Techno-economic Evaluation of Utility-Scale Power Plants Based on the Indirect sCO_2 Brayton Cycle

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LIST OF EXHIBITS

ACRONYMS AND ABBREVIATIONS

AACE	Association for the Advancement of Cost Engineering
Ar	Argon
Aspen	Aspen Plus®
ASU	Air separation unit
atm	Atmosphere (14.696 psi)
AUSC	Advanced ultra-supercritical
BEC	Bare erected cost
BFD	Block flow diagram
BFW	Boiler feed water
BOP	Balance of plant
Btu	British thermal unit
Btu/hr	British thermal units per hour
Btu/kWh	British thermal units per kilowatt hour
Btu/lb	British thermal units per pound
CCCMP	Clean Coal and Carbon Management Program
CCF	Capital charge factor
CCS	Carbon capture and sequestration
CF	Capacity factor
CFB	Circulating fluidized bed
CH_4	Methane
CM	Construction management
CO	Carbon monoxide
CO_2	Carbon dioxide
COE	Cost of electricity
COS	Carbonyl sulfide
CPU	CO_2 purification unit
DCF	Discounted cash flow
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy
EOR	Enhanced oil recovery
EPA	Environmental Protection Agency
EPC	Engineer/procure/construct
EPCM	Engineering/procurement/ construction management
FE	Fossil energy
FEED	Front-end engineering design
FG	Flue gas
FGD	Flue gas desulfurization
FO	Fuel oil
ft	Foot, Feet
gal	Gallon
GE	General Electric
gpm	Gallons per minute
Gt	Gigatonne
GW	Gigawatt
h, hr	Hour
H_2	Hydrogen
H_2O	Water
HHV	Higher heating value
H.O.	Home office
hp	Horsepower
HP	High pressure
HRSG	Heat recovery steam generator
HTR	High-temperature recuperator
I&C	Instrumentation and control
IC	Intercooler
ICR	Information Collection Request
ID	Induced draft
IGCC	Integrated gasification combined cycle
IOU	Investor-owned utility
IP	Intermediate pressure
IRROE	Internal rate of return on equity
Kg/m^3	Kilogram per square meter
kJ/kg	Kilojoule per kilogram
km	Kilometer
kW, kWe	Kilowatt electric
kWh	Kilowatt-hour
kWt	Kilowatt thermal
lb	Pound
lb/hr	Pounds per hour
LHV	Lower heating value
LMTD	Log mean temperature difference
LP	Low pressure
LTR	Low-temperature recuperator
m	Meter
M	Thousand
m^3/min	Square meter per minute

MAC	Main air compressor
MAF	Moisture and ash free
MESA	Mission Execution and Strategic Analysis
MM	Million
MMBtu	Million British thermal units
MMBtu/hr	Million British thermal units per hour
MPa	Megapascal
MVA	Monitoring, verification, and accounting
MW, MWe	Megawatt electric
MWh	Megawatt-hour
N_2	Nitrogen
N_2O	Nitrous oxide
NE	Nuclear Energy
Neg.	Negligible
NETL	National Energy Technology Laboratory
NOx	Oxides of nitrogen
O_2	Oxygen
O&M	Operation and maintenance
PA	Primary air
PC	Pulverized coal
PO	Primary oxidant
POTW	Publicly owned treatment works
ppm	Parts per million
ppmv	Parts per million volume
PSFM	Power Systems Financial Model
psi	Pounds per square inch
psia	Pound per square inch absolute
psig	Pound per square inch gage
QGESS	Quality Guidelines for Energy Systems Studies
R&D	Research and development
RD&D	Research, development, and demonstration
Rht	Reheat
ROM	Reduced order model
SC	Supercritical
sCO_2	Supercritical carbon dioxide
SCR	Selective catalytic reduction
SO_2	Sulfur dioxide
SOx	Oxides of sulfur
T&S	Transport and storage
TASC	Total as-spent cost
TEA	Techno-economic evaluation
TG	Turbine generator
TIT	Turbine inlet temperature
TOC	Total overnight cost
tonne	Metric ton (1,000 kg)
TPC	Total plant cost
TRL	Technology Readiness Level
U.S.	United States
V-L	Vapor liquid portion of stream (excluding solids)
vol%	Volume percent
VTR	Very high-temperature recuperator
WGS	Water gas shift
Wh/lb	Watt-hours per pound
$/MMBtu	Dollars per million British thermal units
$K	Thousands of dollars
$M, $MM	Millions of dollars
°C	Degrees Celsius
°F	Degrees Fahrenheit

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EXECUTIVE SUMMARY

This report presents the results of a techno-economic analysis (TEA) of a coal-fired utility scale power plant based on the indirect supercritical carbon dioxide (sCO_2) Brayton cycle using an oxy-fired circulating fluidized bed (CFB). A baseline plant configuration was examined as well as three variations to the sCO_2 power cycle examining the impact of reheat (Rht), main compressor intercooling (IC), and a combination of reheat and main compressor intercooling (RhtIC). Each plant configuration was assessed at two turbine inlet temperatures of 620 °C and 760 °C.

