1,136	0	5,849	8.8%	513	0%	0	15.0%	954	7,316	13
1.4	Other Coal Handling	1,233	0	263	0	1,496	8.7%	131	0%	0	15.0%	244	1,871	3
1.5	Sorbent Receive & Unload	162	0	49	0	210	8.8%	19	0%	0	15.0%	34	263	0
1.6	Sorbent Stackout & Reclaim	2,610	0	478	0	3,089	8.7%	269	0%	0	15.0%	504	3,861	7
1.7	Sorbent Conveyors	931	201	228	0	1,361	8.7%	118	0%	0	15.0%	222	1,701	3
1.8	Other Sorbent Handling	563	132	295	0	990	8.8%	87	0%	0	15.0%	162	1,239	2
1.9	Coal & Sorbent Hnd.Foundations	0	4,823	6,084	0	10,906	9.3%	1,020	0%	0	15.0%	1,789	13,715	25
	SUBTOTAL 1.	**$19,203**	**$5,156**	**$11,474**	**$0**	**$35,833**		**$3,211**		**$0**		**$5,857**	**$44,900**	**$82**
2	COAL PREP & FEED SYSTEMS													
2.1	Coal Crushing & Drying	2,269	0	442	0	2,711	8.7%	236	0%	0	15.0%	442	3,389	6
2.2	Prepared Coal Storage & Feed	5,809	0	1,268	0	7,077	8.7%	619	0%	0	15.0%	1,154	8,850	16
2.3	Slurry Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.4	Misc. Coal Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.5	Sorbent Prep Equipment	4,446	192	923	0	5,561	8.7%	484	0%	0	15.0%	907	6,953	13
2.6	Sorbent Storage & Feed	536	0	205	0	741	8.9%	66	0%	0	15.0%	121	928	2
2.7	Sorbent Injection System	0	0	0	0	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	0.0%	0	0	0
2.9	Coal & Sorbent Feed Foundation	0	569	478	0	1,047	9.2%	96	0%	0	15.0%	171	1,314	2
	SUBTOTAL 2.	**$13,059**	**$761**	**$3,316**	**$0**	**$17,136**		**$1,502**		**$0**		**$2,796**	**$21,434**	**$39**
3	FEEDWATER & MISC. BOP SYSTEMS													
3.1	Feedwater System	21,694	0	7,008	0	28,702	8.8%	2,513	0%	0	15.0%	4,682	35,897	65
3.2	Water Makeup & Pretreating	5,466	0	1,759	0	7,225	9.4%	677	0%	0	20.0%	1,581	9,483	17
3.3	Other Feedwater Subsystems	6,642	0	2,807	0	9,448	8.9%	842	0%	0	15.0%	1,544	11,834	22
3.4	Service Water Systems	1,071	0	583	0	1,654	9.3%	154	0%	0	20.0%	362	2,170	4
3.5	Other Boiler Plant Systems	8,195	0	8,091	0	16,286	9.4%	1,528	0%	0	15.0%	2,672	20,486	37
3.6	FO Supply Sys & Nat Gas	271	0	338	0	609	9.3%	57	0%	0	15.0%	100	765	1
3.7	Waste Treatment Equipment	2,954	0	1,684	0	4,638	9.7%	449	0%	0	20.0%	1,017	6,105	11
3.8	Misc. Power Plant Equipment	2,874	0	878	0	3,751	9.6%	360	0%	0	20.0%	822	4,934	9
	SUBTOTAL 3.	**$49,167**	**$0**	**$23,148**	**$0**	**$72,315**		**$6,580**		**$0**		**$12,780**	**$91,674**	**$167**
4	PC BOILER & ACCESSORIES													
4.1	PC (Oxycombustion) Boiler	173,264	0	97,219	0	270,482	9.7%	26,199	10%	27,048	10.0%	32,373	356,102	648
4.2	ASU/Oxidant Compression	115,048	0	94,130	0	209,178	9.7%	20,261	0%	0	10.0%	22,944	252,383	459
4.3	Open	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.4	Boiler BoP (w/ID Fans)	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.5	Primary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.6	Secondary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.7	Major Component Rigging	0	w/4.1	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.8	PC Foundations	0	w/14.1	w/14.1	0	0	0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 4.	**$288,312**	**$0**	**$191,349**	**$0**	**$479,661**		**$46,460**		**$27,048**		**$55,317**	**$608,486**	**$1,107**

Exhibit 3-96 Case 7 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & %	Eng'g CM H.O. & Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
5A	FLUE GAS CLEANUP							*						
5.1	Absorber Vessels & Accessories	53,675	0	11,555	0	65,231	9.5%	6,174	0%	0	10.0%	7,140	78,545	143
5.2	Other FGD	2,803	0	3,176	0	5,980	9.6%	576	0%	0	10.0%	656	7,211	13
5.3	Bag House & Accessories	13,302	0	8,442	0	21,744	9.6%	2,080	0%	0	10.0%	2,382	26,207	48
5.4	Other Particulate Removal Materials	879	0	941	0	1,820	9.6%	175	0%	0	10.0%	199	2,194	4
5.5	Gypsum Dewatering System	5,419	0	921	0	6,340	9.4%	599	0%	0	10.0%	694	7,633	14
5.6	Mercury Removal System	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.7	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.8	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.9	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 5A.	**$76,079**	**$0**	**$25,035**	**$0**	**$101,114**		**$9,604**		**$0**		**$11,072**	**$121,790**	**$222**
5B	CO2 REMOVAL & COMPRESSION													
5B.1	CO2 Condensing Heat Exchanger	5,573	0	465	0	6,038	10%	604	0%	0	15.0%	996	7,638	14
5B.2	CO2 Compression & Drying	42,687	0	34,925	0	77,612	10%	7,761	0%	0	20.0%	17,075	102,448	186
5B.3	CO2 Pipeline											0	0	0
5B.4	CO2 Storage											0	0	0
5B.5	CO2 Monitoring											0	0	0
	SUBTOTAL 5B.	**$48,259**	**$0**	**$35,391**	**$0**	**$83,650**		**$8,365**		**$0**		**$18,071**	**$110,086**	**$200**
6	NITROGEN EXPANDER/GENERATOR													
6.1	Nitrogen Expander/Generator	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.2	Nitrogen Expander/Generator Accessories	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.3	Compressed Air Piping	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.4	Nitrogen Expander/Generator Foundations	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 6.	**$0**	**$0**	**$0**	**$0**	**$0**		**$0**		**$0**		**$0**	**$0**	**$0**
7	HRSG, DUCTING & STACK													
7.1	Flue Gas Recycle Heat Exchanger	1,145	0	96	0	1,241	10%	124	0%	0	15.0%	205	1,570	3
7.2	SCR System	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
7.3	Ductwork	9,301	0	5,976	0	15,276	8.7%	1,334	0%	0	15.0%	2,492	19,102	35
7.4	Stack	1,476	0	864	0	2,340	9.6%	224	0%	0	10.0%	256	2,820	5
7.9	HRSG, Duct & Stack Foundations	0	860	977	0	1,836	9.3%	171	0%	0	20.0%	401	2,409	4
	SUBTOTAL 7.	**$11,922**	**$860**	**$7,911**	**$0**	**$20,693**		**$1,853**		**$0**		**$3,354**	**$25,900**	**$47**
8	STEAM TURBINE GENERATOR													
8.1	Steam TG & Accessories	62,249	0	8,261	0	70,510	9.6%	6,751	0%	0	10.0%	7,726	84,988	155
8.2	Turbine Plant Auxiliaries	419	0	898	0	1,317	9.7%	128	0%	0	10.0%	145	1,590	3
8.3	Condenser & Auxiliaries	7,142	0	2,632	0	9,774	9.5%	929	0%	0	10.0%	1,070	11,773	21
8.4	Steam Piping	20,359	0	10,038	0	30,397	8.3%	2,537	0%	0	15.0%	4,940	37,874	69
8.9	TG Foundations	0	1,312	2,073	0	3,385	9.4%	319	0%	0	20.0%	741	4,444	8
	SUBTOTAL 8.	**$90,169**	**$1,312**	**$23,902**	**$0**	**$115,383**		**$10,663**		**$0**		**$14,622**	**$140,668**	**$256**
9	COOLING WATER SYSTEM													
9.1	Cooling Towers	12,920	0	4,023	0	16,943	9.5%	1,608	0%	0	10.0%	1,855	20,407	37
9.2	Circulating Water Pumps	2,282	0	176	0	2,457	8.6%	210	0%	0	10.0%	267	2,934	5
9.3	Circ. Water System Auxiliaries	607	0	81	0	688	9.4%	65	0%	0	10.0%	75	828	2
9.4	Circ. Water Piping	0	4,813	4,664	0	9,477	9.2%	873	0%	0	15.0%	1,553	11,903	22
9.5	Make-up Water System	520	0	695	0	1,216	9.5%	115	0%	0	15.0%	200	1,531	3
9.6	Component Cooling Water System	481	0	383	0	863	9.4%	81	0%	0	15.0%	142	1,086	2
9.9	Circ. Water System Foundations	0	2,909	4,622	0	7,531	9.4%	709	0%	0	20.0%	1,648	9,888	18
	SUBTOTAL 9.	**$16,810**	**$7,722**	**$14,644**	**$0**	**$39,176**		**$3,662**		**$0**		**$5,739**	**$48,576**	**$88**

Exhibit 3-96 Case 7 Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & %	Eng'g CM H.O. & Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
10	ASH/SPENT SORBENT HANDLING SYS													
10.1	Ash Coolers	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.2	Cyclone Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.3	HGCU Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.4	High Temperature Ash Piping	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.5	Other Ash Recovery Equipment	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.6	Ash Storage Silos	676	0	2,083	0	2,759	9.7%	269	0%	0	10.0%	303	3,331	6
10.7	Ash Transport & Feed Equipment	4,377	0	4,483	0	8,860	9.5%	838	0%	0	10.0%	970	10,668	19
10.8	Misc. Ash Handling Equipment	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
10.9	Ash/Spent Sorbent Foundation	0	161	189	0	350	9.3%	33	0%	0	20.0%	77	459	1
	SUBTOTAL 10.	**$5,053**	**$161**	**$6,756**	**$0**	**$11,969**		**$1,139**		**$0**		**$1,349**	**$14,457**	**$26**
11	ACCESSORY ELECTRIC PLANT													
11.1	Generator Equipment	1,856	0	301	0	2,158	9.3%	200	0%	0	7.5%	177	2,534	5
11.2	Station Service Equipment	6,708	0	2,204	0	8,913	9.6%	852	0%	0	7.5%	732	10,497	19
11.3	Switchgear & Motor Control	7,713	0	1,311	0	9,023	9.3%	835	0%	0	10.0%	986	10,845	20
11.4	Conduit & Cable Tray	0	4,835	16,719	0	21,555	9.6%	2,063	0%	0	15.0%	3,543	27,160	49
11.5	Wire & Cable	0	9,124	17,613	0	26,737	8.4%	2,253	0%	0	15.0%	4,349	33,339	61
11.6	Protective Equipment	261	0	888	0	1,149	9.8%	112	0%	0	10.0%	126	1,388	3
11.7	Standby Equipment	1,443	0	33	0	1,476	9.5%	140	0%	0	10.0%	162	1,777	3
11.8	Main Power Transformers	8,293	0	140	0	8,432	7.6%	641	0%	0	10.0%	907	9,980	18
11.9	Electrical Foundations	0	373	915	0	1,289	9.5%	122	0%	0	20.0%	282	1,693	3
	SUBTOTAL 11.	**$26,274**	**$14,333**	**$40,125**	**$0**	**$80,731**		**$7,218**		**$0**		**$11,263**	**$99,213**	**$181**
12	INSTRUMENTATION & CONTROL													
12.1	PC Control Equipment	w/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.2	Combustion Turbine Control	N/A	0	N/A	0	0	0%	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%	0	0	0
12.4	Other Major Component Control	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
12.5	Signal Processing Equipment	W/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.6	Control Boards, Panels & Racks	564	0	338	0	902	9.6%	87	0%	0	15.0%	148	1,137	2
12.7	Computer Accessories	5,695	0	995	0	6,690	9.5%	637	0%	0	10.0%	733	8,060	15
12.8	Instrument Wiring & Tubing	3,088	0	6,125	0	9,212	8.5%	785	0%	0	15.0%	1,500	11,497	21
12.9	Other I & C Equipment	1,609	0	3,651	0	5,260	9.7%	512	0%	0	10.0%	577	6,350	12
	SUBTOTAL 12.	**$10,955**	**$0**	**$11,109**	**$0**	**$22,065**		**$2,021**		**$0**		**$2,958**	**$27,043**	**$49**
13	IMPROVEMENTS TO SITE													
13.1	Site Preparation	0	55	1,098	0	1,153	9.9%	114	0%	0	20.0%	253	1,520	3
13.2	Site Improvements	0	1,823	2,264	0	4,087	9.8%	401	0%	0	20.0%	898	5,386	10
13.3	Site Facilities	3,267	0	3,222	0	6,489	9.8%	637	0%	0	20.0%	1,425	8,551	16
	SUBTOTAL 13.	**$3,267**	**$1,878**	**$6,584**	**$0**	**$11,729**		**$1,152**		**$0**		**$2,576**	**$15,458**	**$28**
14	BUILDINGS & STRUCTURES													
14.1	Boiler Building	0	8,815	7,752	0	16,567	9.0%	1,488	0%	0	15.0%	2,708	20,763	38
14.2	Turbine Building	0	12,726	11,860	0	24,586	9.0%	2,214	0%	0	15.0%	4,020	30,819	56
14.3	Administration Building	0	638	675	0	1,313	9.1%	119	0%	0	15.0%	215	1,646	3
14.4	Circulation Water Pumphouse	0	138	110	0	248	8.9%	22	0%	0	15.0%	40	310	1
14.5	Water Treatment Buildings	0	705	643	0	1,349	9.0%	121	0%	0	15.0%	220	1,690	3
14.6	Machine Shop	0	427	287	0	713	8.9%	63	0%	0	15.0%	117	893	2
14.7	Warehouse	0	289	290	0	579	9.0%	52	0%	0	15.0%	95	726	1
14.8	Other Buildings & Structures	0	236	201	0	437	9.0%	39	0%	0	15.0%	72	548	1
14.9	Waste Treating Building & Str.	0	445	1,351	0	1,796	9.4%	170	0%	0	15.0%	295	2,261	4
	SUBTOTAL 14.	**$0**	**$24,420**	**$23,169**	**$0**	**$47,589**		**$4,288**		**$0**		**$7,781**	**$59,658**	**$109**
	Total Cost	**$658,530**	**$56,601**	**$423,913**	**$0**	**$1,139,044**		**$107,717**		**$27,048**		**$155,534**	**$1,429,344**	**$2,601**

Exhibit 3-97 Case 7 Owner's Costs

Owner's Costs	$1,000	$/kW
Preproduction Costs		
6 Months All Labor	$9,513	$17
1 Month Maintenance Materials	$1,426	$3
1 Month Non-fuel Consumables	$794	$1
1 Month Waste Disposal	$313	$1
25% of 1 Months Fuel Cost at 100% CF	$1,892	$3
2% of TPC	$28,587	$52
Total	**$42,523**	**$77**
Inventory Capital		
60 day supply of fuel and consumables at 100% CF	$16,315	$30
0.5% of TPC (spare parts)	$7,147	$13
Total	**$23,462**	**$43**
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$214,402	$390
Financing Costs	$38,592	$70
Total Overnight Costs (TOC)	**$1,749,223**	**$3,184**
TASC Multiplier	1.134	
Total As-Spent Cost (TASC)	**$1,983,619**	**$3,610**

Exhibit 3-98 Case 7 O&M Costs

INITIAL & ANNUAL O&M EXPENSES						
Case:	Case 7 - Oxycombustion Boiler					
Plant Size (MWe):	549.45			**Heat Rate (Btu/kWh):**		11,528
Primary/Secondary Fuel:	Illinois #6 Bituminous Coal			**Fuel Cost ($/MM Btu):**		1.64
Design/Construction	5 years			**Book Life (yrs):**		30
TPC (Plant Cost) Year:	June 2007			**TPI Year:**		2012
Capacity Factor (%):	85			**CO**2 Captured (TPD):		15,480
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate (base):		$34.65	$/hour			
Operating Labor Burden:		30.00	% of base			
Labor Overhead Charge:		25.00	% of labor			
Operating Labor Requirements per Shift:		**units/mod.**		**Total Plant**		
Skilled Operator		2.0		2.0		
Operator		9.0		9.0		
Foreman		1.0		1.0		
Lab Tech's etc.		2.0		2.0		
TOTAL Operating Jobs		14.0		14.0		
					$	**$/kW-net**
Annual Operating Labor Cost (calc'd)					5,524,319	10.05
Maintenance Labor Cost (calc'd)					9,695,998	17.65
Administrative & Support Labor (calc'd)					3,805,079	6.93
Property Taxes and Insurance					28,586,879	52.03
TOTAL FIXED OPERATING COSTS					**47,612,275**	**86.65**
VARIABLE OPERATING COSTS						
					$	**$/kWh-net**
Maintenance Material Costs (calc'd)					**$14,544,111**	**0.00355**
Consumables	**Consumption**		**Unit**	**Initial**		
	Initial	**/Day**	**Cost**	**Cost**	**$**	**$/kWh-net**
Water (/1000 gallons)	0	6,183	1.08	$0	$2,074,831	0.00051
Chemicals						
MU & WT Chem. (lb)	0	29,928	0.17	$0	$1,606,962	0.00039
Limestone (ton)	0	657	21.63	$0	$4,412,872	0.00108
Carbon (Hg Removal) (lb)	0	0	1.05	$0	$0	0.00000
MEA Solvent (ton)	0	0	2249.89	$0	$0	0.00000
Caustic Soda, NaOH (ton)	0	0	433.68	$0	$0	0.00000
Sulfuric acid, H_2SO_4 (ton)	0	0	138.78	$0	$0	0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	0.00000
Activated C, MEA (lb)	0	0	1.05	$0	$0	0.00000
Ammonia, 19% soln (ton)	0	0	129.80	$0	$0	0.00000
Subtotal Chemicals				**$0**	**$6,019,835**	**0.00147**
Other						
Supplemental Fuel (MMBtu)	0	0	6.55	$0	$0	0.00000
SCR Catalyst Replacement	w/equip.	0.0	5775.94	$0	$0	0.00000
Emission Penalties	0	0	0.00	$0	$0	0.00000
Subtotal Other				**$0**	**$0**	**0.00000**
Waste Disposal						
Spent Mercury Catalyst (lb)	0	0	0.42	$0	$0	0.00000
Flyash (ton)	0	507	16.23	$0	$2,550,288	0.00062
Bottom Ash (ton)	0	127	16.23	$0	$637,587	0.00016
Subtotal Solid Waste Disposal				**$0**	**$3,187,875**	**0.00078**
By-products & Emissions						
Gypsum (tons)	0	0	0.00	$0	$0	0.00000
Sulfur (tons)	0	0	0.00	$0	$0	0.00000
Subtotal By-Products				**$0**	**$0**	**0.00000**
TOTAL VARIABLE OPERATING COSTS					**$25,826,653**	**0.00631**
Coal FUEL (tons)	**0**	**6,516**	**38.18**	**$0**	**$77,187,679**	**0.01887**
NATURAL GAS FUEL (Mscf)	**0**	**0**	**6.76**	**$0**	**$0**	**0.00000**