Exhibit ES-1 shows the results for the overall process efficiency (higher heating value (HHV) basis) and cost of electricity (COE) without transportation and storage for the cases including reference Rankine plants at commensurate turbine inlet temperatures.

Exhibit ES-1 Overall process efficiency and first-year COE

	Turbine Inlet Temperature 620 °C					Turbine Inlet Temperature 760 °C				
	Rankine	sCO_2				Rankine	sCO_2			
	SC	Baseline	Reheat	IC	RhtIC	AUSC	Baseline	Reheat	IC	RhtIC
Efficiency (% HHV)	33.6	34.7	36.2	35.3	36.8	36.9	39.5	40.8	39.9	41.2
COE w/o T&S ($/MWh)	125.7	128.2	126.0	124.7	123.0	123.2	120.0	120.8	117.8	118.5

The results show that increasing the turbine inlet temperature from 620 °C (1148 °F) to 760 °C (1400 °F) increases process efficiency by 4.4 to 4.8 percentage points. This result is consistent with prior sensitivity analyses on indirect sCO_2 cycle sensitivity to turbine inlet temperature. [1]

The use of reheat and main compressor intercooling, either singly or in combination, increases process efficiency moderately from 0.4 to 2.1 percentage points. The efficiency boost from reheat and main compressor intercooling is greater for the 620 °C cases than for the 760 °C cases. The increase in process efficiency is due to both an increase in the intrinsic efficiency of the sCO_2 cycle and an increase in the amount of recovered heat.

Regarding the economic analysis, a major goal of the study was to examine the impact of lowering the turbine inlet temperature from 760 °C to 620 °C on the estimated COE. Lowering the turbine inlet temperature has direct and secondary effects that act to both decrease and increase cost. A lower turbine inlet temperature acts to lower costs primarily through a reduction in CO_2 piping cost and a reduction in the duty of the high-temperature recuperator, whereas it acts to increase costs by reducing process efficiency leading to increased fuel costs, increasing sCO_2 flow rates in the power cycle leading to increased sCO_2 cycle equipment costs, and increasing balance of plant (BOP) costs. The above changes result in a net increase in the COE for the lower turbine inlet temperature cases.

In examining the impacts on plant economics relative to the baseline cases, the effect of reheat is to increase COE (slightly) for the 760 °C turbine inlet temperature case and decrease COE for the 620 °C turbine inlet temperature case, primarily due to the impact on piping costs. Intercooling the main CO_2 compressor decreases COE for both the 760 °C case and the 620 °C case. Finally, using reheat and main CO_2 compressor intercooling decreases COE for both the 760 °C turbine inlet temperature case and the 620 °C turbine inlet temperature case.

Several sensitivity analyses were performed to examine how variations in the operating state or capital cost estimates would impact the performance and economic results. The sensitivity to minimum recuperator temperature approach indicated that the value used in this study was economically attractive and that the minimum COE occurred at a minimum approach temperature of 4-5 °C. A detailed comparison of performance and cost was made for two runs of Case RhtIC760, one with a minimum temperature approach of 10 °F and the other with a minimum temperature approach of 10 °C.

The sensitivity analysis to flue gas recycle fraction indicated that the lower the recycle fraction, the higher the process efficiency and the lower the COE. However, operability constraints limit the maximum oxygen concentration in the bed and hence limit the minimum flue gas recycle fraction. A detailed economic comparison of performance was made for two runs of Case RhtIC760, one with a flue gas recycle fraction of 0.45 and the other with a flue gas recycle fraction of 0.715.

The sensitivity analysis to flue gas cooler duty indicated that the current state point is optimum with respect to this variable. The sensitivity to CO_2 cooler temperature suggested that significant improvements in cost and efficiency may be realized with lower cooler temperatures. Finally, the sensitivity analysis to capital cost quantified the effect of uncertainty in the capital cost estimate on the estimated COE.

The results of the sensitivity analyses lead to recommendations to further explore improvements in overall cost and performance by exploring the feasibility and benefits of a lower CO_2 cooler temperature and by possibly lowering the flue gas recycle fraction further. Since uncertainty in the cost and performance models for the oxy-fired CFB and the sCO_2 power cycle components is significantly greater than that for the BOP, it is recommended that more detailed engineering designs of this equipment be undertaken using state-of-the-art 3-D computational fluid dynamic modeling.

It is further recommended that systems analysis studies be performed on alternate process configurations than those investigated in this study and work in this area has already begun. A preliminary analysis for a cycle that extends Case RhtIC760 to include a condensing CO_2 section results in an efficiency of 41.9 percent HHV and 115.8 COE without T&S ($/MWh).

1 INTRODUCTION

The United States (U.S.) Department of Energy's (DOE) Clean Coal and Carbon Management Program (CCCMP) provides a worldwide leadership role in the development of advanced fossil fuel-based energy conversion technologies, with a focus on electric power generation with carbon capture and storage (CCS). As part of DOE's Office of Fossil Energy (FE), the National Energy Technology Laboratory (NETL) implements research, development, and demonstration (RD&D) programs that address the challenges of reducing greenhouse gas emissions. To meet these challenges, FE/NETL evaluates advanced power cycles that will maximize system efficiency and economic performance, while minimizing CO_2 emissions and the costs of CCS.

NETL is addressing supercritical carbon dioxide (sCO_2) indirect power cycle research and development (R&D) needs cooperatively with other DOE Offices (Nuclear Energy (NE), and Energy Efficiency and Renewable Energy (EERE)). NETL conducts R&D for indirect and direct cycles in-house and by working with motivated industrial/academic partners through NETL-administered financial assistance. Recent activities are aimed at developing equipment components (e.g., turbomachinery, recuperators, oxy-fuel combustors/boilers, materials) that both internal and external studies have identified as currently available only at low technical readiness levels (TRLs).

The indirect cycles that use sCO_2 in a closed loop as the working fluid have the advantage of using a wide range of thermal heat sources (e.g., nuclear, concentrated solar, fossil, waste heat). This results in the power plant design being dependent on the temperature of this thermal heat source with the overall efficiency usually increasing with temperature. System analysis studies by many research organizations including NETL have projected efficiency improvements of 2 – 6 percentage points when compared with Rankine cycles operating at similar process conditions. Direct cycles are based on incorporating fossil fuel combustion that heats a large flowrate of recirculating sCO_2, which acts as a diluent in a semi-closed cycle that removes the generated CO_2 for sequestration or for enhanced oil recovery (EOR). For these cycles, the range of operating parameters (temperature, pressure) can vary considerably compared to indirect cycles. An additional question for direct cycles that use coal-derived syngas is how to remove contaminants from the combustion process that occurs at high pressure and temperature conditions.

As part of NETL's systems analysis efforts, an earlier study provides a sensitivity analysis for the indirect sCO_2 recompression Brayton cycle for demonstrating and examining the potential benefits, which include the potential for higher efficiency, high-power density (more compact) equipment, reduced capital costs, and emissions reductions compared to steam based power cycles. [1] That study, based on a generic heat source, was used as the basis for the current work, integrating the recompression cycle with a coal-fueled oxy-combustion CFB at a nominal power plant size of 550 MWe. NETL has reviewed this type of system in an earlier funded program for which NETL suggested a number of revisions and improvements. [2]

The power plants in this study where modeled using Aspen Plus® (Aspen). A baseline case was developed with moderate temperature conditions of 1148 °F (620 °C) and aggressive temperature conditions of 1400 °F (760 °C) for the sCO_2 turbine expander inlet temperature. Additional cases are used to examine possible improvements to the baseline recompression cycle that include adding a reheat section, using main compressor intercooling, and a case that includes both modifications. The analysis included estimates of system performance and first-year cost of electricity (COE). All cases are compared to a reference oxy-combustion Rankine cycle at equivalent turbine inlet temperature.

2 Design Basis

The design bases from NETL's Bituminous Baseline Study [3] and Quality Guidelines for Energy System Studies (QGESS) series [4] [5] [6] were adopted so that the results from this study are consistent with established results.

The following paragraphs in this section describe environmental operating conditions, bituminous coal feedstock properties, water use, method of economic evaluation, and technology-specific descriptions of advanced technologies within DOE's R&D portfolio.

2.1 Site Characteristics

All plants in this study are assumed to be located at a generic plant site in the Midwestern United States, with ambient conditions and site characteristics as presented in Exhibit 2-1 and Exhibit 2-2.

Exhibit 2-1 Site ambient conditions

Parameter	Value
Elevation, (ft)	0
Barometric Pressure, MPa (psia)	0.10 (14.696)
Design Ambient Temperature, Dry Bulb, °C (°F)	15 (59)
Design Ambient Temperature, Wet Bulb, °C (°F)	11 (51.5)
Design Ambient Relative Humidity, %	60

Exhibit 2-2 Site characteristics

Parameter	Value
Location	Greenfield, Midwestern U.S.
Topography	Level
Size, acres	300
Transportation	Rail
Ash/Slag Disposal	Off Site
Water	Municipal (50%)/Groundwater (50%)
Access	Land locked, having access by rail and highway
CO_2 Transport and Storage	Compressed to 15.3 MPa (2,215 psia), transported 100 kilometers (62 miles) and stored in a representative saline formation in the Illinois Basin

The land area for all cases assumes that 30 acres are required for the plant proper; the balance provides a buffer of approximately 0.25 miles to the fence line. In all cases, the turbine is assumed to be enclosed in a turbine building. The circulating fluidized bed combustor in all cases is not enclosed. Other site-specific design parameters are not quantified for this study. Allowances for normal site access conditions and construction are included in the cost estimates.