Exhibit 3-99 Equipment List for Case 4, 5, 6, and 7

ACCOUNT 1 FUEL AND SORBENT HANDLING

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	Bottom Trestle Dumper and Receiving Hoppers	N/A	181 tonne (200 ton)	181 tonne (200 ton)	181 tonne (200 ton)	181 tonne (200 ton)	2 (0)
2	Feeder	Belt	572 tonne/hr (630 tph)	572 tonne/hr (630 tph)	572 tonne/hr (630 tph)	572 tonne/hr (630 tph)	2 (0)
3	Conveyor No. 1	Belt	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1 (0)
4	Transfer Tower No. 1	Enclosed	N/A	N/A	N/A	N/A	1 (0)
5	Conveyor No. 2	Belt	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1 (0)
6	As-Received Coal Sampling System	Two-stage	N/A	N/A	N/A	N/A	1 (0)
7	Stacker/Reclaimer	Traveling, linear	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1,134 tonne/hr (1,250 tph)	1 (0)
8	Reclaim Hopper	N/A	45 tonne (50 ton)	54 tonne (60 ton)	54 tonne (60 ton)	54 tonne (60 ton)	2 (1)
9	Feeder	Vibratory	191 tonne/hr (210 tph)	209 tonne/hr (230 tph)	200 tonne/hr (220 tph)	200 tonne/hr (220 tph)	2 (1)
10	Conveyor No. 3	Belt w/ tripper	381 tonne/hr (420 tph)	408 tonne/hr (450 tph)	408 tonne/hr (450 tph)	408 tonne/hr (450 tph)	1 (0)
11	Crusher Tower	N/A	N/A	N/A	N/A	N/A	1 (0)
12	Coal Surge Bin w/ Vent Filter	Dual outlet	191 tonne (210 ton)	209 tonne (230 ton)	200 tonne (220 ton)	200 tonne (220 ton)	2 (0)
13	Crusher	Impactor reduction	8 cm x 0 - 3 cm x 0 (3 in x 0 - 1-1/4 in x 0)	8 cm x 0 - 3 cm x 0 (3 in x 0 - 1-1/4 in x 0)	8 cm x 0 - 3 cm x 0 (3 in x 0 - 1-1/4 in x 0)	8 cm x 0 - 3 cm x 0 (3 in x 0 - 1-1/4 in x 0)	2 (0)

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
14	As-Fired Coal Sampling System	Swing hammer	N/A	N/A	N/A	N/A	1 (1)
15	Conveyor No. 4	Belt w/tripper	381 tonne/hr (420 tph)	408 tonne/hr (450 tph)	408 tonne/hr (450 tph)	408 tonne/hr (450 tph)	1 (0)
16	Transfer Tower No. 2	Enclosed	N/A	N/A	N/A	N/A	1 (0)
17	Conveyor No. 5	Belt w/ tripper	381 tonne/hr (420 tph)	408 tonne/hr (450 tph)	408 tonne/hr (450 tph)	408 tonne/hr (450 tph)	1 (0)
18	Coal Silo w/ Vent Filter and Slide Gates	Field erected	816 tonne (900 ton)	907 tonne (1,000 ton)	907 tonne (1,000 ton)	907 tonne (1,000 ton)	3 (0)
19	Limestone Truck Unloading Hopper	N/A	N/A	36 tonne (40 ton)	36 tonne (40 ton)	36 tonne (40 ton)	1 (0)
20	Limestone Feeder	Belt	N/A	109 tonne/hr (120 tph)	109 tonne/hr (120 tph)	109 tonne/hr (120 tph)	1 (0)
21	Limestone Conveyor No. L1	Belt	N/A	109 tonne/hr (120 tph)	109 tonne/hr (120 tph)	109 tonne/hr (120 tph)	1 (0)
22	Limestone Reclaim Hopper	N/A	N/A	18 tonne (20 ton)	18 tonne (20 ton)	18 tonne (20 ton)	1 (0)
23	Limestone Reclaim Feeder	Belt	N/A	82 tonne/hr (90 tph)	82 tonne/hr (90 tph)	82 tonne/hr (90 tph)	1 (0)
24	Limestone Conveyor No. L2	Belt	N/A	82 tonne/hr (90 tph)	82 tonne/hr (90 tph)	82 tonne/hr (90 tph)	1 (0)
25	Limestone Day Bin	w/ actuator	N/A	336 tonne (370 ton)	327 tonne (360 ton)	327 tonne (360 ton)	2 (0)

ACCOUNT 2 COAL AND SORBENT PREPARATION AND FEED

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	Coal Feeder	Gravimetric	45 tonne/hr (50 tph)	45 tonne/hr (50 tph)	45 tonne/hr (50 tph)	45 tonne/hr (50 tph)	6 (0)

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
2	Coal Pulverizer	Ball type or equivalent	45 tonne/hr (50 tph)	45 tonne/hr (50 tph)	45 tonne/hr (50 tph)	45 tonne/hr (50 tph)	6 (0)
3	Limestone Weigh Feeder	Gravimetric	N/A	27 tonne/hr (30 tph)	27 tonne/hr (30 tph)	27 tonne/hr (30 tph)	1 (1)
4	Limestone Ball Mill	Rotary	N/A	27 tonne/hr (30 tph)	27 tonne/hr (30 tph)	27 tonne/hr (30 tph)	1 (1)
5	Limestone Mill Slurry Tank with Agitator	N/A	N/A	105,992 liters (28,000 gal)	105,992 liters (28,000 gal)	105,992 liters (28,000 gal)	1 (1)
6	Limestone Mill Recycle Pumps	Horizontal centrifugal	N/A	1,779 lpm @ 12m H_2O (470 gpm @ 40 ft H_2O)	1,741 lpm @ 12m H_2O (460 gpm @ 40 ft H_2O)	1,779 lpm @ 12m H_2O (470 gpm @ 40 ft H_2O)	1 (1)
7	Hydroclone Classifier	4 active cyclones in a 5 cyclone bank	N/A	454 lpm (120 gpm) per cyclone	416 lpm (110 gpm) per cyclone	454 lpm (120 gpm) per cyclone	1 (1)
8	Distribution Box	2-way	N/A	N/A	N/A	N/A	1 (1)
9	Limestone Slurry Storage Tank with Agitator	Field erected	N/A	598,095 liters (158,000 gal)	590,524 liters (156,000 gal)	590,524 liters (156,000 gal)	1 (1)
10	Limestone Slurry Feed Pumps	Horizontal centrifugal	N/A	1,249 lpm @ 9m H_2O (330 gpm @ 30 ft H_2O)	1,211 lpm @ 9m H_2O (320 gpm @ 30 ft H_2O)	1,249 lpm @ 9m H_2O (330 gpm @ 30 ft H_2O)	1 (1)

ACCOUNT 3 FEEDWATER AND MISCELLANEOUS SYSTEMS AND EQUIPMENT

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	1,389,246 liters (367,000 gal)	1,464,954 liters (387,000 gal)	1,438,456 liters (380,000 gal)	1,457,384 liters (385,000 gal)	2 (0)
2	Condensate Pumps	Vertical canned	29,526 lpm @ 213 m H_2O (7,800 gpm @ 700 ft H_2O)	30,662 lpm @ 213 m H_2O (8,100 gpm @ 700 ft H_2O)	31,797 lpm @ 213 m H_2O (8,400 gpm @ 700 ft H_2O)	30,662 lpm @ 213 m H_2O (8,100 gpm @ 700 ft H_2O)	1 (1)
3	Deaerator and Storage Tank	Horizontal spray type	2,310,146 kg/hr (5,093,000 lb/hr), 5 min. residence time	2,436,698 kg/hr (5,372,000 lb/hr), 5 min. residence time	2,392,246 kg/hr (5,274,000 lb/hr), 5 min. residence time	2,422,637 kg/hr (5,341,000 lb/hr), 5 min. residence time	1 (0)
4	Boiler Feed Pump/Turbine	Barrel type, multi-stage, centrifugal	38,611 lpm @ 3,444 m H_2O (10,200 gpm @ 11,300 ft H_2O)	40,882 lpm @ 3,444 m H_2O (10,800 gpm @ 11,300 ft H_2O)	40,125 lpm @ 3,444 m H_2O (10,600 gpm @ 11,300 ft H_2O)	40,504 lpm @ 3,444 m H_2O (10,700 gpm @ 11,300 ft H_2O)	1 (1)
5	Startup Boiler Feed Pump, Electric Motor Driven	Barrel type, multi-stage, centrifugal	11,735 lpm @ 3,444 m H_2O (3,100 gpm @ 11,300 ft H_2O)	12,113 lpm @ 3,444 m H_2O (3,200 gpm @ 11,300 ft H_2O)	12,113 lpm @ 3,444 m H_2O (3,200 gpm @ 11,300 ft H_2O)	12,113 lpm @ 3,444 m H_2O (3,200 gpm @ 11,300 ft H_2O)	1 (0)
6	LP Feedwater Heater 1A/1B	Horizontal U-tube	884,505 kg/hr (1,950,000 lb/hr)	920,793 kg/hr (2,030,000 lb/hr)	948,008 kg/hr (2,090,000 lb/hr)	911,721 kg/hr (2,010,000 lb/hr)	2 (0)
7	LP Feedwater Heater 2A/2B	Horizontal U-tube	884,505 kg/hr (1,950,000 lb/hr)	920,793 kg/hr (2,030,000 lb/hr)	948,008 kg/hr (2,090,000 lb/hr)	911,721 kg/hr (2,010,000 lb/hr)	2 (0)
8	LP Feedwater Heater 3A/3B	Horizontal U-tube	884,505 kg/hr (1,950,000 lb/hr)	920,793 kg/hr (2,030,000 lb/hr)	948,008 kg/hr (2,090,000 lb/hr)	911,721 kg/hr (2,010,000 lb/hr)	2 (0)
9	LP Feedwater Heater 4A/4B	Horizontal U-tube	884,505 kg/hr (1,950,000 lb/hr)	920,793 kg/hr (2,030,000 lb/hr)	948,008 kg/hr (2,090,000 lb/hr)	911,721 kg/hr (2,010,000 lb/hr)	2 (0)
10	HP Feedwater Heater 6	Horizontal U-tube	2,308,785 kg/hr (5,090,000 lb/hr)	2,435,791 kg/hr (5,370,000 lb/hr)	2,390,432 kg/hr (5,270,000 lb/hr)	2,422,183 kg/hr (5,340,000 lb/hr)	1 (0)
11	HP Feedwater Heater 7	Horizontal U-tube	2,308,785 kg/hr (5,090,000 lb/hr)	2,435,791 kg/hr (5,370,000 lb/hr)	2,390,432 kg/hr (5,270,000 lb/hr)	2,422,183 kg/hr (5,340,000 lb/hr)	1 (0)

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
12	HP Feedwater heater 8	Horizontal U-tube	2,308,785 kg/hr (5,090,000 lb/hr)	2,435,791 kg/hr (5,370,000 lb/hr)	2,390,432 kg/hr (5,270,000 lb/hr)	2,422,183 kg/hr (5,340,000 lb/hr)	1 (0)
13	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	18,144 kg/hr, 2.8 MPa, 343°C (40,000 lb/hr, 400 psig, 650°F)	1 (0)
14	Fuel Oil System	No. 2 fuel oil for light off	1,135,624 liter (300,000 gal)	1,135,624 liter (300,000 gal)	1,135,624 liter (300,000 gal)	1,135,624 liter (300,000 gal)	1 (0)
15	Service Air Compressors	Flooded Screw	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	2 (1)
16	Instrument Air Dryers	Duplex, regenerative	28 m^3/min (1,000 scfm)	28 m^3/min (1,000 scfm)	28 m^3/min (1,000 scfm)	28 m^3/min (1,000 scfm)	2 (1)
17	Closed Cycle Cooling Heat Exchangers	Shell and tube	53 GJ/hr (50 MMBtu/hr) each	53 GJ/hr (50 MMBtu/hr) each	53 GJ/hr (50 MMBtu/hr) each	53 GJ/hr (50 MMBtu/hr) each	2 (0)
18	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	20,820 lpm @ 30 m H_2O (5,500 gpm @ 100 ft H_2O)	20,820 lpm @ 30 m H_2O (5,500 gpm @ 100 ft H_2O)	20,820 lpm @ 30 m H_2O (5,500 gpm @ 100 ft H_2O)	20,820 lpm @ 30 m H_2O (5,500 gpm @ 100 ft H_2O)	2 (1)
19	Engine-Driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 88 m H_2O (1,000 gpm @ 290 ft H_2O)	3,785 lpm @ 88 m H_2O (1,000 gpm @ 290 ft H_2O)	3,785 lpm @ 88 m H_2O (1,000 gpm @ 290 ft H_2O)	3,785 lpm @ 88 m H_2O (1,000 gpm @ 290 ft H_2O)	1 (1)
20	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 64 m H_2O (700 gpm @ 210 ft H_2O)	2,650 lpm @ 64 m H_2O (700 gpm @ 210 ft H_2O)	2,650 lpm @ 64 m H_2O (700 gpm @ 210 ft H_2O)	2,650 lpm @ 64 m H_2O (700 gpm @ 210 ft H_2O)	1 (1)
21	Raw Water Pumps	Stainless steel, single suction	17,299 lpm @ 43 m H_2O (4,570 gpm @ 140 ft H_2O)	20,214 lpm @ 43 m H_2O (5,340 gpm @ 140 ft H_2O)	19,646 lpm @ 43 m H_2O (5,190 gpm @ 140 ft H_2O)	19,836 lpm @ 43 m H_2O (5,240 gpm @ 140 ft H_2O)	2 (1)
22	Filtered Water Pumps	Stainless steel, single suction	1 lpm @ 49 m H_2O (0 gpm @ 160 ft H_2O)	757 lpm @ 49 m H_2O (200 gpm @ 160 ft H_2O)	719 lpm @ 49 m H_2O (190 gpm @ 160 ft H_2O)	757 lpm @ 49 m H_2O (200 gpm @ 160 ft H_2O)	2 (1)
23	Filtered Water Tank	Vertical, cylindrical	882 liter (233 gal)	738,155 liter (195,000 gal)	681,374 liter (180,000 gal)	719,228 liter (190,000 gal)	1 (0)

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
24	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly, electrodeionization unit	908 lpm (240 gpm)	984 lpm (260 gpm)	946 lpm (250 gpm)	984 lpm (260 gpm)	1 (1)
25	Liquid Waste Treatment System	--	10 years, 24-hour storm	10 years, 24-hour storm	10 years, 24-hour storm	10 years, 24-hour storm	1 (0)

ACCOUNT 4 BOILER AND ACCESSORIES

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	Boiler	Supercritical, drum, wall-fired, low NOx burners, overfire air	2,308,785 kg/hr steam @ 25.5 MPa/607°C/629°C (5,090,000 lb/hr steam @ 3,700 psig/1,125°F/1,165°F)	2,435,791 kg/hr steam @ 25.5 MPa/607°C/629°C (5,370,000 lb/hr steam @ 3,700 psig/1,125°F/1,165°F)	2,394,968 kg/hr steam @ 25.5 MPa/607°C/629°C (5,280,000 lb/hr steam @ 3,700 psig/1,125°F/1,165°F)	2,422,183 kg/hr steam @ 25.5 MPa/607°C/629°C (5,340,000 lb/hr steam @ 3,700 psig/1,125°F/1,165°F)	1 (0)
2	Primary Air Fan	Centrifugal	185,066 kg/hr, 3,500 m^3/min @ 47 cm WG (408,000 lb/hr, 123,600 acfm @ 19 in. WG)	205,024 kg/hr, 2,404 m^3/min @ 47 cm WG (452,000 lb/hr, 84,900 acfm @ 19 in. WG)	205,024 kg/hr, 2,461 m^3/min @ 47 cm WG (452,000 lb/hr, 86,900 acfm @ 19 in. WG)	160,118 kg/hr, 1,923 m^3/min @ 47 cm WG (353,000 lb/hr, 67,900 acfm @ 19 in. WG)	2 (0)
3	Forced Draft Fan	Centrifugal	602,824 kg/hr, 11,392 m^3/min @ 123 cm WG (1,329,000 lb/hr, 402,300 acfm @ 48 in. WG)	667,688 kg/hr, 7,824 m^3/min @ 123 cm WG (1,472,000 lb/hr, 276,300 acfm @ 48 in. WG)	666,781 kg/hr, 8,005 m^3/min @ 123 cm WG (1,470,000 lb/hr, 282,700 acfm @ 48 in. WG)	521,178 kg/hr, 6,258 m^3/min @ 123 cm WG (1,149,000 lb/hr, 221,000 acfm @ 48 in. WG)	2 (0)

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
4	Induced Draft Fan	Centrifugal	1,199,298 kg/hr, 23,279 m^3/min @ 46 cm WG (2,644,000 lb/hr, 822,100 acfm @ 18 in. WG)	1,314,964 kg/hr, 22,571 m^3/min @ 89 cm WG (2,899,000 lb/hr, 797,100 acfm @ 35 in. WG)	1,306,800 kg/hr, 22,416 m^3/min @ 95 cm WG (2,881,000 lb/hr, 791,600 acfm @ 37 in. WG)	1,117,198 kg/hr, 19,272 m^3/min @ 95 cm WG (2,463,000 lb/hr, 680,600 acfm @ 37 in. WG)	2 (0)
5	ASU Main Air Compressor	Centrifugal, multi-stage	15,744 m^3/min @ 0.6 MPa (556,000 scfm @ 086 psia)	17,103 m^3/min @ 0.6 MPa (604,000 scfm @ 086 psia)	16,849 m^3/min @ 0.6 MPa (595,000 scfm @ 086 psia)	16,877 m^3/min @ 0.6 MPa (596,000 scfm @ 086 psia)	2 (0)
6	Cold Box	Vendor design	6,532 tonne/day (7,200 tpd) of 95% purity oxygen	7,167 tonne/day (7,900 tpd) of 95% purity oxygen	6,985 tonne/day (7,700 tpd) of 95% purity oxygen	7,076 tonne/day (7,800 tpd) of 95% purity oxygen	2 (0)

ACCOUNT 5 FLUE GAS CLEANUP

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	Fabric Filter	Single stage, high-ratio with pulse-jet online cleaning system	1,199,298 kg/hr (2,644,000 lb/hr) 99.8% efficiency	1,314,964 kg/hr (2,899,000 lb/hr) 99.8% efficiency	1,306,800 kg/hr (2,881,000 lb/hr) 99.8% efficiency	1,117,198 kg/hr (2,463,000 lb/hr) 99.8% efficiency	2 (0)
2	Absorber Module	Counter-current open spray	N/A	44,514 m^3/min (1,572,000 acfm)	44,203 m^3/min (1,561,000 acfm)	38,001 m^3/min (1,342,000 acfm)	1 (0)
3	Recirculation Pumps	Horizontal centrifugal	N/A	155,202 lpm @ 64 m H_2O (41,000 gpm @ 210 ft H_2O)	155,202 lpm @ 64 m H_2O (41,000 gpm @ 210 ft H_2O)	132,489 lpm @ 64 m H_2O (35,000 gpm @ 210 ft H_2O)	5 (1)
4	Bleed Pumps	Horizontal centrifugal	N/A	5,451 lpm (1,440 gpm) at 20 wt% solids	5,375 lpm (1,420 gpm) at 20 wt% solids	5,375 lpm (1,420 gpm) at 20 wt% solids	2 (1)

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
5	Oxidation Air Blowers	Centrifugal	N/A	21 m^3/min @ 0.3 MPa (750 acfm @ 42 psia)	21 m^3/min @ 0.3 MPa (740 acfm @ 42 psia)	21 m^3/min @ 0.3 MPa (740 acfm @ 42 psia)	2 (1)
6	Agitators	Side entering	N/A	50 hp	50 hp	50 hp	5 (1)
7	Dewatering Cyclones	Radial assembly, 5 units each	N/A	1,363 lpm (360 gpm) per cyclone	1,363 lpm (360 gpm) per cyclone	1,363 lpm (360 gpm) per cyclone	2 (0)
8	Vacuum Filter Belt	Horizontal belt	N/A	43 tonne/hr (47 tph) of 50 wt % slurry	43 tonne/hr (47 tph) of 50 wt % slurry	43 tonne/hr (47 tph) of 50 wt % slurry	2 (1)
9	Filtrate Water Return Pumps	Horizontal centrifugal	N/A	833 lpm @ 12 m H_2O (220 gpm @ 40 ft H_2O)	833 lpm @ 12 m H_2O (220 gpm @ 40 ft H_2O)	833 lpm @ 12 m H_2O (220 gpm @ 40 ft H_2O)	1 (1)
10	Filtrate Water Return Storage Tank	Vertical, lined	N/A	529,958 lpm (140,000 gal)	529,958 lpm (140,000 gal)	529,958 lpm (140,000 gal)	1 (0)
11	Process Makeup Water Pumps	Horizontal centrifugal	N/A	568 lpm @ 21 m H_2O (150 gpm @ 70 ft H_2O)	454 lpm @ 21 m H_2O (120 gpm @ 70 ft H_2O)	530 lpm @ 21 m H_2O (140 gpm @ 70 ft H_2O)	1 (1)

ACCOUNT 5B CARBON DIOXIDE RECOVERY

Equipment No.	Descriptio n	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	CO2 Compresso r	Centrifugal, or Shock Compression (Case 6)	296,205 kg/h @ 15.3 MPa (653,020 lb/h @ 2,215 psia)	326,222 kg/h @ 15.3 MPa (719,196 lb/h @ 2,215 psia)	321,202 kg/h @ 15.3 MPa (708,129 lb/h @ 2,214 psia)	321,820 kg/h @ 15.3 MPa (709,491 lb/h @ 2,215 psia)	2 (0)

ACCOUNT 7 HRSG, DUCTING & STACK

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	Stack	Reinforced concrete with FRP liner	46 m (150 ft) high x 4.4 m (15 ft) diameter	46 m (150 ft) high x 3.6 m (12 ft) diameter	46 m (150 ft) high x 3.6 m (12 ft) diameter	46 m (150 ft) high x 3.3 m (11 ft) diameter	1 (0)

ACCOUNT 8 STEAM TURBINE GENERATOR AND AUXILIARIES

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	Steam Turbine	Commercially available advanced steam turbine	806 MW 24.1 MPa/599°C/621°C (3,500 psig/ 1,110°F/1,150°F)	832 MW 24.1 MPa/599°C/621°C (3,500 psig/ 1,110°F/1,150°F)	857 MW 24.1 MPa/599°C/621°C (3,500 psig/ 1,110°F/1,150°F)	827 MW 24.1 MPa/599°C/621°C (3,500 psig/ 1,110°F/1,150°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	900 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	920 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	950 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	920 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)
3	Surface Condenser	Single pass, divided waterbox including vacuum pumps	3,471 GJ/hr (3,290 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	3,397 GJ/hr (3,220 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	3,735 GJ/hr (3,540 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	3,366 GJ/hr (3,190 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	821,400 lpm @ 30 m (217,000 gpm @ 100 ft)	919,900 lpm @ 30 m (243,000 gpm @ 100 ft)	897,100 lpm @ 30 m (237,000 gpm @ 100 ft)	904,700 lpm @ 30 m (239,000 gpm @ 100 ft)	2 (1)
2	Cooling Tower	Evapora-tive, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT / 4,568 GJ/hr (4,330 MMBtu/hr) heat duty	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT / 5,138 GJ/hr (4,870 MMBtu/hr) heat duty	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT / 5,001 GJ/hr (4,740 MMBtu/hr) heat duty	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT / 5,043 GJ/hr (4,780 MMBtu/hr) heat duty	1 (0)

ACCOUNT 10 ASH/SPENT SORBENT RECOVERY AND HANDLING

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	Economizer Hopper (part of boiler scope of supply)	--	--	--	--	--	4 (0)
2	Bottom Ash Hopper (part of boiler scope of supply)	--	--	--	--	--	2 (0)
3	Clinker Grinder	--	4.5 tonne/hr (5 tph)	5.4 tonne/hr (6 tph)	5.4 tonne/hr (6 tph)	5.4 tonne/hr (6 tph)	1 (1)
4	Pyrites Hopper (part of pulverizer scope of supply included with boiler)	--	--	--	--	--	6 (0)
5	Hydroejectors	--	--	--	--	--	12 (0)
6	Economizer /Pyrites Transfer Tank	--	--	--	--	--	1 (0)

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
7	Ash Sluice Pumps	Vertical, wet pit	189 lpm @ 17 m H_2O (50 gpm @ 56 ft H_2O)	227 lpm @ 17 m H_2O (60 gpm @ 56 ft H_2O)	227 lpm @ 17 m H_2O (60 gpm @ 56 ft H_2O)	227 lpm @ 17 m H_2O (60 gpm @ 56 ft H_2O)	1 (1)
8	Ash Seal Water Pumps	Vertical, wet pit	7,571 lpm @ 9 m H_2O (2000 gpm @ 28 ft H_2O)	7,571 lpm @ 9 m H_2O (2,000 gpm @ 28 ft H_2O)	7,571 lpm @ 9 m H_2O (2000 gpm @ 28 ft H_2O)	7,571 lpm @ 9 m H_2O (2000 gpm @ 28 ft H_2O)	1 (1)
9	Hydrobins	--	189 lpm (50 gpm)	227 lpm (60 gpm)	227 lpm (60 gpm)	227 lpm (60 gpm)	1 (1)
10	Baghouse Hopper (part of baghouse scope of supply)	--	--	--	--	--	24 (0)
11	Air Heater Hopper (part of boiler scope of supply)	--	--	--	--	--	10 (0)
12	Air Blower	--	18 m^3/min @ 0.2 MPa (640 scfm @ 24 psi)	20 m^3/min @ 0.2 MPa (690 scfm @ 24 psi)	19 m^3/min @ 0.2 MPa (680 scfm @ 24 psi)	19 m^3/min @ 0.2 MPa (680 scfm @ 24 psi)	1 (1)
13	Fly Ash Silo	Reinforced concrete	590 tonne (1,300 ton)	635 tonne (1,400 ton)	635 tonne (1,400 ton)	635 tonne (1,400 ton)	2 (0)
14	Slide Gate Valves	--	--	--	--	--	2 (0)
15	Unloader	--	--	--	--	--	1 (0)
16	Telescoping Unloading Chute	--	109 tonne/hr (120 tph)	118 tonne/hr (130 tph)	118 tonne/hr (130 tph)	118 tonne/hr (130 tph)	1 (0)

ACCOUNT 11 ACCESSORY ELECTRIC PLANT

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
1	STG Transformer	Oil-filled	24 kV/345 kV, 650 MVA, 3-ph, 60 Hz	24 kV/345 kV, 650 MVA, 3-ph, 60 Hz	24 kV/345 kV, 650 MVA, 3-ph, 60 Hz	24 kV/345 kV, 650 MVA, 3-ph, 60 Hz	1 (0)
2	Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 236 MVA, 3-ph, 60 Hz	24 kV/4.16 kV, 264 MVA, 3-ph, 60 Hz	24 kV/4.16 kV, 290 MVA, 3-ph, 60 Hz	24 kV/4.16 kV, 259 MVA, 3-ph, 60 Hz	1 (1)
3	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 35 MVA, 3-ph, 60 Hz	4.16 kV/480 V, 40 MVA, 3-ph, 60 Hz	4.16 kV/480 V, 43 MVA, 3-ph, 60 Hz	4.16 kV/480 V, 39 MVA, 3-ph, 60 Hz	1 (1)
4	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	24 kV, 3-ph, 60 Hz	24 kV, 3-ph, 60 Hz	24 kV, 3-ph, 60 Hz	1 (0)
5	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	4.16 kV, 3-ph, 60 Hz	4.16 kV, 3-ph, 60 Hz	4.16 kV, 3-ph, 60 Hz	1 (1)
6	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	480 V, 3-ph, 60 Hz	480 V, 3-ph, 60 Hz	480 V, 3-ph, 60 Hz	1 (1)
7	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	750 kW, 480 V, 3-ph, 60 Hz	750 kW, 480 V, 3-ph, 60 Hz	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

ACCOUNT 12 INSTRUMENTATION AND CONTROL

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 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	Operator stations/printers and engineering stations/printers	Operator stations/printers and engineering stations/printers	Operator stations/printers and engineering stations/printers	1 (0)
2	DCS - Processor	Microprocessor with redundant input/output	N/A	N/A	N/A	N/A	1 (0)

Equipment No.	Description	Type	Case 4 Design Condition	Case 5 Design Condition	Case 6 Design Condition	Case 7 Design Condition	Operating Qty. (Spares)
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	Fully redundant, 25% spare	Fully redundant, 25% spare	Fully redundant, 25% spare	1 (0)

3.8 CUMULATIVE CASE – COMBINATION OF EXAMINED TECHNOLOGIES

The Cumulative Case is intended to model the cumulative effect and any synergies of the proposed PC oxycombustion concepts in the cases outlined in the above sections with the intent of assessing how this scenario may contribute to meeting the DOE CO_2 capture cost target.

An outcome of this case will be to confirm current R&D program cost and performance targets as well as set new targets necessary to meet the aggressive capture target of no more than 35% increase in COE above an equivalent power plant without capture.

A process BFD for the Cumulative Case is shown in Exhibit 3-100, and the corresponding stream tables are shown in Exhibit 3-101.

Heat and Mass Balance Diagram

Heat and mass balance diagrams are shown for the following subsystems in Exhibit 3-102 and Exhibit 3-103:

- Boiler and flue gas cleanup
- Steam cycle and feed water (power block)

Energy, Carbon, Sulfur, and Water Balances

An overall plant energy balance is provided in tabular form in Exhibit 3-104. The power out is the steam turbine power after generator losses.

Carbon, sulfur, and water balances are shown in Exhibit 3-105 through Exhibit 3-107.

Performance Summary

A performance summary is provided in Exhibit 3-108.

Costing Table

Tables of capital costs, owner's costs, and O&M costs are provided in Exhibit 3-109 through Exhibit 3-110, respectively.

Equipment List

The equipment list for the Cumulative Case is shown in Exhibit 3-112.