2.2 Coal Characteristics

Coal properties from NETL's QGESS are shown in Exhibit 2-3 for the bituminous coal used in this study. [7]

Exhibit 2-3 Bituminous design coal analysis

Rank	Bituminous	
Seam	Illinois No. 6 (Herrin)	
Sample location	Franklin Co., Illinois	
Proximate analysis	**Dry basis, %**	**As received, %**
Moisture	0.0	11.12
Ash	10.91	9.70
Volatile matter	39.37	34.99
Fixed carbon	49.72	44.19
Total	100.00	100.00
Ultimate analysis	**Dry basis, %**	**As received, %**
Carbon	71.72	63.75
Hydrogen	5.06	4.50
Nitrogen	1.41	1.25
Sulfur	2.82	2.51
Chlorine	0.33	0.29
Ash	10.91	9.70
Moisture	0.00	11.12
Oxygen[1]	7.75	6.88
Total	100.00	100.00
Heating value	**Dry basis**	**As received**
HHV, kJ/kg	30,506	27,113
HHV, Btu/lb	13,126	11,666
LHV, kJ/kg	29,444	26,151
LHV, Btu/lb	12,712	11,252
Trace components (ppmd)		
Mercury[2]	0.150	-

[1] By difference
[2] Mercury value is the mean plus one standard deviation using the Environmental Protection Agency's (EPA) Information Collection Request (ICR) data

2.3 Raw Water Withdrawal and Consumption

A water balance was performed for each case based on the major water consumers in the process. The total water demand for each subsystem was determined, and internal recycle water available from various sources, such as boiler feedwater (BFW) blowdown and condensate from syngas, was applied to offset the water demand. The difference between demand and recycle is defined as raw water withdrawal. Raw water withdrawal represents the water removed from the ground or diverted from a surface water source for use in the plant. Raw water consumption is defined as the portion of raw water withdrawn that is evaporated, transpired, incorporated into products, or otherwise not returned to the water source from which it was withdrawn.

Raw water makeup is assumed to be provided 50 percent by a publicly owned treatment works (POTW) and 50 percent from groundwater.

2.4 Capacity Factor

This study assumes that each new plant would be dispatched any time it is available and could generate maximum capacity when online. Therefore, capacity factor and availability are equal. The capacity factor for all cases in this study was 85 percent.

The addition of CO_2 capture and other advanced technology to each case is assumed to have no impact on the capacity factor. This assumption was made to enable a comparison based on the impact of capital and variable operating costs only. Otherwise, any differences in anticipated availability between the conventional and advanced technology cases would impact the COE for the advanced technology cases and obfuscate the contribution due to performance and economics of the advanced technology under investigation.