Exhibit 3-100 Process Block Flow Diagram for Cumulative Case

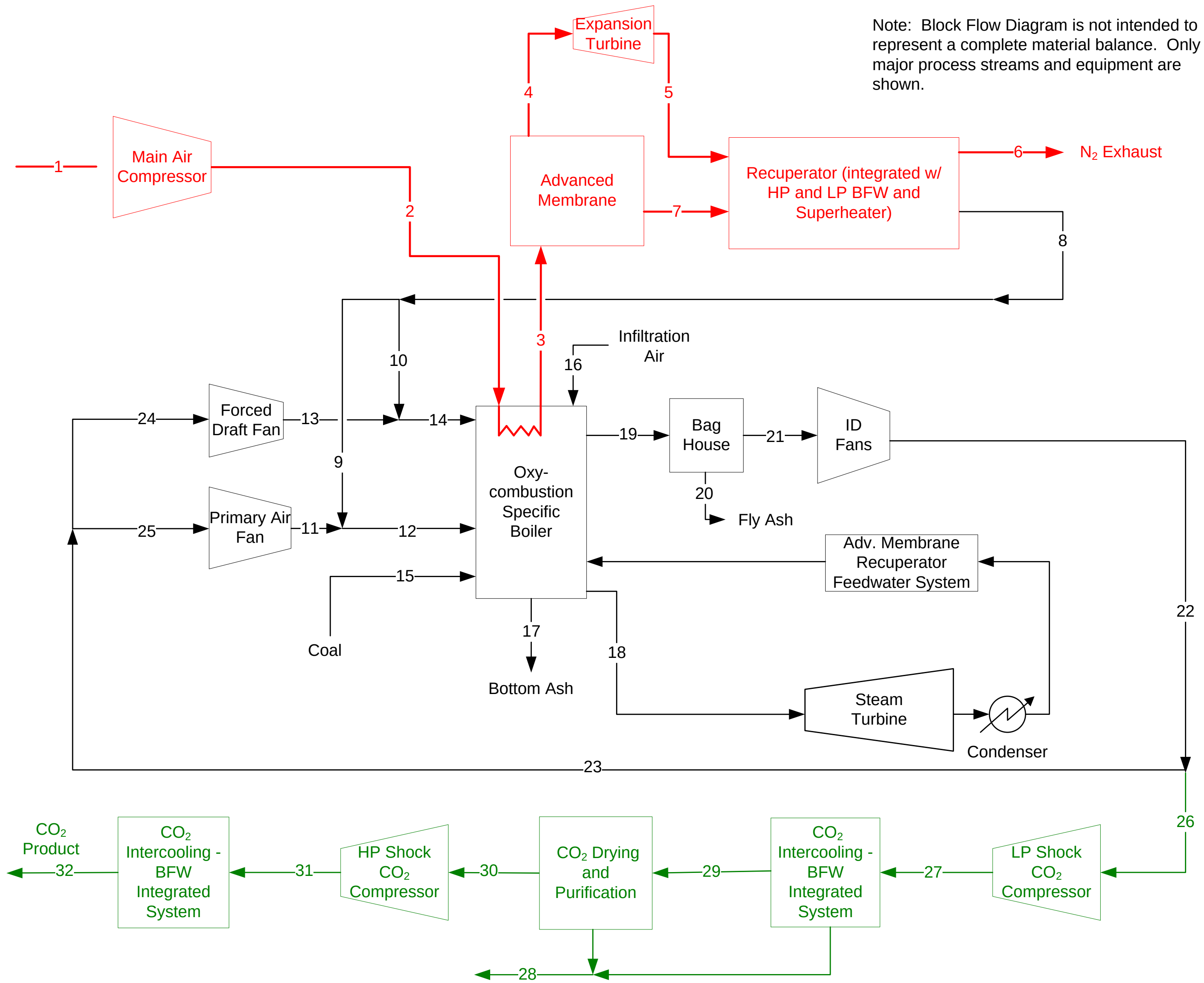


Exhibit 3-101 Stream Table for Cumulative Case

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
V-L Mole Fraction																
Ar	0.0092	0.0092	0.0092	0.0107	0.0107	0.0107	0.0000	0.0000	0.0000	0.0000	0.0009	0.0006	0.0009	0.0006	0.0000	0.0092
CO_2	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0000	0.0000	0.0000	0.0000	0.5739	0.3913	0.5739	0.3913	0.0000	0.0005
H_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	0.0000	0.0000
H_2O	0.0101	0.0101	0.0101	0.0118	0.0118	0.0118	0.0000	0.0000	0.0000	0.0000	0.3089	0.2106	0.3089	0.2106	0.0000	0.0101
N_2	0.7729	0.7729	0.7729	0.9041	0.9041	0.9041	0.0000	0.0000	0.0000	0.0000	0.0793	0.0541	0.0793	0.0541	0.0000	0.7729
O_2	0.2074	0.2074	0.2074	0.0728	0.0728	0.0728	1.0000	1.0000	1.0000	1.0000	0.0286	0.3377	0.0286	0.3377	0.0000	0.2074
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0085	0.0058	0.0085	0.0058	0.0000	0.0000
CH_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	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	0.0000	0.0000
C_3H_8	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	0.0000	0.0000
C_4H_{10}	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	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	0.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	84,136	84,136	84,136	71,921	71,921	71,921	12,216	12,216	2,871	9,345	6,151	9,022	20,024	29,369	0	1,683
V-L Flowrate (kg/hr)	2,427,837	2,427,837	2,427,837	2,036,955	2,036,955	2,036,955	390,882	390,882	91,857	299,025	212,427	304,285	691,519	990,544	0	48,557
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	191,790	0
Temperature (°C)	15	390	802	802	330	60	802	66	66	66	194	160	186	154	15	15
Pressure (MPa, abs)	0.10	1.48	1.48	1.34	0.10	0.10	0.17	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.10	0.10
Enthalpy (kJ/kg)[A]	30.57	418.79	879.64	892.22	362.08	80.46	814.08	60.21	60.21	60.21	610.91	444.66	602.54	438.82	---	30.57
Density (kg/m^3)	1.2	7.8	4.8	4.3	0.6	1.0	0.6	1.4	1.4	1.4	1.0	1.0	1.0	1.0	---	1.2
V-L Molecular Weight	28.856	28.856	28.856	28.322	28.322	28.322	31.999	31.999	31.999	31.999	34.535	33.728	34.535	33.728	---	28.856
V-L Flowrate (lb_{mol}/hr)	185,489	185,489	185,489	158,558	158,558	158,558	26,931	26,931	6,329	20,602	13,561	19,890	44,145	64,747	0	3,710
V-L Flowrate (lb/hr)	5,352,465	5,352,465	5,352,465	4,490,718	4,490,718	4,490,718	861,747	861,747	202,511	659,236	468,322	670,833	1,524,538	2,183,775	0	107,049
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	422,825	0
Temperature (°F)	59	734	1,475	1,475	625	140	1,475	150	151	151	380	320	367	310	59	59
Pressure (psia)	14.7	215.0	215.0	195.0	15.2	14.8	25.0	17.5	17.5	17.5	16.2	16.2	15.3	15.3	14.7	14.7
Enthalpy (Btu/lb)[A]	13.1	180.0	378.2	383.6	155.7	34.6	350.0	25.9	25.9	25.9	262.6	191.2	259.0	188.7	---	13.1
Density (lb/ft^3)	0.076	0.484	0.299	0.266	0.037	0.065	0.039	0.086	0.086	0.086	0.062	0.065	0.060	0.063	---	0.076

A - Reference conditions are 32.02 F & 0.089 PSIA

Exhibit 3-101 Stream Table for Cumulative Case (Continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
V-L Mole Fraction																
Ar	0.0000	0.0000	0.0009	0.0000	0.0009	0.0009	0.0009	0.0009	0.0009	0.0011	0.0011	0.0000	0.0012	0.0013	0.0013	0.0013
CO_2	0.0000	0.0000	0.5739	0.0000	0.5739	0.5739	0.5739	0.5739	0.5739	0.7006	0.7006	0.0000	0.8114	0.8304	0.8304	0.8304
H_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	0.0000	0.0000
H_2O	0.0000	1.0000	0.3089	0.0000	0.3089	0.3089	0.3089	0.3089	0.3089	0.1564	0.1564	1.0000	0.0229	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0793	0.0000	0.0793	0.0793	0.0793	0.0793	0.0793	0.0968	0.0968	0.0000	0.1121	0.1147	0.1147	0.1147
O_2	0.0000	0.0000	0.0286	0.0000	0.0286	0.0286	0.0286	0.0286	0.0286	0.0349	0.0349	0.0000	0.0404	0.0414	0.0414	0.0414
SO_2	0.0000	0.0000	0.0085	0.0000	0.0085	0.0085	0.0085	0.0085	0.0085	0.0103	0.0103	0.0000	0.0119	0.0122	0.0122	0.0122
CH_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	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	0.0000	0.0000
C_3H_8	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	0.0000	0.0000
C_4H_{10}	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	0.0000	0.0000
Total	0.0000	1.0000	1.0000	0.0000	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 (kg_{mol}/hr)	0	75,487	43,915	0	43,915	43,915	26,175	20,024	6,151	14,535	14,535	5,481	12,550	12,262	12,262	12,262
V-L Flowrate (kg/hr)	0	1,359,926	1,516,577	0	1,516,577	1,516,577	903,946	691,519	212,427	554,949	554,949	98,739	519,192	514,004	514,004	514,004
Solids Flowrate (kg/hr)	3,720	0	14,878	14,878	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	732	177	15	177	181	181	181	181	58	318	66	21	21	272	21
Pressure (MPa, abs)	0.10	27.68	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.24	0.10	1.23	1.23	15.27	15.26
Enthalpy (kJ/kg)[A]	---	3,844.30	676.49	---	591.67	597.12	597.12	597.12	597.12	237.78	509.63	276.75	8.66	6.86	221.04	-194.91
Density (kg/m^3)	---	64.1	0.9	---	0.9	0.9	0.9	0.9	0.9	1.4	9.7	953.0	22.7	22.5	145.1	703.8
V-L Molecular Weight	---	18.015	34.535	---	34.535	34.535	34.535	34.535	34.535	38.180	38.180	18.016	41.369	41.918	41.918	41.918
V-L Flowrate (lb_{mol}/hr)	0	166,421	96,815	0	96,815	96,815	57,706	44,145	13,561	32,044	32,044	12,083	27,668	27,034	27,034	27,034
V-L Flowrate (lb/hr)	0	2,998,123	3,343,481	0	3,343,481	3,343,481	1,992,861	1,524,538	468,322	1,223,454	1,223,454	217,681	1,144,622	1,133,184	1,133,184	1,133,184
Solids Flowrate (lb/hr)	8,200	0	32,800	32,800	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	1,350	350	59	350	359	359	359	359	136	605	151	70	70	521	70
Pressure (psia)	14.7	4,014.7	14.4	14.7	14.2	14.7	14.7	14.7	14.7	14.7	179.9	14.7	178.9	178.9	2,214.7	2,213.7
Enthalpy (Btu/lb)[A]	---	1,652.7	290.8	---	254.4	256.7	256.7	256.7	256.7	102.2	219.1	119.0	3.7	2.9	95.0	-83.8
Density (lb/ft^3)	---	4.004	0.057	---	0.057	0.058	0.058	0.058	0.058	0.088	0.604	59.492	1.414	1.403	9.059	43.935

Exhibit 3-102 Heat and Mass Balance, Boiler and Gas Cleanup Systems for Cumulative Case

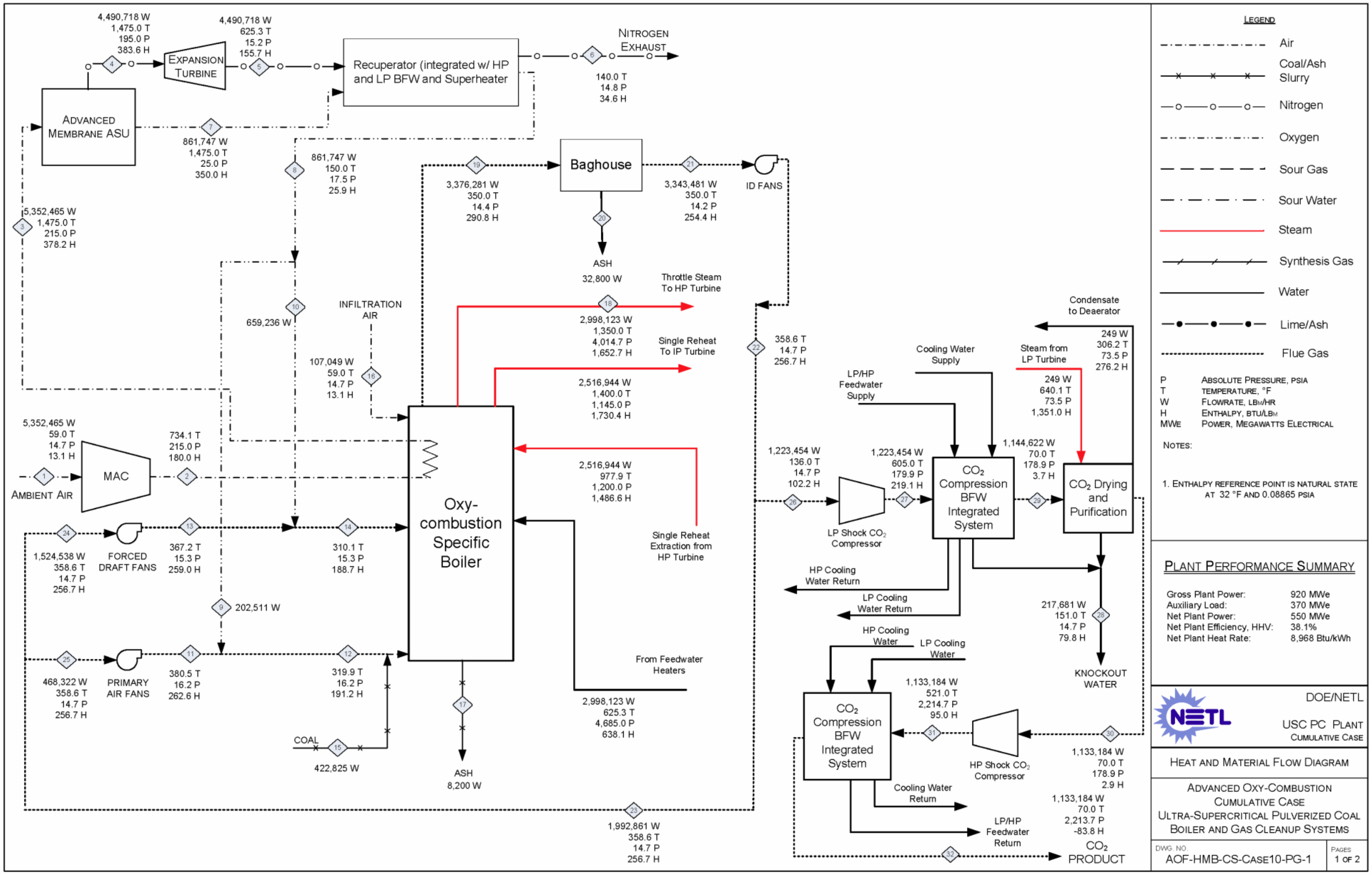


Exhibit 3-103 Heat and Mass Balance, Power Block Systems for Cumulative Case

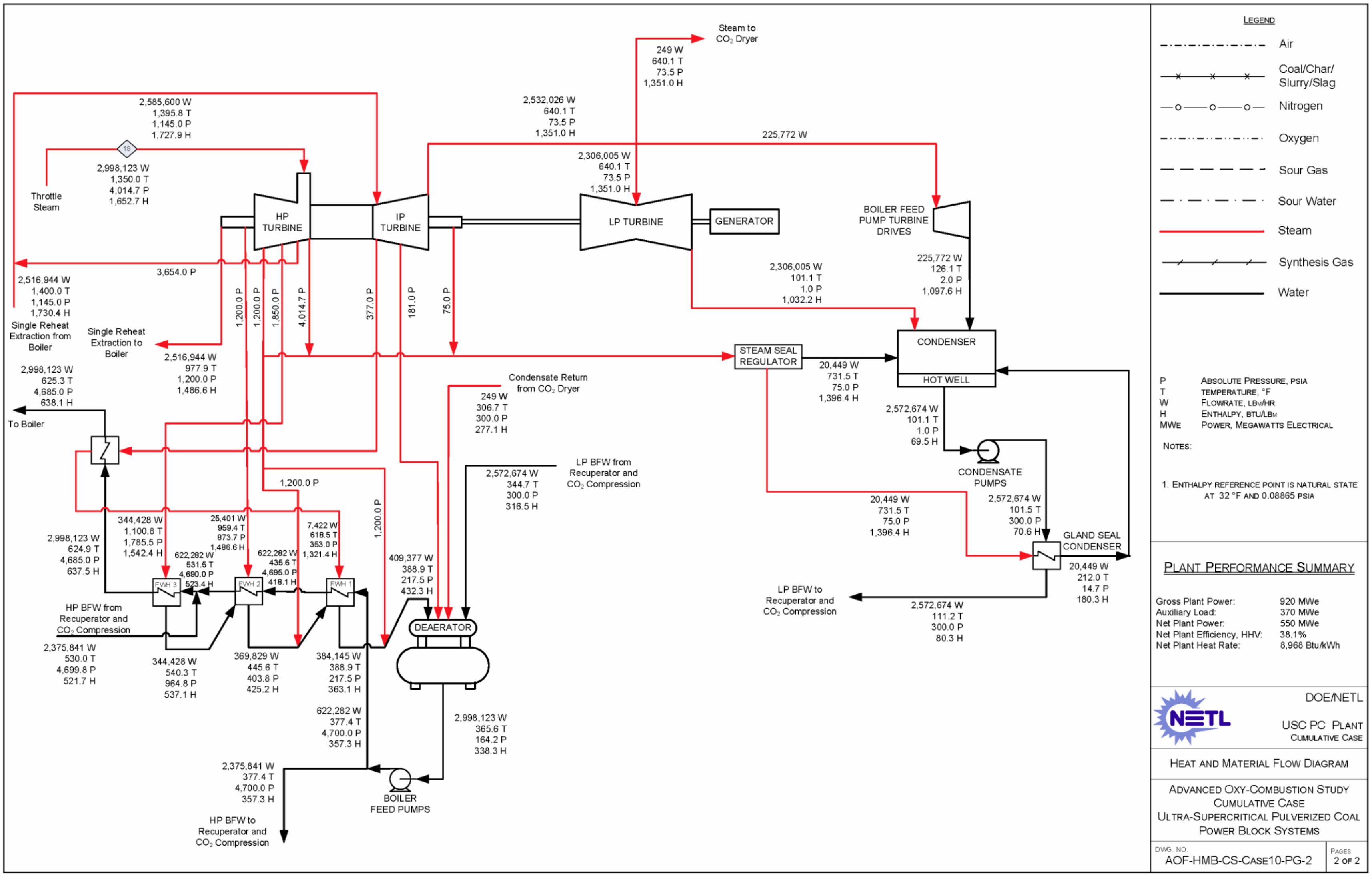


Exhibit 3-104 Cases 10 Energy Balance

	HHV	Sensible + Latent	Power	Total
Heat In GJ/hr (MMBtu/hr)				
Coal	5,204 (4,933)	*4.4 (4.1)*		5,209 (4,937)
Combustion Air		75.7 (71.8)		75.7 (71.8)
Raw Water Makeup		82.2 (77.9)		82.2 (77.9)
Auxiliary Power			1,333 (1,263)	1,333 (1,263)
Totals	**5,204 (4,933)**	**162.3 (153.8)**	**1,333 (1,263)**	**6,699 (6,349)**
Heat Out GJ/hr (MMBtu/hr)				
Boiler Loss		35.8 (33.9)		35.8 (33.9)
Bottom Ash		0.5 (0.4)		0.5 (0.4)
Fly Ash		1.9 (1.8)		1.9 (1.8)
MAC Cooling		0.0 (0.0)		0.0 (0.0)
ASU Vent		163.9 (155.3)		163.9 (155.3)
Condenser		2,618.2 (2,481.5)		2,618.2 (2,481.5)
CO_2 Cooling		98.1 (93.0)		98.1 (93.0)
CO_2		-100.2 (-95.0)		-100.2 (-95.0)
Flue Gas Cooling		225.4 (213.6)		225.4 (213.6)
Cooling Tower Blowdown		39.3 (37.2)		39.3 (37.2)
Process Losses*		*303.5 (287.7)*		*303.5 (287.7)*
Power			3,313 (3,140)	3,313 (3,140)
Totals		**3,386 (3,210)**	**3,313 (3,140)**	**6,699 (6,349)**

Note: Italicized numbers are estimated
Reference conditions are 0°C (32.02°F) & 0.6 kPa (0.089 psia)
* Process losses are estimated to match the heat input to the plant and include losses from: steam turbine, combustion reactions, and gas cooling.

Exhibit 3-105 Cumulative Case Carbon Balance

Carbon In		**Carbon Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	122,273 (269,566)	CO_2 Product	122,304 (269,634)
Air (CO_2)	473 (1,043)	Separated Air	464 (1,023)
		Convergence Tolerance*	-22 (-48)
Total	122,746 (270,609)	Total	122,746 (270,609)

*by difference

Exhibit 3-106 Cumulative Case Sulfur Balance

Sulfur In		**Sulfur Out**	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	4,807 (10,598)	Gypsum	0 (0)
		CO_2 Product	4,806 (10,596)
		Convergence Tolerance*	1 (1)
Total	4,807 (10,598)	Total	4,807 (10,598)

*by difference

Exhibit 3-107 Cumulative Case Water Balance

Water Use	**Water Demand**	**Internal Recycle**	**Raw Water Withdrawal**	**Process Water Discharge**	**Raw Water Consumption**
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)
Cooling Tower	23.5 (6,206)	1.65 (435)	21.8 (5,771)	5.28 (1,396)	16.56 (4,375)
Total	**23.5 (6,206)**	**1.65 (435)**	**21.8 (5,771)**	**5.28 (1,396)**	**16.56 (4,375)**

Exhibit 3-108 Cumulative Case Performance Summary

Plant Output		
Steam Turbine Power	624,700	kW_e
Nitrogen Expander Power	295,500	kW_e
Gross Power	**920,200**	kWe
Auxiliary Load		
Coal Handling and Conveying	440	kW_e
Limestone Handling & Reagent Preparation	0	kW_e
Pulverizers	2,880	kW_e
Ash Handling	550	kW_e
Primary Air Fans	860	kW_e
Forced Draft Fans	1,080	kW_e
Induced Draft Fans	2,380	kW_e
Air Separation Unit Main Air Compressor	269,910	kW_e
ASU Auxiliaries	0	kW_e
Baghouse	70	kW_e
FGD Pumps and Agitators	0	kWe
CO_2 Compression	76,250	kW_e
Condensate Pumps	890	kW_e
Boiler Feedwater Booster Pumps[2]	N/A	kW_e
Miscellaneous Balance of Plant[3]	2,000	kW_e
Steam Turbine Auxiliaries	400	kW_e
Circulating Water Pumps	6,030	kW_e
Cooling Tower Fans	3,520	kW_e
Transformer Losses	2,880	kW_e
Total	370,140	kW_e
Plant Performance		
Net Auxiliary Load	370,140	kW_e
Net Plant Power	550,060	kW_e
Net Plant Efficiency (HHV)	38.1%	
Net Plant Heat Rate (HHV)	9,461 (8,968)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	191,790 (422,825)	kg/hr (lb/hr)
Natural Gas	N/A	kg/hr (lb/hr)
Coal Thermal Input	1,445,623	kW_{th}
Natural Gas Thermal Input	N/A	kW_{th}
Thermal Input[1,4] (Coal + Natural Gas)	1,445,623	kW_{th}
Condenser Duty	2,618 (2,482)	GJ/hr (MMBtu/hr)
Raw Water Usage	21.8 (5,771)	m^3/min (gpm)
1 - HHV of As Received Illinois No. 6 coal is 27,135 kJ/kg (11,666 Btu/lb)		
2 - Boiler feed pumps are turbine driven		
3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads		

Exhibit 3-109 Cumulative Case Capital Costs

Department:	NETL Office of Program Planning and Analysis	Cost Base:	June 2007
Project:	Advancing Oxycombustion Technology	Prepared:	13-Apr-12
Case:	Case TOT - Cumulative Technology Case		x $1, 000
Plant Size:	550 MW, net; Capital Charge Factor 0.158; Capacity Factor 0.85		

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL HANDLING SYSTEM													
1.1	Coal Receive & Unload	3,359	0	1,534	0	4,893	8.9%	437	0%	0	15.0%	800	6,130	11
1.2	Coal Stackout & Reclaim	4,341	0	984	0	5,325	8.8%	466	0%	0	15.0%	869	6,659	12
1.3	Coal Conveyors & Yd Crus	4,036	0	973	0	5,009	8.8%	439	0%	0	15.0%	817	6,266	11
1.4	Other Coal Handling	1,056	0	225	0	1,281	8.7%	112	0%	0	15.0%	209	1,602	3
1.5	Sorbent Receive & Unload	0	0	0	0	0	8.8%	0	0%	0	15.0%	0	0	0
1.6	Sorbent Stackout & Reclaim	0	0	0	0	0	8.7%	0	0%	0	15.0%	0	0	0
1.7	Sorbent Conveyors	0	0	0	0	0	8.7%	0	0%	0	15.0%	0	0	0
1.8	Other Sorbent Handling	0	0	0	0	0	8.8%	0	0%	0	15.0%	0	0	0
1.9	Coal & Sorbent Hnd.Foundations	0	3,891	4,908	0	8,799	9.3%	823	0%	0	15.0%	1,443	11,065	20
	SUBTOTAL 1.	**$12,792**	**$3,891**	**$8,625**	**$0**	**$25,308**		**$2,277**		**$0**		**$4,138**	**$31,722**	**$58**
2	COAL PREP & FEED SYSTEMS													
2.1	Coal Crushing & Drying	1,924	0	375	0	2,298	8.7%	201	0%	0	15.0%	375	2,874	5
2.2	Prepared Coal Storage & Feed	4,925	0	1,075	0	6,000	8.7%	525	0%	0	15.0%	979	7,504	14
2.3	Slurry Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.4	Misc. Coal Prep & Feed	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
2.5	Sorbent Prep Equipment	0	0	0	0	0	8.7%	0	0%	0	15.0%	0	0	0
2.6	Sorbent Storage & Feed	0	0	0	0	0	8.9%	0	0%	0	15.0%	0	0	0
2.7	Sorbent Injection System	0	0	0	0	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	0.0%	0	0	0
2.9	Coal & Sorbent Feed Foundation	0	456	383	0	839	9.2%	77	0%	0	15.0%	138	1,054	2
	SUBTOTAL 2.	**$6,849**	**$456**	**$1,833**	**$0**	**$9,138**		**$803**		**$0**		**$1,491**	**$11,432**	**$21**
3	FEEDWATER & MISC. BOP SYSTEMS													
3.1	Feedwater System	15,550	0	5,023	0	20,573	8.8%	1,801	0%	0	15.0%	3,356	25,730	47
3.2	Water Makeup & Pretreating	4,122	0	1,327	0	5,449	9.4%	511	0%	0	20.0%	1,192	7,151	13
3.3	Other Feedwater Subsystems	4,760	0	2,012	0	6,772	8.9%	604	0%	0	15.0%	1,106	8,482	15
3.4	Service Water Systems	808	0	440	0	1,248	9.3%	116	0%	0	20.0%	273	1,636	3
3.5	Other Boiler Plant Systems	5,707	0	5,634	0	11,340	9.4%	1,064	0%	0	15.0%	1,861	14,265	26
3.6	FO Supply Sys & Nat Gas	254	0	318	0	572	9.3%	53	0%	0	15.0%	94	719	1
3.7	Waste Treatment Equipment	1,085	0	619	0	1,704	9.7%	165	0%	0	20.0%	374	2,243	4
3.8	Misc. Power Plant Equipment	2,699	0	825	0	3,524	9.6%	338	0%	0	20.0%	772	4,635	8
	SUBTOTAL 3.	**$34,985**	**$0**	**$16,196**	**$0**	**$51,181**		**$4,652**		**$0**		**$9,028**	**$64,861**	**$118**
4	PC BOILER & ACCESSORIES													
4.1	USC PC (Oxycombustion) Boiler	183,592	0	92,200	0	275,791	9.7%	26,713	25%	68,948	10.0%	37,145	408,598	743
4.2	ASU (Advanced Membrane)/Oxidant Compression	66,843	0	54,689	0	121,532	9.7%	11,772	0%	0	10.0%	13,330	146,634	267
4.3	Open	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.4	Boiler BoP (w/ID Fans)	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
4.5	Primary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.6	Secondary Air System	w/4.1	0	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.7	Major Component Rigging	0	w/4.1	w/4.1	0	0	0%	0	0%	0	0.0%	0	0	0
4.8	PC Foundations	0	w/14.1	w/14.1	0	0	0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 4.	**$250,434**	**$0**	**$146,889**	**$0**	**$397,323**		**$38,485**		**$68,948**		**$50,476**	**$555,232**	**$1,009**

Exhibit 3-109 Cumulative Case Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
5A	FLUE GAS CLEANUP							*						
5.1	Absorber Vessels & Accessories	0	0	0	0	0	9.5%	0	0%	0	10.0%	0	0	0
5.2	Other FGD	0	0	0	0	0	9.6%	0	0%	0	10.0%	0	0	0
5.3	Bag House & Accessories	11,138	0	7,068	0	18,206	9.6%	1,741	0%	0	10.0%	1,995	21,943	40
5.4	Other Particulate Removal Materials	738	0	789	0	1,527	9.6%	147	0%	0	10.0%	167	1,842	3
5.5	Gypsum Dewatering System	0	0	0	0	0	9.4%	0	0%	0	10.0%	0	0	0
5.6	Mercury Removal System	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.7	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.8	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
5.9	Open	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 5A.	**$11,876**	**$0**	**$7,858**	**$0**	**$19,734**		**$1,888**		**$0**		**$2,162**	**$23,784**	**$43**
5B	CO2 REMOVAL & COMPRESSION													
5B.1	CO2 Condensing Heat Exchanger	3,239	0	270	0	3,509	10%	351	0%	0	15.0%	579	4,439	8
5B.2	CO2 Compression & Drying	31,973	0	10,030	0	42,003	10%	4,017	0%	0	20.0%	9,204	55,224	100
5B.3	CO2 Additional BFW Heat Exchanger	4,962	0	414	0	5,376	10%	538	0%	0	20.0%	1,183	7,097	13
5B.3	CO2 Pipeline											0	0	0
5B.4	CO2 Storage											0	0	0
5B.5	CO2 Monitoring											0	0	0
	SUBTOTAL 5B.	**$40,173**	**$0**	**$10,715**	**$0**	**$50,888**		**$4,906**		**$0**		**$10,966**	**$66,760**	**$121**
6	NITROGEN EXPANDER/GENERATOR													
6.1	Nitrogen Expander/Generator	38,008	0	16,289	0	54,297	9.6%	5,199	0%	0	10.0%	5,950	65,445	119
6.2	Nitrogen Expander/Generator Accessories	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.3	Compressed Air Piping	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
6.4	Nitrogen Expander/Generator Foundations	0	0	0	0	0	10%	0	0%	0	0.0%	0	0	0
	SUBTOTAL 6.	**$38,008**	**$0**	**$16,289**	**$0**	**$54,297**		**$5,199**		**$0**		**$5,950**	**$65,445**	**$119**
7	HRSG, DUCTING & STACK													
7.1	Flue Gas Recycle Heat Exchanger	0	0	0	0	0	10.0%	0	0%	0	15.0%	0	0	0
7.2	ASU Superheater	11,588	0	968	0	12,556	10.0%	1,256	20%	2,511	15.0%	2,448	18,771	34
7.3	ASU HP FWH	18,431	0	1,539	0	19,970	10.0%	1,997	10%	1,997	15.0%	3,595	27,559	50
7.4	ASU LP FWH	20,707	0	1,729	0	22,436	10.0%	2,244	0%	0	15.0%	3,702	28,381	52
7.5	SCR System	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
7.6	Ductwork	8,457	0	5,434	0	13,891	8.7%	1,213	10%	1,389	15.0%	2,474	18,967	34
7.7	Stack	1,306	0	764	0	2,070	9.6%	198	0%	0	10.0%	227	2,494	5
7.9	HRSG, Duct & Stack Foundations	0	831	944	0	1,775	9.3%	165	0%	0	20.0%	388	2,328	4
	SUBTOTAL 7.	**$60,489**	**$831**	**$11,377**	**$0**	**$72,697**		**$7,073**		**$5,897**		**$12,834**	**$98,501**	**$179**
8	STEAM TURBINE GENERATOR													
8.1	Steam TG & Accessories	53,183	0	7,058	0	60,241	9.6%	5,768	15%	9,036	10.0%	7,504	82,549	150
8.2	Turbine Plant Auxiliaries	358	0	767	0	1,125	9.7%	109	0%	0	10.0%	123	1,358	2
8.3	Condenser & Auxiliaries	6,431	0	2,370	0	8,801	9.5%	836	0%	0	10.0%	964	10,601	19
8.4	Steam Piping	14,523	0	7,161	0	21,684	8.3%	1,810	0%	0	15.0%	3,524	27,018	49
8.9	TG Foundations	0	1,126	1,779	0	2,905	9.4%	273	0%	0	20.0%	636	3,814	7
	SUBTOTAL 8.	**$74,495**	**$1,126**	**$19,135**	**$0**	**$94,755**		**$8,796**		**$9,036**		**$12,751**	**$125,339**	**$228**
9	COOLING WATER SYSTEM													
9.1	Cooling Towers	9,757	0	3,038	0	12,795	9.5%	1,215	0%	0	10.0%	1,401	15,410	28
9.2	Circulating Water Pumps	1,616	0	124	0	1,740	8.6%	149	0%	0	10.0%	189	2,078	4
9.3	Circ. Water System Auxiliaries	468	0	62	0	530	9.4%	50	0%	0	10.0%	58	638	1
9.4	Circ. Water Piping	0	3,708	3,594	0	7,302	9.2%	673	0%	0	15.0%	1,196	9,171	17
9.5	Make-up Water System	410	0	548	0	958	9.5%	91	0%	0	15.0%	157	1,206	2
9.6	Component Cooling Water System	371	0	295	0	665	9.4%	62	0%	0	15.0%	109	837	2
9.9	Circ. Water System Foundations	0	2,287	3,633	0	5,920	9.4%	557	0%	0	20.0%	1,295	7,772	14
	SUBTOTAL 9.	**$12,621**	**$5,995**	**$11,294**	**$0**	**$29,910**		**$2,796**		**$0**		**$4,406**	**$37,112**	**$67**

Exhibit 3-109 Cumulative Case Capital Costs (continued)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected	Eng'g CM H.O. & Fee %	Eng'g CM H.O. & Fee Total	Process Cont. %	Process Cont. Total	Project Cont. %	Project Cont. Total	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
10	ASH/SPENT SORBENT HANDLING SYS													
10.1	Ash Coolers	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.2	Cyclone Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.3	HGCU Ash Letdown	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.4	High Temperature Ash Piping	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.5	Other Ash Recovery Equipment	N/A	0	N/A	0	0	0%	0	0%	0	0.0%	0	0	0
10.6	Ash Storage Silos	587	0	1,809	0	2,396	9.7%	233	0%	0	10.0%	263	2,892	5
10.7	Ash Transport & Feed Equipment	3,800	0	3,892	0	7,692	9.5%	727	0%	0	10.0%	842	9,261	17
10.8	Misc. Ash Handling Equipment	0	0	0	0	0	0.0%	0	0%	0	0.0%	0	0	0
10.9	Ash/Spent Sorbent Foundation	0	140	164	0	304	9.3%	28	0%	0	20.0%	66	398	1
	SUBTOTAL 10.	**$4,387**	**$140**	**$5,865**	**$0**	**$10,391**		**$989**		**$0**		**$1,171**	**$12,552**	**$23**
11	ACCESSORY ELECTRIC PLANT													
11.1	Generator Equipment	1,640	0	266	0	1,907	9.3%	177	0%	0	7.5%	156	2,239	4
11.2	Station Service Equipment	8,143	0	2,676	0	10,819	9.6%	1,035	0%	0	7.5%	889	12,742	23
11.3	Switchgear & Motor Control	9,362	0	1,591	0	10,953	9.3%	1,014	0%	0	10.0%	1,197	13,164	24
11.4	Conduit & Cable Tray	0	5,869	20,295	0	26,164	9.6%	2,504	0%	0	15.0%	4,300	32,969	60
11.5	Wire & Cable	0	11,075	21,380	0	32,456	8.4%	2,735	0%	0	15.0%	5,279	40,469	74
11.6	Protective Equipment	261	0	888	0	1,149	9.8%	112	0%	0	10.0%	126	1,388	3
11.7	Standby Equipment	1,304	0	30	0	1,333	9.5%	126	0%	0	10.0%	146	1,606	3
11.8	Main Power Transformers	7,447	0	125	0	7,572	7.6%	575	0%	0	10.0%	815	8,962	16
11.9	Electrical Foundations	0	320	786	0	1,106	9.5%	105	0%	0	20.0%	242	1,453	3
	SUBTOTAL 11.	**$28,157**	**$17,265**	**$48,037**	**$0**	**$93,460**		**$8,383**		**$0**		**$13,150**	**$114,992**	**$209**
12	INSTRUMENTATION & CONTROL													
12.1	PC Control Equipment	w/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.2	Combustion Turbine Control	N/A	0	N/A	0	0	0%	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%	0	0	0
12.4	Other Major Component Control	0	0	0	0	0	0%	0	0%	0	0.0%	0	0	0
12.5	Signal Processing Equipment	W/12.7	0	w/12.7	0	0	0%	0	0%	0	0.0%	0	0	0
12.6	Control Boards, Panels & Racks	597	0	358	0	955	9.6%	92	0%	0	15.0%	157	1,204	2
12.7	Computer Accessories	6,031	0	1,054	0	7,085	9.5%	675	0%	0	10.0%	776	8,536	16
12.8	Instrument Wiring & Tubing	3,270	0	6,487	0	9,757	8.5%	831	0%	0	15.0%	1,588	12,176	22
12.9	Other I & C Equipment	1,704	0	3,867	0	5,571	9.7%	543	0%	0	10.0%	611	6,725	12
	SUBTOTAL 12.	**$11,602**	**$0**	**$11,766**	**$0**	**$23,368**		**$2,140**		**$0**		**$3,133**	**$28,641**	**$52**
13	IMPROVEMENTS TO SITE													
13.1	Site Preparation	0	53	1,066	0	1,120	9.9%	110	0%	0	20.0%	246	1,476	3
13.2	Site Improvements	0	1,770	2,199	0	3,969	9.8%	390	0%	0	20.0%	872	5,231	10
13.3	Site Facilities	3,173	0	3,129	0	6,301	9.8%	618	0%	0	20.0%	1,384	8,304	15
	SUBTOTAL 13.	**$3,173**	**$1,824**	**$6,394**	**$0**	**$11,390**		**$1,119**		**$0**		**$2,502**	**$15,011**	**$27**
14	BUILDINGS & STRUCTURES													
14.1	Boiler Building	0	8,751	7,695	0	16,446	9.0%	1,477	0%	0	15.0%	2,688	20,612	37
14.2	Turbine Building	0	12,577	11,722	0	24,299	9.0%	2,188	0%	0	15.0%	3,973	30,460	55
14.3	Administration Building	0	629	665	0	1,294	9.1%	117	0%	0	15.0%	212	1,622	3
14.4	Circulation Water Pumphouse	0	109	86	0	195	8.9%	17	0%	0	15.0%	32	244	0
14.5	Water Treatment Buildings	0	543	495	0	1,037	9.0%	93	0%	0	15.0%	170	1,300	2
14.6	Machine Shop	0	421	283	0	703	8.9%	62	0%	0	15.0%	115	880	2
14.7	Warehouse	0	285	286	0	571	9.0%	52	0%	0	15.0%	93	716	1
14.8	Other Buildings & Structures	0	233	198	0	431	9.0%	39	0%	0	15.0%	70	540	1
14.9	Waste Treating Building & Str.	0	433	1,314	0	1,747	9.4%	165	0%	0	15.0%	287	2,199	4
	SUBTOTAL 14.	**$0**	**$23,979**	**$22,744**	**$0**	**$46,723**		**$4,210**		**$0**		**$7,640**	**$58,573**	**$106**
	Total Cost	**$590,041**	**$55,507**	**$345,016**	**$0**	**$990,564**		**$93,715**		**$83,881**		**$141,796**	**$1,309,956**	**$2,381**