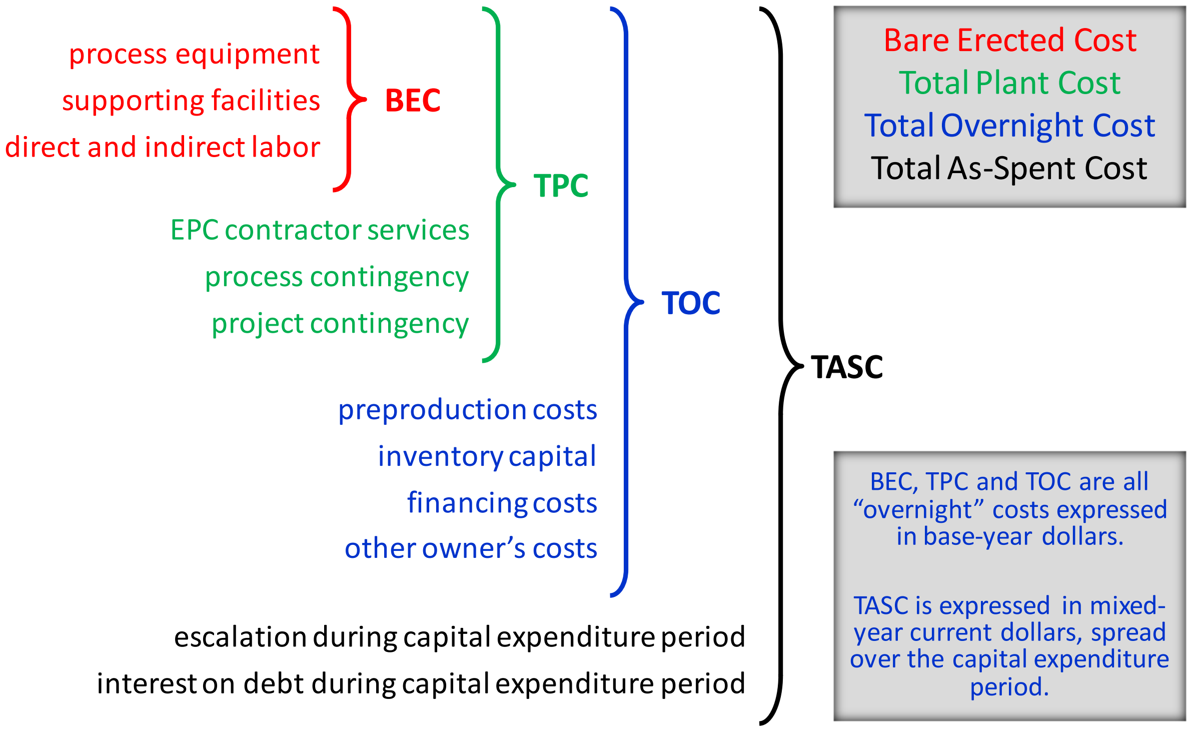
2.5 Cost Estimating Methodology

The estimating methodology for capital costs, operation and maintenance (O&M) costs, and CO_2 transport and storage (T&S) costs is described in the following sections. The finance structure, basis for the discounted cash flow analysis, and COE calculations are also summarized. Additional detail is available in NETL's QGESS series. [4] [5] [8]

2.5.1 Capital Costs

As illustrated in Exhibit 2-4, this study reports capital cost at four levels: Bare erected cost (BEC), total plant cost (TPC), total overnight cost (TOC) and total as-spent cost (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 2011. TASC is expressed in mixed-year, current-year dollars over the entire five-year capital expenditure period.

Exhibit 2-4 Capital cost levels and their elements



2.5.1.1 Cost Estimate Classification

As described in NETL's Bituminous Baseline Study, cost estimates for conventional configurations have an expected accuracy range of -15/+30 percent. This accuracy range is consistent with the low side of a "Feasibility Study" (association for the Advancement of Cost Engineering International [AACE] Class 4). [9] NETL's pathway studies and other advanced technology assessments typically would be classified at the high (or more variable) end of the accuracy range for a Feasibility Study (-15/+50 percent) or low end of the accuracy range for a "Concept Screening" (Class 5, -20/+100 percent). The accuracy range depends on several factors given that the advanced technology cost and performance are based on a variety of sources (projections from pilot scale or preliminary lab data or from R&D goals or targets with minimal project definition).

2.5.1.2 Technology Maturity

The cases examined in this study include technologies at different commercial maturity levels. As the purpose of this analysis is to assess the impact of successful R&D, and subsequent market adoption of the technology, the estimates represent fully demonstrated, well-developed commercial technology, or n^{th} of-a-kind plants.

2.5.1.3 Contracting Strategy

Cost estimates are based on an engineering/procurement/construction management (EPCM) approach utilizing multiple subcontracts. This approach provides the owner with greater control of the project while minimizing, if not eliminating, most of the risk premiums typically included in an engineer/procure/construct (EPC) contract price.

In a traditional lump sum EPC contract, the contractor assumes all risk for performance, schedule, and cost. However, as a result of current market conditions, EPC contractors appear reluctant to assume that overall level of risk. Rather, the current trend appears to be a modified EPC approach where much of the risk remains with the owner. Where contractors are willing to accept the risk in EPC type lump-sum arrangements, it is reflected in the project cost. In today's market, contractor premiums for accepting these risks, particularly performance risk, can be substantial and increase the overall project costs dramatically.

The EPCM approach that is used as the basis for cost estimates in this study is anticipated to be the most cost effective approach for the owner. While the owner retains the cost and technology risks, those risks reduce with time as scope is better defined at the time of contract award(s).

2.5.1.4 Estimate Scope

Cost estimates in this study represent a complete power plant facility located on a generic site. The plant boundary limit is defined as the total plant facility within the "fence line," including coal receiving and water supply system, and terminating at the high voltage side of the main power transformers. CO_2 T&S cost is not included in the reported capital cost or O&M costs, but is calculated separately and added to the COE.

2.5.1.5 Capital Cost Assumptions

Capital and O&M costs are estimated using cost algorithms consistent with a conceptual level scope definition, which incorporates the following: 1) NETL Bituminous Baseline Study costs (estimated by WorleyParsons), 2) literature and/or vendor supplied costs, and 3) R&D target costs for advanced technologies. Plant size, number of process trains, sparing philosophy, and as much equipment-specific design as possible are incorporated into the cost algorithms.