Exhibit 3-110 Cumulative Case Owner's Costs

Owner's Costs	$1,000	$/kW
Preproduction Costs		
6 Months All Labor	$8,723	$16
1 Month Maintenance Materials	$1,240	$2
1 Month Non-fuel Consumables	$243	$0
1 Month Waste Disposal	$243	$0
25% of 1 Months Fuel Cost at 100% CF	$1,473	$3
2% of TPC	$26,199	$48
Total	**$38,121**	**$69**
Inventory Capital		
60 day supply of fuel and consumables at 100% CF	$11,998	$22
0.5% of TPC (spare parts)	$6,550	$12
Total	**$18,548**	**$34**
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$196,493	$357
Financing Costs	$35,369	$64
Total Overnight Costs (TOC)	**$1,599,387**	**$2,908**
TASC Multiplier	1.134	
Total As-Spent Cost (TASC)	**$1,813,705**	**$3,297**

Exhibit 3-111 Cumulative Case O&M Costs

INITIAL & ANNUAL O&M EXPENSES						
Case:	Case TOT - Cumulative Technology Case					
Plant Size (MWe):	550.06			**Heat Rate (Btu/kWh):**		8,968
Primary/Secondary Fuel:	Illinois #6 Bituminous Coal			**Fuel Cost ($/MM Btu):**		1.64
Design/Construction	5 years			**Book Life (yrs):**		30
TPC (Plant Cost) Year:	June 2007			**TPI Year:**		2012
Capacity Factor (%):	85			**CO_2 Captured (TPD):**		11,856
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate (base):		$34.65	$/hour			
Operating Labor Burden:		30.00	% of base			
Labor Overhead Charge:		25.00	% of labor			
Operating Labor Requirements per Shift:		**units/mod.**		**Total Plant**		
Skilled Operator		2.0		2.0		
Operator		9.0		9.0		
Foreman		1.0		1.0		
Lab Tech's etc.		2.0		2.0		
TOTAL Operating Jobs		14.0		14.0		
					$	**$/kW-net**
Annual Operating Labor Cost (calc'd)					5,524,319	10.04
Maintenance Labor Cost (calc'd)					8,432,078	15.33
Administrative & Support Labor (calc'd)					3,489,099	6.34
Property Taxes and Insurance					26,199,125	47.63
TOTAL FIXED OPERATING COSTS					**43,644,621**	**79.35**
VARIABLE OPERATING COSTS						
					$	**$/kWh-net**
Maintenance Material Costs (calc'd)					**$12,648,216**	**0.00309**
Consumables	**Consumption**		**Unit**	**Initial**		
	Initial	**/Day**	**Cost**	**Cost**	**$**	**$/kWh-net**
Water (/1000 gallons)	0	4,155	1.08	$0	$1,394,303	0.00034
Chemicals						
MU & WT Chem. (lb)	0	20,112	0.17	$0	$1,079,892	0.00026
Limestone (ton)	0	0	21.63	$0	$0	0.00000
Carbon (Hg Removal) (lb)	0	0	1.05	$0	$0	0.00000
MEA Solvent (ton)	0	0	2249.89	$0	$0	0.00000
Caustic Soda, NaOH (ton)	0	0	433.68	$0	$0	0.00000
Sulfuric acid, H_2SO_4 (ton)	0	0	138.78	$0	$0	0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	0.00000
Activated C, MEA (lb)	0	0	1.05	$0	$0	0.00000
Ammonia, 19% soln (ton)	0	0	129.80	$0	$0	0.00000
Subtotal Chemicals				**$0**	**$1,079,892**	**0.00026**
Other						
Supplemental Fuel (MMBtu)	0	0	6.55	$0	$0	0.00000
SCR Catalyst Replacement	w/equip.	0.0	5775.94	$0	$0	0.00000
Emission Penalties	0	0	0.00	$0	$0	0.00000
Subtotal Other				**$0**	**$0**	**0.00000**
Waste Disposal						
Spent Mercury Catalyst (lb)	0	0	0.42	$0	$0	0.00000
Flyash (ton)	0	394	16.23	$0	$1,981,346	0.00048
Bottom Ash (ton)	0	98	16.23	$0	$495,337	0.00012
Subtotal Solid Waste Disposal				**$0**	**$2,476,683**	**0.00060**
By-products & Emissions						
Gypsum (tons)	0	0	0.00	$0	$0	0.00000
Sulfur (tons)	0	0	0.00	$0	$0	0.00000
TOTAL VARIABLE OPERATING COSTS					**$17,599,094**	**0.00430**
Coal FUEL (tons)	**0**	**5,074**	**38.18**	**$0**	**$60,109,126**	**0.01468**
NATURAL GAS FUEL (Mscf)	**0**	**0**	**6.76**	**$0**	**$0**	**0.00000**

Exhibit 3-112 Equipment List for Cumulative Case

ACCOUNT 1 FUEL AND SORBENT 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	36 tonne (40 ton)	2 (1)
9	Feeder	Vibratory	154 tonne/hr (170 tph)	2 (1)
10	Conveyor No. 3	Belt w/ tripper	318 tonne/hr (350 tph)	1 (0)
11	Crusher Tower	N/A	N/A	1 (0)
12	Coal Surge Bin w/ Vent Filter	Dual outlet	154 tonne (170 ton)	2 (0)
13	Crusher	Impactor reduction	8 cm x 0 - 3 cm x 0 (3 in x 0 - 1-1/4 in x 0)	2 (0)
14	As-Fired Coal Sampling System	Swing hammer	N/A	1 (1)
15	Conveyor No. 4	Belt w/tripper	318 tonne/hr (350 tph)	1 (0)
16	Transfer Tower No. 2	Enclosed	N/A	1 (0)
17	Conveyor No. 5	Belt w/ tripper	318 tonne/hr (350 tph)	1 (0)

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
18	Coal Silo w/ Vent Filter and Slide Gates	Field erected	726 tonne (800 ton)	3 (0)

ACCOUNT 2 COAL AND SORBENT PREPARATION AND FEED

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	Coal Feeder	Gravimetric	36 tonne/hr (40 tph)	6 (0)
2	Coal Pulverizer	Ball type or equivalent	36 tonne/hr (40 tph)	6 (0)

ACCOUNT 3 FEEDWATER AND MISCELLANEOUS SYSTEMS AND EQUIPMENT

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	897,143 liters (237,000 gal)	2 (0)
2	Condensate Pumps	Vertical canned	21,577 lpm @ 244 m H_2O (5,700 gpm @ 800 ft H_2O)	1 (1)
3	Deaerator and Storage Tank	Horizontal spray type	1,495,948 kg/hr (3,298,000 lb/hr), 5 min. tank	1 (0)
4	Boiler Feed Pump/Turbine	Barrel type, multi-stage, centrifugal	24,984 lpm @ 3,871 m H_2O (6,600 gpm @ 12,700 ft H_2O)	1 (1)
5	Startup Boiler Feed Pump, Electric Motor Driven	Barrel type, multi-stage, centrifugal	7,571 lpm @ 3,871 m H_2O (2,000 gpm @ 12,700 ft H_2O)	1 (0)
6	LP Feedwater Heater 1A/1B	Horizontal U-tube	639,565 kg/hr (1,410,000 lb/hr)	2 (0)

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
7	LP Feedwater Heater 2A/2B	Horizontal U-tube	639,565 kg/hr (1,410,000 lb/hr)	2 (0)
8	LP Feedwater Heater 3A/3B	Horizontal U-tube	639,565 kg/hr (1,410,000 lb/hr)	2 (0)
9	LP Feedwater Heater 4A/4B	Horizontal U-tube	639,565 kg/hr (1,410,000 lb/hr)	2 (0)
10	HP Feedwater Heater 6	Horizontal U-tube	1,496,855 kg/hr (3,300,000 lb/hr)	1 (0)
11	HP Feedwater Heater 7	Horizontal U-tube	1,496,855 kg/hr (3,300,000 lb/hr)	1 (0)
12	HP Feedwater heater 8	Horizontal U-tube	1,496,855 kg/hr (3,300,000 lb/hr)	1 (0)
13	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)
14	Fuel Oil System	No. 2 fuel oil for light off	1,135,624 liter (300,000 gal)	1 (0)
15	Service Air Compressors	Flooded Screw	28 m^3/min @ 0.7 MPa (1,000 scfm @ 100 psig)	2 (1)
16	Instrument Air Dryers	Duplex, regenerative	28 m^3/min (1,000 scfm)	2 (1)
17	Closed Cycle Cooling Heat Exchangers	Shell and tube	176 GJ/hr (167 MMBtu/hr) each	2 (0)
18	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	69,273 lpm @ 30 m H_2O (18,300 gpm @ 100 ft H_2O)	2 (1)

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
19	Engine-Driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 88 m H_2O (1,000 gpm @ 290 ft H_2O)	1 (1)
20	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 64 m H_2O (700 gpm @ 210 ft H_2O)	1 (1)
21	Raw Water Pumps	Stainless steel, single suction	12,795 lpm @ 43 m H_2O (3,380 gpm @ 140 ft H_2O)	2 (1)
22	Filtered Water Pumps	Stainless steel, single suction	1 lpm @ 49 m H_2O (0 gpm @ 160 ft H_2O)	2 (1)
23	Filtered Water Tank	Vertical, cylindrical	596 liter (158 gal)	1 (0)
24	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly, electrodeionization unit	606 lpm (160 gpm)	1 (1)
25	Liquid Waste Treatment System	--	10 years, 24-hour storm	1 (0)

ACCOUNT 4 BOILER AND ACCESSORIES

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	Boiler	Supercritical, drum, wall-fired, low NO_x burners, overfire air	1,496,855 kg/hr steam @ 29.0 MPa/741°C/768°C (3,300,000 lb/hr steam @ 4,200 psig/1,365°F/1,415°F)	1 (0)
2	Primary Air Fan	Centrifugal	117,027 kg/hr, 2,093 m^3/min @ 47 cm WG (258,000 lb/hr, 73,900 acfm @ 19 in. WG)	2 (0)
3	Forced Draft Fan	Centrifugal	380,110 kg/hr, 6,813 m^3/min @ 123 cm WG (838,000 lb/hr, 240,600 acfm @ 48 in. WG)	2 (0)
4	Induced Draft Fan	Centrifugal	834,156 kg/hr, 15,348 m^3/min @ 46 cm WG (1,839,000 lb/hr, 542,000 acfm @ 18 in. WG)	2 (0)
5	ASU Main Air Compressor	Centrifugal, multi-stage	18,264 m^3/min @ 1.5 MPa (645,000 scfm @ 215 psia)	2 (0)
6	Advanced Membrane ASU	Vendor design	5,171 tonne/day (5,700 tpd) of 100% purity oxygen	2 (0)
7	Nitrogen Expander	Centrifugal, multi-stage	15,631 m^3/min @ 0.1 MPa (552,000 scfm @ 015 psia)	2 (0)
8	Recuperator	Single pass, multi-stage	1,308 GJ/hr (1,240 MMBtu/hr), Inlet N_2 temperature 330°C (625°F), Inlet O_2 temperature 802°C (1,475°F), N_2 temperature decrease 270°C (485°F), O_2 temperature decrease 736°C (1,325°F)	1 (0)

ACCOUNT 5 FLUE GAS CLEANUP

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	Fabric Filter	Single stage, high-ratio with pulse-jet online cleaning system	834,156 kg/hr (1,839,000 lb/hr) 99.8% efficiency	2 (0)

ACCOUNT 5B CARBON DIOXIDE RECOVERY

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	CO_2 Compressor	Centrifugal	246,475 kg/h @ 15.3 MPa (543,385 lb/h @ 2,214 psia)	2 (0)

ACCOUNT 7 HRSG, DUCTING & STACK

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	Stack	Reinforced concrete with FRP liner	46 m (150 ft) high x 3.6 m (12 ft) diameter	1 (0)

ACCOUNT 8 STEAM TURBINE GENERATOR AND AUXILIARIES

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	Steam Turbine	Commercially available advanced steam turbine	658 MW 27.6 MPa/732°C/760°C (4,000 psig/ 1350°F/1400°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	730 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)
3	Surface Condenser	Single pass, divided waterbox including vacuum pumps	2,880 GJ/hr (2,730 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	605,700 lpm @ 30 m (160,000 gpm @ 100 ft)	2 (1)
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT / 3,376 GJ/hr (3,200 MMBtu/hr) heat duty	1 (0)

ACCOUNT 10 ASH/SPENT SORBENT RECOVERY AND HANDLING

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	Economizer Hopper (part of boiler scope of supply)	--	--	4 (0)
2	Bottom Ash Hopper (part of boiler scope of supply)	--	--	2 (0)
3	Clinker Grinder	--	4.5 tonne/hr (5 tph)	1 (1)
4	Pyrites Hopper (part of pulverizer scope of supply included with boiler)	--	--	6 (0)
5	Hydroejectors	--	--	12 (0)
6	Economizer /Pyrites Transfer Tank	--	--	1 (0)

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
7	Ash Sluice Pumps	Vertical, wet pit	151 lpm @ 17 m H_2O (40 gpm @ 56 ft H_2O)	1 (1)
8	Ash Seal Water Pumps	Vertical, wet pit	7,571 lpm @ 9 m H_2O (2,000 gpm @ 28 ft H_2O)	1 (1)
9	Hydrobins	--	151 lpm (40 gpm)	1 (1)
10	Baghouse Hopper (part of baghouse scope of supply)	--	--	24 (0)
11	Air Heater Hopper (part of boiler scope of supply)	--	--	10 (0)
12	Air Blower	--	15 m^3/min @ 0.2 MPa (530 scfm @ 24 psi)	1 (1)
13	Fly Ash Silo	Reinforced concrete	499 tonne (1,100 ton)	2 (0)
14	Slide Gate Valves	--	--	2 (0)
15	Unloader	--	--	1 (0)
16	Telescoping Unloading Chute	--	91 tonne/hr (100 tph)	1 (0)

ACCOUNT 11 ACCESSORY ELECTRIC PLANT

Equipment No.	Description	Type	Design Condition	Operating Qty. (Spares)
1	STG Transformer	Oil-filled	24 kV/345 kV, 300 MVA, 3-ph, 60 Hz	1 (0)
2	Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 408 MVA, 3-ph, 60 Hz	1 (1)
3	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 61 MVA, 3-ph, 60 Hz	1 (1)
4	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1 (0)
5	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1 (1)
6	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1 (1)
7	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

ACCOUNT 12 INSTRUMENTATION AND CONTROL

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)

3.9 COMPARATIVE PERFORMANCE SUMMARY

This study was designed to incorporate advanced oxycombustion technologies anticipated to improve cost and/or performance over an oxycombustion system composed of currently available technologies. The performance summaries for all cases are shown in Exhibit 3-113. In the seven cases examining advanced technology, the net plant efficiency changes over the current state-of-the-art for oxycombustion technology (29.3% HHV) in the range from -0.1% to +3.7% absolute percentage points (excluding the cumulative case).

In Cases 1, 1A, and the Cumulative Case, all of which utilize an advanced membrane ASU, the auxiliary loads as well as the gross power production are comparatively larger than the remaining cases. Auxiliary loads are larger than a cryogenic ASU because the membrane system pressurizes the feed air to ~215 psia compared to ~85 psia for a conventional ASU, has no intercooling, and has a lower O_2 yield such that more feed air is required per mass of O_2 product. The high auxiliary power in the advanced membrane cases is not so detrimental since much of this compression power is recovered in a hot gas expander and the ASU heat input is partially recovered in the boiler feedwater system. The net result is similar to what is seen in gas turbine operation, except the compression load and gross power production of the hot gas expander are explicitly accounted for here. Case 1A uses natural gas to provide the heating for the membrane system and so the overall system efficiency of this case includes this heat input even though it does not explicitly contribute to power production.

Exhibit 3-113 Plant Performance Summary

Case	Base Case	Case 1	Case 1A	Case 3	Case 4	Case 5	Case 6	Case 7	Case 10	
Description	Current Technology	Advanced Membrane/Boiler Integration	Advanced Membrane/NG Integration	USC w/Advanced Material	Co-Sequestration	Advanced Recycle	Advanced CO_2 Compression	Oxyfuel Boiler	Cumulative	
Plant Output										
Steam Turbine Power	790,800	620,500	662,300	765,900	765,500	790,600	814,000	785,900	624,700	kW_e
Advanced Membrane Expander Power	N/A	345,200	272,400	N/A	N/A	N/A	N/A	N/A	295,500	kW_e
Gross Power	**790,800**	**965,700**	**934,700**	**765,900**	**765,500**	**790,600**	**814,000**	**785,900**	**920,200**	kWe
Auxiliary Load										
Coal Handling and Conveying	500	480	440	480	480	500	500	500	440	kW_e
Limestone Handling & Reagent Preparation	1,210	1,100	930	1,090	0	1,210	1,190	1,200	0	kW_e
Pulverizers	3,740	3,390	2,860	3,380	3,450	3,740	3,680	3,690	2,880	kW_e
Ash Handling	720	650	550	650	660	720	710	710	550	kW_e
Primary Air Fans	1,010	910	770	910	1,410	980	1,010	790	860	kW_e
Forced Draft Fans	1,280	1,150	990	1,150	1,800	1,240	1,270	1,010	1,080	kW_e
Induced Draft Fans	7,080	6,330	5,390	6,380	3,610	6,610	7,010	6,030	2,380	kW_e
Air Separation Unit Main Air Compressor	125,720	315,240	296,100	113,350	115,970	125,880	123,950	124,190	269,910	kW_e
ASU Auxiliaries	1,000	0	0	1,000	1,000	1,000	1,000	1,000	0	kW_e
Baghouse	90	90	70	80	90	90	90	90	70	kW_e
FGD Pumps and Agitators	4,050	3,680	3,230	3,650	0	4,050	3,990	4,000	0	kWe
CO_2 Compression	73,410	64,170	55,550	65,070	67,770	73,620	98,700	72,520	76,250	kW_e
Condensate Pumps	1,040	810	880	960	1,020	1,040	1,070	1,050	890	kW_e
Boiler Feedwater Booster Pumps	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	kW_e
Miscellaneous Balance of Plant[2,3]	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	kW_e
Steam Turbine Auxiliaries	400	400	400	400	400	400	400	400	400	kW_e
Circulating Water Pumps	9,160	7,730	7,310	7,990	8,170	9,180	8,930	9,010	6,030	kW_e
Cooling Tower Fans	5,340	4,510	4,270	4,670	4,770	5,360	5,220	5,260	3,520	kW_e
Transformer Losses	3,030	3,000	3,040	2,880	2,880	3,030	3,160	3,000	2,880	kW_e
Total	240,780	415,640	384,780	216,090	215,480	240,650	263,880	236,450	370,140	kW_e
Plant Performance										
Net Auxiliary Load	240,780	415,640	384,780	216,090	215,480	240,650	263,880	236,450	370,140	kW_e
Net Plant Power	550,020	550,060	549,920	549,810	550,020	549,950	550,120	549,450	550,060	kW_e
Net Plant Efficiency (HHV)	29.3%	32.2%	33.0%	32.4%	31.7%	29.2%	29.7%	29.6%	38.1%	
Net Plant Heat Rate (HHV)	12,300 (11,658)	11,167 (10,584)	10,904 (10,335)	11,120 (10,540)	11,347 (10,754)	12,317 (11,675)	12,124 (11,492)	12,163 (11,528)	9,461 (8,968)	kJ/kWhr (Btu/kWhr)
Coal Feed Flowrate	249,312 (549,638)	226,371 (499,062)	190,935 (420,941)	225,320 (496,745)	229,991 (507,043)	249,640 (550,361)	245,804 (541,905)	246,282 (542,960)	191,790 (422,825)	kg/hr (lb/hr)
Natural Gas	N/A	N/A	15,544 (34,268)	N/A	N/A	N/A	N/A	N/A	N/A	kg/hr (lb/hr)
Coal Thermal Input[1]	1,879,193	1,706,276	1,439,182	1,698,356	1,733,562	1,881,666	1,852,755	1,856,362	1,445,623	kW_{th}
Natural Gas Thermal Input[4]	N/A	N/A	226,458	N/A	N/A	N/A	N/A	N/A	N/A	kW_{th}
Thermal Input (Coal + Natural Gas)	1,879,193	1,706,276	1,665,640	1,698,356	1,733,562	1,881,666	1,852,755	1,856,362	1,445,623	kW_{th}
Condenser Duty	3,079 (2,918)	2,831 (2,683)	2,821 (2,674)	2,648 (2,510)	3,160 (2,995)	3,088 (2,927)	3,398 (3,221)	3,062 (2,902)	2,618 (2,482)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	33.0 (8,729)	27.6 (7,304)	27.2 (7,186)	29.6 (7,822)	30.2 (7,976)	33.2 (8,777)	32.2 (8,499)	32.5 (8,587)	21.8 (5,771)	m^3/min (gpm)

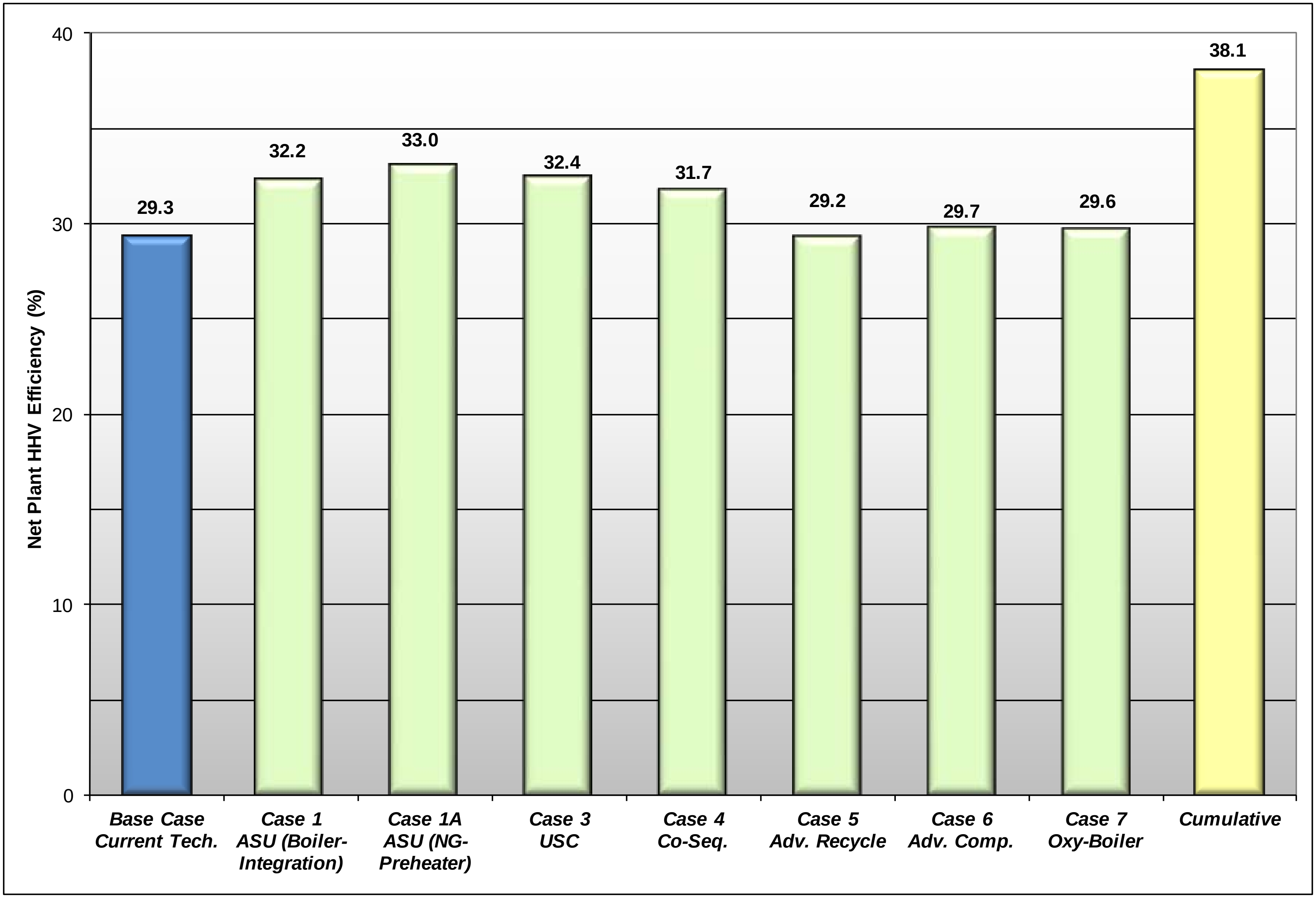
1 - HHV of as-received Illinois No. 6 coal is 27,135 kJ/kg(11,666 Btu/lb)

2 - Boiler feed pumps are turbine driven

3 - Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

4 - HHV of natural gas is 22,549 Btu/lb

Exhibit 3-114 Case Efficiency Summary



Efficiency

The overall system energy efficiencies (based on HHV) are shown in Exhibit 3-114. The primary conclusions regarding plant efficiencies that can be drawn are:

- Among the conventional ASU–based cases, Case 3 (USC steam cycle) shows the highest improvement in plant efficiency compared to SC oxycombustion technology (base case). The improvement is 3.1 efficiency percentage points (9.6 percent heat rate improvement), which is what can be expected for similar upgrades in steam conditions in all PC plants.
- Excluding the advanced membrane ASU cases, Case 4 (co-sequestration) shows the second highest improvement in plant efficiency compared to the base case. The improvement is 2.4 efficiency percentage points, or 7.8 percent heat rate improvement. Not only is there a savings in auxiliary loads because an FGD is no longer required, but additional heat can be recovered from the flue gas. When a wet FGD is used, the flue gas is quenched down to ~150°F; without an FGD useful sensible heat from the flue gas can be recovered in the boiler feedwater system, increasing the overall system efficiency by maintaining a high level of available heat. It should be noted that this system requires advanced materials that do not yet exist which are capable of withstanding the extremely high sulfur concentrations that can result with medium or high sulfur coals. For higher sulfur coals especially, advanced materials may be required in the boiler through to the compression system and may add significant cost.
- Of the two advanced membrane cases (excluding the cumulative case), Case 1A (natural gas preheater integration) has the greatest efficiency improvement at 3.7 absolute percentage points (11 percent heat rate improvement). Due to the high temperature and high pressure operation of the advanced membrane system, a significant amount of power and heat recovery from the vitiated air is possible, offsetting some of the input energy to the system by generating power in a manner similar to that of a natural gas combined cycle. However, the 90% CO_2 capture requirement limits the thermodynamic performance of this cycle in a unique way. The amount of natural gas required to completely preheat the membrane feed would result in an excessive amount of vented CO_2, decreasing overall CO_2 capture below 90%. Therefore, a regenerative heat exchanger immediately prior to the vitiated gas expander was used to perform a portion of the preheat in an effort to reduce the amount of vented CO_2 (to maintain a 90% capture rate).
- Case 1 (advanced membrane with boiler heat integration) shows a 2.9 absolute percentage points (9.2 percent heat rate) improvement over the base case. Due to the high temperature and high pressure operation of the membrane, a significant amount of power and heat recovery from the vitiated air is possible, offsetting some of the thermal input required by the process by using a hot gas expander to produce additional power. Providing the required heat from the coal-fired boiler results in a higher coal feed rate than Case 1A, which leads to increased O_2 demand and higher auxiliary loads (including CO_2 compression). The result is a lower overall efficiency than Case 1A where the required heat is provided using natural gas, but a higher overall CO_2 capture efficiency.

- In Case 6, advanced CO_2 compression technology increases plant efficiency by 0.4 percentage points (14 percent of heat rate) compared to the current oxycombustion technology case. While the shock wave compression technology has the potential for recovering significant levels of heat from two-stage compressors, two-stage compression as expected was found to require more total power than the typical 8-stage compression with intercooling. The amount of compression heat that could be integrated back into the system was not found to significantly offset the higher compression power requirements of the shock compression technology, despite the more efficient shock compression stage efficiencies.

- Case 5 using the advanced recycle concept was found to have nearly no impact on efficiency. The reason for this lies not in Case 5 but in the relatively small detrimental effect of the preheat process that occurs in the base case. In the base case, heat was extracted from the steam cycle and sent directly, and entirely, to the boiler. This study assumed the base case system was adiabatic with a few exceptions (e.g. 1% boiler heat loss). As a result, the extracted heat for recycle is largely retained in the overall system and placed in the boiler where additional benefit may still be realized. The small heat loss and the small amount of heat extracted from the feedwater system leads to negligible change in system performance in the base case. Any reduction in auxiliary fan loads resulting from advanced recycle was found to be insignificant.

- Case 7 using an advanced oxycombustion boiler showed low levels of improvement in plant efficiency nearing ~0.3 percent absolute compared to the base case. The benefits of the oxycombustion boiler are: its smaller design (saving capital cost), its ability to reduce the FGR required, and its ability to promote heat transfer at higher temperatures (higher adiabatic flame temperature tolerance). The reduction in FGR reduces the fan loads required to accommodate the recycle. These fan loads are not very significant compared to the rest of the auxiliaries so the efficiency increase due to this benefit is relatively minor. The benefit of higher boiler temperatures is largely limited by materials constraints. While a higher temperature is achievable in the boiler, higher steam conditions are not and thus limit the benefit of a higher flame temperature. Without complex CFD modeling, it is difficult to quantify the heat transfer profile of a boiler exhibiting a higher flame temperature; it is possible that additional benefits may be realized due to a more advantageous heat transfer profile, but these effects were not examined in this study.

- As expected the Cumulative Case shows the highest improvement in plant efficiency; the efficiency is increased by 8.8 percentage points absolute (23 percent heat rate improvement). If the efficiency effects of all individual cases are added together (choosing Case 1 over Case 1A for cost reasons), the result is a net improvement of 9.1 total percentage points. It can then be said that on average, over 95 percent of the potential benefit of each individual technology is realized in the Cumulative Case, suggesting that most of the benefits provided by the individual cases are mutually exclusive and all benefit oxycombustion in their own right.

Water Use

Water withdrawal was largely similar among all cases. Nearly all oxycombustion cases examined in this study increase the water use above that required for a supercritical PC plant without CCS (9.7 gpm/MW) between 50% and 65%. However, cases with an advanced membrane-based ASU only increase supercritical PC water use by ~35%. This is because a large portion of gross plant power (~33%-50%) is produced via a power cycle (hot gas expander) that does not require cooling. The heat not recovered from expander exhaust gas is allowed to leave the system without the need to cool or condense water. This reduces water losses via evaporation from a cooling tower. The combined performance enhancements of all advanced technologies reduce water withdrawal in the Cumulative Case to be only ~10% higher than a state of the art supercritical plant. The disparity in water withdrawal amongst the cases here could be reduced if the base plant incorporated dry cooling.

Air Emissions

With the sole exception of Case 1A, all oxycombustion cases in this study assumed that:

1. During normal operation no gas is vented through the stack, thus no air emissions, and
2. Geologic CO_2 sequestration can accommodate any amount of impurity in the sequestered CO_2 such that no purification is required.

These two assumptions lead to the potential for virtually zero air emissions plants, which implies 100% CO_2 capture for all cases except Case 1A.

In Case 1A, the stack emits flue gas generated by the natural gas-fired direct heater in the advanced membrane ASU system during normal operation. This results in CO_2 emissions of 205 lb/MWhnet, which equates to roughly 92% CO_2 capture. In Case 1A, sulfur, particulate matter, and mercury emissions are negligible because of the nature of the natural gas fuel. NO_x emissions for this case are also assumed to be negligible since natural gas combustion temperatures in the ASU system only reach 1,475°F.

In all cases, it was assumed that no CO_2 purification is required for geologic sequestration. It should be noted that if CO_2 purification is required, there will likely be additional CO_2 emissions from the purification process. The emissions constituent type and amount has yet to be determined and will depend largely on the component targeted for reduction in the CO_2 product. In previous NETL studies of CO_2 purification it has been estimated that as much as 10% of the total CO_2 generated may be lost as fugitive emissions from the purification process.

3.10 COMPARATIVE ECONOMIC SUMMARY

Capital Cost

Total Overnight Cost (TOC) highlights are presented below. Normalized TOC (expressed in $/kW) for all cases including the Current Oxycombustion Technology case are shown in Exhibit 3-115.

- Case 4 (co-sequestration) has the lowest TOC among the individual technology cases at $2,927/kW. The Case 4 TOC is $292/kW (or 9 percent) lower than the current technology case. The major reason for this cost reduction is that current technology uses an FGD unit to capture sulfur oxides, while the Case 4 technology eliminates the FGD unit by sequestering the sulfur oxides. This reduction in cost entails some technical risk since the boiler and flue gas recycle must be made of materials that are resistant to corrosion from sulfur-containing gases; this is reflected in the increased process contingency in the boiler and ductwork equipment accounts. These sulfur resistant materials are also more expensive, further offsetting some of the cost savings associated with elimination of the FGD unit.