For NETL's Bituminous Baseline Study, WorleyParsons developed capital cost estimates for each plant using the company's in-house database and conceptual estimating models for each of the specific technologies. This database and the respective models are maintained by WorleyParsons as part of a commercial power plant design base of experience for similar equipment in the company's range of power and process projects. A reference bottoms-up estimate for each major component provides the basis for the estimating models.

2.5.1.6 Contingency

Process and project contingencies are included in cost 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.

Process contingency is intended to compensate for uncertainty in cost estimates caused by performance uncertainties associated with the development status of a technology. Process contingencies are applied to each equipment item or plant section based on its current technology development status.

AACE 16R-90 states that project contingency for a budget-type estimate (AACE Class 4 or 5) should be 15-30 percent of the sum of BEC, EPC fees, and process contingency. [9] This rule is used as a general guideline; however, some project contingency values occur below this range for very common, conventional technologies.

For consistency, process and project contingencies used in NETL's Bituminous Baseline Study form the basis for all major equipment in each plant section. As such, advanced technologies are assumed to embed expected costs in the BEC when the advanced technology costs are based on R&D goals or targets. Any bottoms-up cost estimates associated with advanced technologies include the appropriate level of contingency based on the completeness of the project definition and engineering before comparison is made to the R&D goals or targets used in this study for that advanced technology.

2.5.1.7 Owner's Costs

Exhibit 2-5 displays the method used to estimate owner's costs. Interest and escalation during construction are not included as owner's costs but are factored into the COE via the capital charge factor and are included in the TASC. Interest and escalation costs vary based on the capital expenditure period and the financing scenario.

2.5.2 O&M Costs

The operating costs and related maintenance expenses pertain to those charges associated with operating and maintaining a power plant over its expected life. There are two components to O&M costs: fixed O&M, which is independent of operating hours of power generation, and variable O&M, which is proportional to power generation.

2.5.2.1 Fixed O&M Costs

Fixed O&M costs are constant and are incurred whether or not the power plant is operating at any point in time. Fixed O&M costs are essentially a function of TPC.

- Operating Labor - The average base labor rate used to calculate annual labor cost is $39.70/hour. The associated labor burden is estimated at 30 percent of the base labor rate.
- Maintenance Labor - Maintenance labor cost is evaluated based on relationships of maintenance cost to initial capital cost.
- Labor administration and Overhead Charges – These are assessed at a rate of 25 percent of the burdened O&M labor.
- Property Taxes and Insurance - Property taxes and insurance are assumed at 2 percent of the TPC.

Exhibit 2-5 Owner's costs included in TOC

Owner's Cost	Estimate Basis
Preproduction (Start-Up) Costs	• 6 months operating labor • 1 month maintenance materials at full capacity • 1 month non-fuel consumables at full capacity • 1 month waste disposal • 25% of one month's fuel cost at full capacity • 2% of TPC
Inventory Capital	• 0.5% of TPC for spare parts • 60-day supply (at full capacity) of fuel. Not applicable for natural gas • 60-day supply (at full capacity) of non-fuel consumables (e.g., chemicals and catalysts) that are stored on site. Does not include catalysts and adsorbents that are batch replacements; such as 1) water gas shift (WGS), carbonyl sulfide (COS), and selective catalytic reduction (SCR) catalysts; and 2) activated carbon
Land	• $3,000/acre (300 acres for CFB)
Financing Cost	• 2.7% of TPC
Other Owner's Costs	• 15% of TPC Significant deviation from this value is possible, because it is very site and owner specific. The lumped cost includes: - Preliminary feasibility studies, including a front-end engineering design (FEED) study - Economic development (costs for incentivizing local collaboration and support) - Construction and/or improvement of roads and/or railroad spurs outside of site boundary - Legal fees - Permitting costs - Owner's engineering - Owner's contingency

2.5.2.2 Variable O&M Costs

Variable O&M costs used in this study are summarized in Exhibit 2-6 below.

Exhibit 2-6 Variable O&M parameters

Item	June 2011 Cost Basis
Bituminous Coal, $/MMBtu	2.9376
Bituminous Coal, $/ton	68.54
Water from POTW, $/1000 gal	1.67
Water Treatment Chemicals, $/lb	0.27
Activated Carbon, $/lb	1.63
COS Catalyst, $/m^3	3,751.70
Water Gas Shift Catalyst, $/ft^3	771.99
Selexol Solvent, $/gal	36.79
Claus Catalyst, $/ft^3	203.15
Trona, $/ton	154.80
Spent Mercury Catalyst Disposal, $/lb	0.65
Slag Disposal, $/ton	25.11
Sulfur Sales, $/ton	0

Consumables and Waste Disposal. The cost of consumables (including fuel) and waste disposal is determined based on individual rates of consumption/production, the unit cost of each specific commodity, and the plant annual operating hours.