- Case 1A (advanced membrane ASU integrated with natural gas-fired direct heater) has the second lowest TOC of all cases except the Cumulative Case at $3,023/kW. The TOC for Case 1A is $196/kW (or 6 percent) lower than current technology. Case 1 (advanced membrane ASU integrated with boiler steam cycle) has the third lowest TOC at $3,137/kW. The TOC for Case 1 is $82/kW (or 2.5 percent) lower than current technology. The lower costs can be attributed to the substitution of the advanced membrane technology for the more expensive ASU in both cases. In this study, it was assumed that the membrane can be constructed for 30% less capital cost than an equivalent size cryogenic ASU. **This is the goal set forth by an NETL-sponsored research and development project on membrane technology**. The authors acknowledge it is possible that the cost to manufacture and install an advanced membrane may ultimately be different. Exhibit 3-35 & Exhibit 3-47 each provide a cost breakdown that can be manipulated at the reader's discretion to recalculate COE based on variable membrane-based ASU capital cost assumptions.
- Case 3 (USC steam cycle) has the highest TOC of all cases. It is $26/kW (or ~1 percent) higher than the current technology case. The higher cost is due to the fact that specialty materials able to withstand higher boiler and steam turbine operating temperatures and pressures are needed for construction. USC technology entails risk; it has not been demonstrated at commercial scale in the U.S. Exhibit 3-116 shows how the increase in efficiency resulting from the USC conditions translates into a lower COE; the efficiency improvement outweighs the increase in cost for a net decrease in COE.
- Case 6 (Advanced CO_2 Compression) has a TOC that is $68/kW (or 2 percent) less than the current technology. Although the Advanced Compressor has a larger gross power requirement than a conventional compressor, its TOC per unit horsepower is less than the conventional compressor TOC. However, the increase in the remaining plant TOC to provide the additional power to run the compressor and the additional heat exchangers required to recover interstage heat partially offset the savings resulting from the compressor.
- Case 5 and 7 have TOC's that are less than 1.1% lower than the current technology case; therefore, aside from any compounded efficiency increases due to coupling these advanced technologies, these cases on their own offer no significant capital cost advantage over current technology.
- The Cumulative Case has the lowest TOC of all the cases at $2,908/kW. The Cumulative Case combines all of the advanced technologies which results in a significantly more efficient power plant. The advanced technologies have not yet been demonstrated and so have more technical risk than current technology. This risk was captured by the increased process contingencies in the advanced technology accounts, however as more

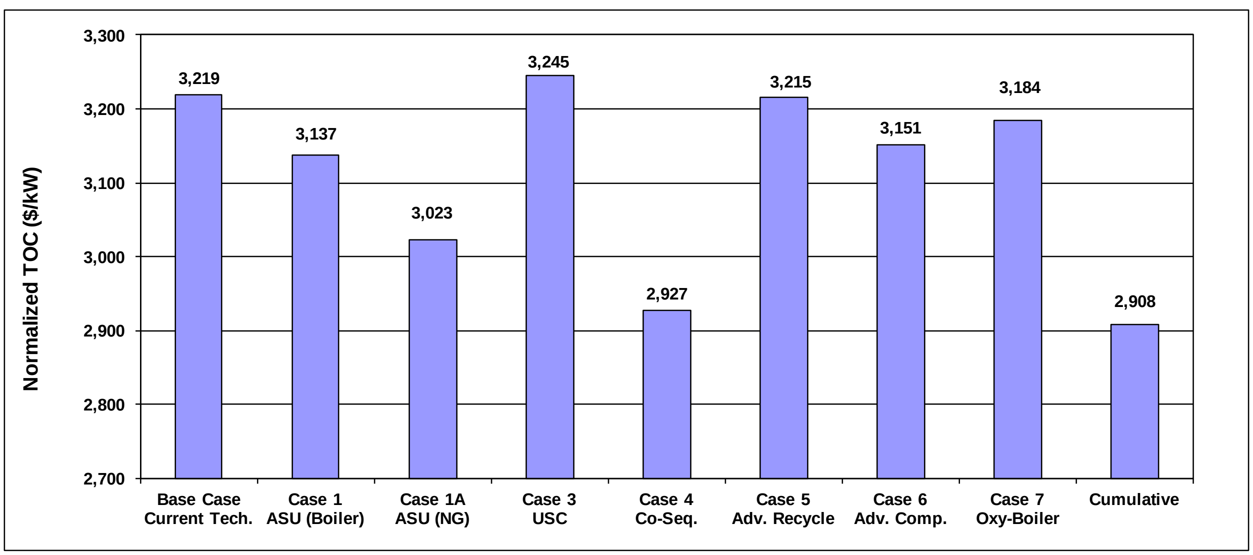
information is gathered on these technologies, the cost accounts broken out in this report can be readily adjusted to recalculate revised costs. Under the current set of assumptions, the TOC for the Cumulative Case is $311/kW (or 10 percent) lower than that of current technology (Base Case). Major reasons for this cost reduction in comparison to current technology are:

1. The Cumulative Case is a significantly more efficient plant as a result of coupling performance-enhancing technologies. It requires 23% less thermal input than the current technology case to achieve the same output, which reduces the overall plant size. Depending on economies of scale, this can reduce the normalized TOC by 15-17%, all else being equal.
2. The elimination of the cost of FGD.
3. The substitution of an advanced membrane ASU for the more expensive conventional ASU. In accordance with a goal set forth by an NETL-sponsored R&D effort on advanced membrane technology, it was assumed that the membrane-based ASU is 30% less expensive than an equivalent cryogenic ASU.

These cost reductions are partially offset by an increase in boiler material and ductwork costs since special materials of construction are required for these items, which have not been demonstrated at commercial scale. Cost reductions are also offset by the increased contingency added due to the risk and uncertainty of the performance of undemonstrated technologies.

As mentioned previously, there is one technology included in the Cumulative Case that does not increase the efficiency of the oxycombustion plant – Advanced Recycle. If the cost savings of this technology do not outweigh its associated efficiency penalty, eliminating it from the Cumulative Case may decrease the TOC and COE even further.

Exhibit 3-115 Total Overnight Cost



Cost of Electricity

The COE for each case, excluding TS&M costs, is shown in Exhibit 3-116. The COE components are also shown in tabular form in Exhibit 3-117. TS&M costs are excluded from the total because they are not included in the DOE goal of limiting the COE increase over a SC PC non-capture plant to 35 percent. The following observations can be made:

- The COE is dominated by capital charges in all cases. The capital cost component of COE comprises 55–65 percent for all cases, including the current technology case. As a result, the ranking of cases from highest to lowest COE generally conforms to the differences in TOC noted above.
- The fuel cost component is the second largest component, representing ~20 percent of the COE. Fuel costs for all cases are similar with the exception of the natural gas-based advanced membrane ASU case (26 percent). The cost of natural gas is significantly higher than coal ($6.55/MMBtu versus $1.64/MMBtu), which is reflected in the relative fuel cost of Case 1A. High natural gas costs are also the reason that, despite Case 1A having a TOC ~3.5% lower than Case 1 and a heat rate ~2.2% lower, Case 1A has a higher COE.
- The TS&M component of COE in the CO_2 capture cases is about 6 percent of the total COE. TS&M costs are virtually the same for all cases, but have not been included in the total COE as described above.

The following observations can also be made with regard to COE (excluding TS&M):

- Among the CO_2 capture cases, the Cumulative Case has the lowest COE at $78.15/MWh. It is 32.7 percent higher (refer to Exhibit 3-117) than that of the non-capture current technology case (air-fired, SC, no carbon capture) and therefore meets the DOE goal of less than 35 percent increase in COE.
- Co-sequestration (Case 4) has the second lowest COE at $82.02/MWh, 39 percent higher than that of the non-capture current technology case.
- Advanced membrane ASU boiler integration (Case 1) has the third lowest COE of $87.19/MWh, 48 percent higher than that of the non-capture current technology case.
- Advanced membrane NG integration, USC steam cycle, no recycle re-heat, advanced CO_2 compression, and reduced recycle (Cases 1A, 3, 5, 6, and 7) have about the same COE as the current oxycombustion technology case (all within 3 percent). Advanced membrane with the NG preheat system has a COE of $91.12/MWh, USC steam cycle has a COE of $89.31/MWh, the advanced recycle (no re-heat) has a COE of $91.03/MWh, the advanced CO_2 compression has a COE of $89.34/MWh, and the Advanced Boiler w/Reduced Recycle has a COE of $89.96/MWh. These are all comparable to the $91.07/MWh for the current technology case.
- While the shock compression equipment is expected to have a major decrease in cost per unit compression power, the required compression power for shock compression was found to be higher than conventional compression. The required increase in gross plant output to provide the additional compression power increases the plant TOC (excluding the compressor) offsetting the savings in the compressor TOC.

Exhibit 3-116 First Year Cost of Electricity

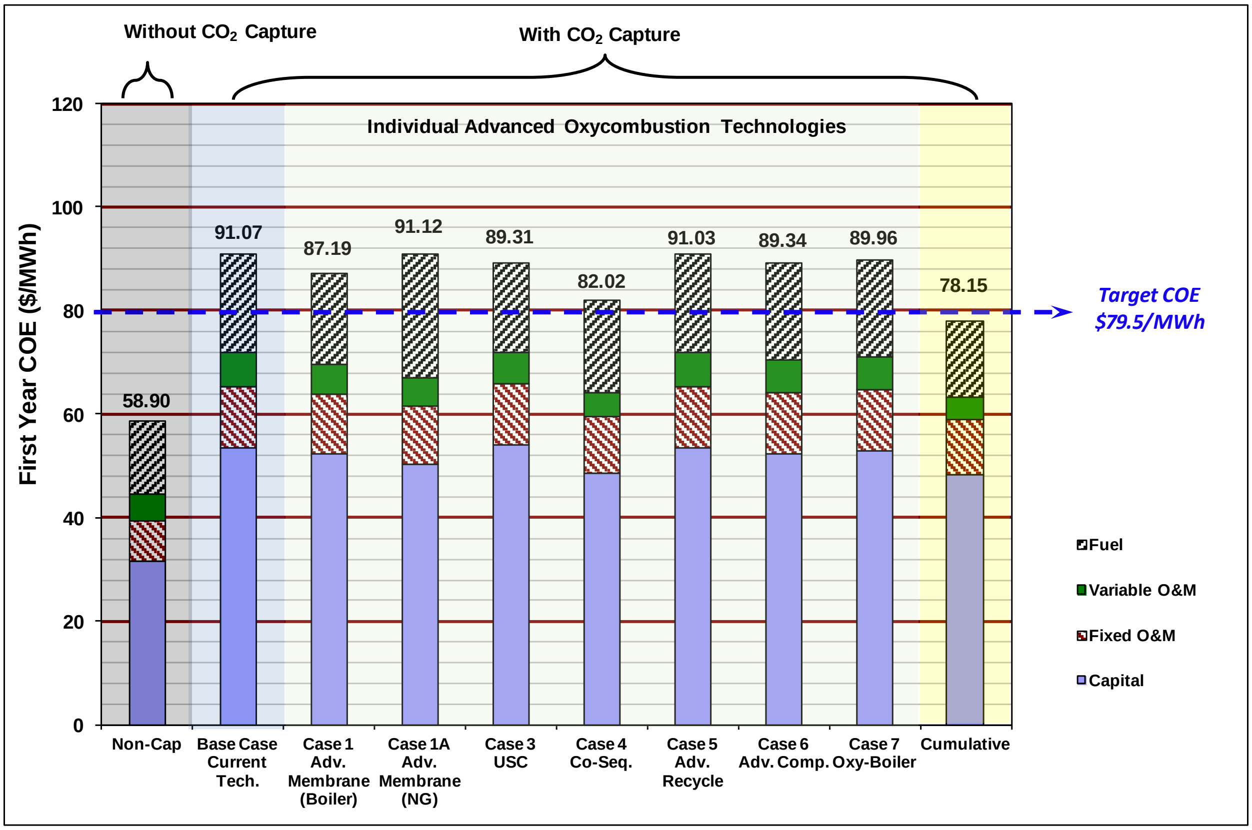


Exhibit 3-117 Increases in Cost of Electricity Over Non-Capture Reference Case

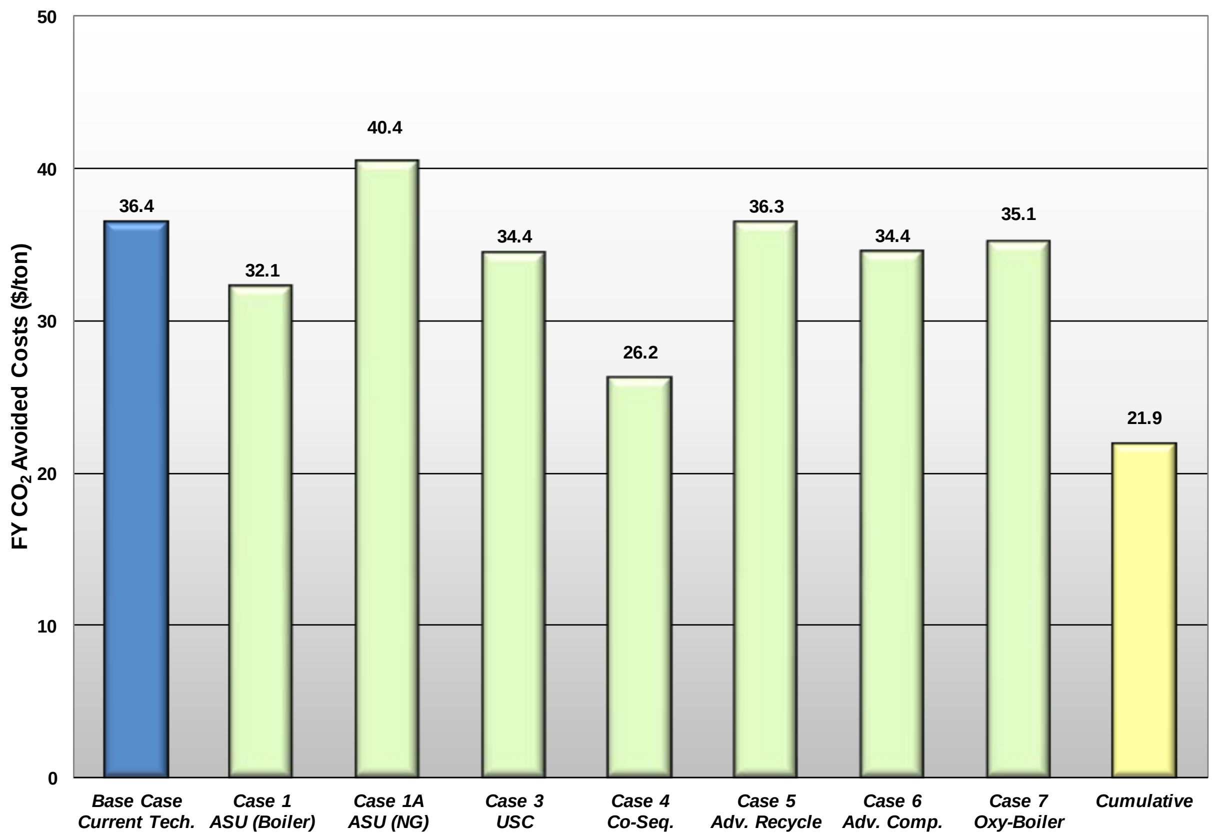
Study Case	First Year Cost of Electricity ($/MWh)						Increase in COE (%)[a]
	Capital	Fixed O&M	Variable O&M	Fuel	TS&M	Total (Less TS&M)	
Non-Capture Reference, Air-fired SC w/o CCS	31.68	7.97	5.03	14.22	0.00	58.90	-
Current OF Technology, O_2-fired SC w/ASU & CCS	53.72	11.81	6.47	19.08	5.83	91.07	54.6
Case 1, O_2-fired SC w/Boiler Adv. Membrane & CCS	52.35	11.53	5.99	17.32	5.60	87.19	48.0
Case 1A, O_2-fired SC w/NG Adv. Membrane & CCS	50.45	11.23	5.63	23.81	5.25	91.12	54.7
Case 3, O_2-fired USC w/ASU & CCS	54.15	11.81	6.10	17.25	5.58	89.31	51.6
Case 4, O_2-fired SC w/ASU & Co-Sequestration	48.85	10.79	4.78	17.60	5.67	82.02	39.3
Case 5, O_2-fired SC w/ASU, Wet Recycle & CCS	53.66	11.80	6.47	19.11	5.91	91.03	54.5
Case 6 O_2-fired SC w/ASU & Shock Compression	52.59	11.60	6.34	18.81	5.87	89.34	51.7
Case 7, O_2-fired SC w/ASU, Adv. Boiler & CCS	53.13	11.65	6.32	18.87	5.89	89.96	52.7
Cumulative Technology Case	**48.52**	**10.66**	**4.30**	**14.68**	**5.28**	**78.15**	**32.7**

[a]Relative to non-capture reference case

Cost of CO_2 Avoided

The cost of CO_2 avoided for each case is shown in Exhibit 3-118. The exhibit was produced using the equation presented in Section 2.6.3 and represents the cost of CO_2 avoided relative to a SC air-fired PC plant with no CO_2 capture. The CO_2 avoided cost trends are similar to the COE trends as noted above. This is a result of relatively consistent CO_2 emissions between the cases and the capital intensive nature of the technologies. Both COE and CO_2 avoided costs track closely to the technology capital costs. The natural gas-based advanced membrane ASU case (Case 1A) has the highest cost of CO_2 avoided of all the cases at \$44/tonne (\$40/ton). This is due to the CO_2 emissions (less CO_2 captured) resulting from venting natural-gas-generated CO_2 in the ASU process. The lowest cost of CO_2 avoided results from the cumulative technology case and is \$24/tonne (\$22/ton).

Exhibit 3-118 Cost of CO_2 Avoided Over Non-Capture Reference Case



3.11 RECOMMENDATIONS FOR FUTURE RESEARCH

The results of this report suggest that both cost and performance improvements need to be made in multiple technologies applicable to the oxycombustion pathway for CO_2 capture if the DOE capture goal is to be met. Not all of the advanced technologies were found to have equivalent cost or performance improvements. In the interest of allocating R&D funding in the most cost-effective manner, future research should be conducted in the areas that provide the most opportunity for improvement.

This section discusses the major conclusions of this study regarding how future research and development should focus on developing oxycombustion-specific technologies for the most beneficial improvements in performance and cost. Based on the results of this study, improvements in the following technologies should have the largest positive impact on oxycombustion:

- **Oxygen Supply**: Advanced membrane-based air separation technology shows promise due to its high temperature and high pressure operation, which allows for a relatively high amount of heat and power recovery. Membrane system integration, membrane performance enhancements, and capital cost reduction should be the main areas of focus for this technology area based on the results of this study.
- **Sulfur-Tolerant Materials**: Research should be conducted to develop sulfur-tolerant materials to handle the recycled flue gas in systems with reduced flue gas desulfurization. It is understood that completely eliminating the FGD may not be possible in the near-term because of materials constraints and potential restrictions on sequestration, however if continual progress is made in these areas, system efficiency will continue to increase in proportion.
- **Oxycombustion Boilers**: As sulfur-tolerant materials are developed, smaller oxycombustion-based boiler designs with enhanced heat transfer may become more effective. Sulfur-tolerant materials will allow less recycle, less flue gas desulfurization requirements, and therefore higher efficiencies all while decreasing the boiler size, and potentially cost depending on the premium for exotic material.
- **Advanced Steam Conditions**: While not specific to oxycombustion, raising steam conditions in the Rankine cycle also has a beneficial effect on oxycombustion systems. Advancing steam conditions in the Rankine cycle can maximize the benefit of the potentially high temperatures of the oxycombustion process and should be taken into consideration when designing oxycombustion-specific boiler designs.

DOE's National Energy Technology Laboratory is currently funding multiple projects in all of the above categories.

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