Co-products and By-products. By-product quantities are determined in a manner like the consumables. However, due to the variable marketability of these by-products, no credit is taken for their potential salable value.

Maintenance Materials. Maintenance material cost is evaluated as a function of initial capital cost.

2.5.3 CO_2 Transport and Storage Costs

The cost of CO_2 T&S in a deep well saline formation is estimated using NETL's CO_2 Saline Storage Cost Model. Additional detail on development of these costs is available in the QGESS on Carbon Dioxide Transport and Storage Costs. [6]

CO_2 T&S costs are reported as first-year costs in $/tonne of CO_2, increasing at a nominal rate of 3 percent per year, consistent with the assumed general inflation rate. From the perspective of the CO_2 source (e.g., a power plant or other energy conversion facility), these costs are treated as a disposal cost for each tonne of CO_2 captured during the assumed 30-year operational period. From the pipeline and storage site's perspective, this cost represents the required revenue stream across the 30-year operational period to cover all costs and provide the required internal rate of return on equity (IRROE). All costs are reported in 2011 dollars to facilitate comparisons with other existing NETL studies.

CO_2 transport costs are based on a maximum daily flowrate of 11,000 tonnes/day through a generic 100 km (62 mile) dedicated pipeline. High-pressure (2,200 psig) CO_2 is provided at the plant gate of the energy conversion facility, and CO_2 exits the pipeline terminus at a pressure of 1,200 psig, remaining in a supercritical phase. The 12-inch pipe diameter is sized for transport using one boost recompression stage along the pipeline length. Transport costs are estimated to be $2.24/tonne CO_2.

Storage costs are based on NETL's CO_2 Saline Storage Cost Model. This model provides detailed cost estimates for the injection and monitoring of CO_2 under U.S. Environmental Protection Agency (EPA) regulations for Class VI injection wells, as well as monitoring and reporting requirements under Subpart RR of the Greenhouse Gas Reporting Rule.

Inputs to the CO_2 Saline Storage Cost Model that have a significant influence on cost include financial parameters, timelines for various stages of storage, and important activities that occur in each stage. The financial parameters include:

- Debt-to-equity ratio: 45 percent/55 percent
- Nominal interest rate on debt: 5.5 percent/year
- Nominal IRROE: 12 percent
- Escalation rate: 3 percent
- A list of financial responsibility requirements for post-injection site care and site closure, which are met by pre-funding a modified trust fund over the period of injection operations
- Project contingency factor of 15 percent and process contingency factor of 20 percent

In the CO_2 Saline Storage Cost Model, the sequestration process is divided into six stages. The timelines and important activities impacting costs for these stages are as follows:

- Regional evaluation and initial site selection: 1 year
- Site characterization: 3 years; four sites undergo site characterization with one successful site selected; pore space rights are leased
- Permitting: 2 years; drill, test, and complete injection wells
- Operations: 30 years; installation of buildings, surface equipment, monitoring wells, and other monitoring equipment; comply with permit requirements; fund modified trust fund to cover financial responsibility requirements for post-injection site care and site closure
- Post-injection site care and site closure: 50 years; continue monitoring, verification, and accounting (MVA) per permit; costs are covered by storage site operator's trust fund

- Long-term stewardship: This stage is not explicitly included in the model. The possible financial implication of long-term stewardship is included in the model as a state-sponsored trust fund that the storage operator pays into during operations

Due to variances in the geologic formations that make up saline formations across the United States, region-specific storage and monitoring costs correspond to the plant locations used in NETL techno-economic studies of energy conversion facilities. Results from the CO_2 Saline Storage Cost Model for storage and monitoring costs are aligned with NETL studies by overlaying four generic plant locations with possible sequestration basins from the cost model, resulting in the following pairings:

- Midwest plant location – Illinois Basin
- Texas plant location – East Texas Basin
- North Dakota plant location – Williston Basin
- Montana plant location – Powder River Basin

CO_2 storage supply-cost curves were developed for each of the four basins of interest with the resulting cost for each basin at 25 gigatonnes (Gt) of potential storage, shown in Exhibit 2-7. Choosing this point on the supply-cost curves provides a conservative estimate of the storage cost since many decades, if not more than a century, will pass before 25 Gt of CO_2 is stored in any of the four individual basins. For example, 25 Gt of storage would be sufficient for 125 GW of coal power with 90 percent CO_2 capture operating over 30 years.

The far-right column of Exhibit 2-7 shows the total T&S costs that are currently used in NETL system studies for each plant location. The “Midwest” location was used in this study.

Exhibit 2-7 CO_2 T&S costs

Plant Location	Basin	Transport (2011$/tonne)	Base Case Storage (2011$/tonne)	T&S Value for System Studies[1] (2011$/tonne)
Midwest	Illinois	2.24	8.69	11
Texas	East Texas		8.83	11
North Dakota	Williston		13.95	16
Montana	Powder River		21.81	24

[1]The sum of T&S costs is rounded to the nearest whole dollar

2.5.4 Finance Structure, Discounted Cash Flow Analysis, and COE

Global economic assumptions are listed in Exhibit 2-8. Finance structures were chosen based on the assumed type of developer/owner (investor-owned utility (IOU) or independent power producer) and the assumed risk profile of the plant being assessed (low-risk or high-risk) (shown in Exhibit 2-9). For this study, the owner/developer is assumed to be an IOU. All circulating fluidized bed (CFB) cases are considered high risk.

Exhibit 2-8 Global economic assumptions

Parameter	Value
Taxes	
Income Tax Rate	38% (Effective 34% Federal, 6% State)
Capital Depreciation	20 years, 150% declining balance
Investment Tax Credit	0%
Tax Holiday	0 years
Contracting and Financing Terms	
Contracting Strategy	EPCM (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%
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%
Escalation of Operating Revenues and Costs	
Escalation of COE (revenue), O&M Costs, and Fuel Costs (nominal annual rate)	3.0%

Exhibit 2-9 Financial structure for IOU high-risk and conventional projects

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

2.5.4.1 Discounted Cash Flow Analysis and Cost of Electricity

NETL's Power Systems Financial Model (PSFM) is a nominal-dollar (current dollar) discounted cash flow (DCF) analysis tool. COE is the revenue received by the generator per net MWh during the power plant's first year of operation, *if 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*. To calculate COE, the PSFM can be used to determine a base-year (2011) COE that, when escalated at an assumed nominal annual general inflation rate of 3 percent, provides the stipulated IRROE over the entire economic analysis period (capital expenditure period plus 30 years of operation).

2.5.4.2 Estimating COE with Capital Charge Factors

For scenarios that adhere to the global economic assumptions listed in Exhibit 2-8, and utilize one of the finance structures listed in Exhibit 2-9, the following simplified equation (Equation 1) can be used to estimate COE as a function of TOC, fixed O&M, variable O&M (including fuel), capacity factor, and net power output.

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

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

Eq. 1

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*), if 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 2-10 that matches the applicable finance structure and capital expenditure period

TOC = total overnight cost, *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 equation requires the application of one of the capital charge factors (CCF) listed in Exhibit 2-10. These CCFs are valid only for the global economic assumptions listed in Exhibit 2-8, the stated finance structure, and the stated capital expenditure period.

Exhibit 2-10 Capital charge factors for COE equation

Finance Structure	High-Risk IOU	Conventional IOU
Capital Charge Factor (CCF)	0.124	0.116
5-Year TASC Multiplier	1.140	1.134

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 2011. As shown in Exhibit 2-8, all factors (COE, O&M, and fuel) are assumed to escalate at a nominal annual general inflation rate of 3.0 percent. Accordingly, all first-year costs (COE and O&M) are equivalent to base-year costs when expressed in base-year (2011) dollars.

2.5.5 Cost of CO_2 Captured and Cost of CO_2 Avoided Summary

The cost of CO_2 captured represents the minimum CO_2 plant gate sales price that will incentivize carbon capture in lieu of a defined reference non-capture plant. The COE of the carbon capture plant includes compression to 2,200 psig, but excludes T&S costs. The cost of CO_2 captured is calculated using Equation 2:

$$Cost\ of\ CO_2\ Captured = \frac{\{COE_{withoutT\&S} - COE_{reference}\}\ \$/MWh}{\{CO_2\ Captured_{with\ removal}\}\ tonnes/MWh} \qquad \textit{Eq. 2}$$

The cost of avoiding CO_2 emissions represents the minimum CO_2 emissions penalty that will incentivize carbon capture in lieu of a defined reference non-capture plant. The COE of the carbon capture plant includes compression to 2,200 psig and CO_2 T&S costs. The first-year cost of CO_2 avoided is calculated using Equation 3:

$$Avoided\ Cost = \frac{\{COE_{with\ T\&S} - COE_{reference}\}\ \$/MWh}{\{CO_2\ Emissions_{reference} - CO_2\ Emissions_{with\ removal}\}\ tonnes/MWh}$$

Eq. 3

The costs of CO_2 captured and avoided are calculated using both Greenfield and Advanced Greenfield reference plants. [10] When calculating the Advanced Greenfield reference plant, both the integrated gasification combined cycle (IGCC) carbon capture plant and the advanced (ultra supercritical pulverized coal (PC)) reference plant use the conventional (low-risk) finance structure identified in Exhibit 2-10. Reference plant metrics are provided below in Exhibit 2-11.

Exhibit 2-11 Common reference plants for CO_2 cost calculations

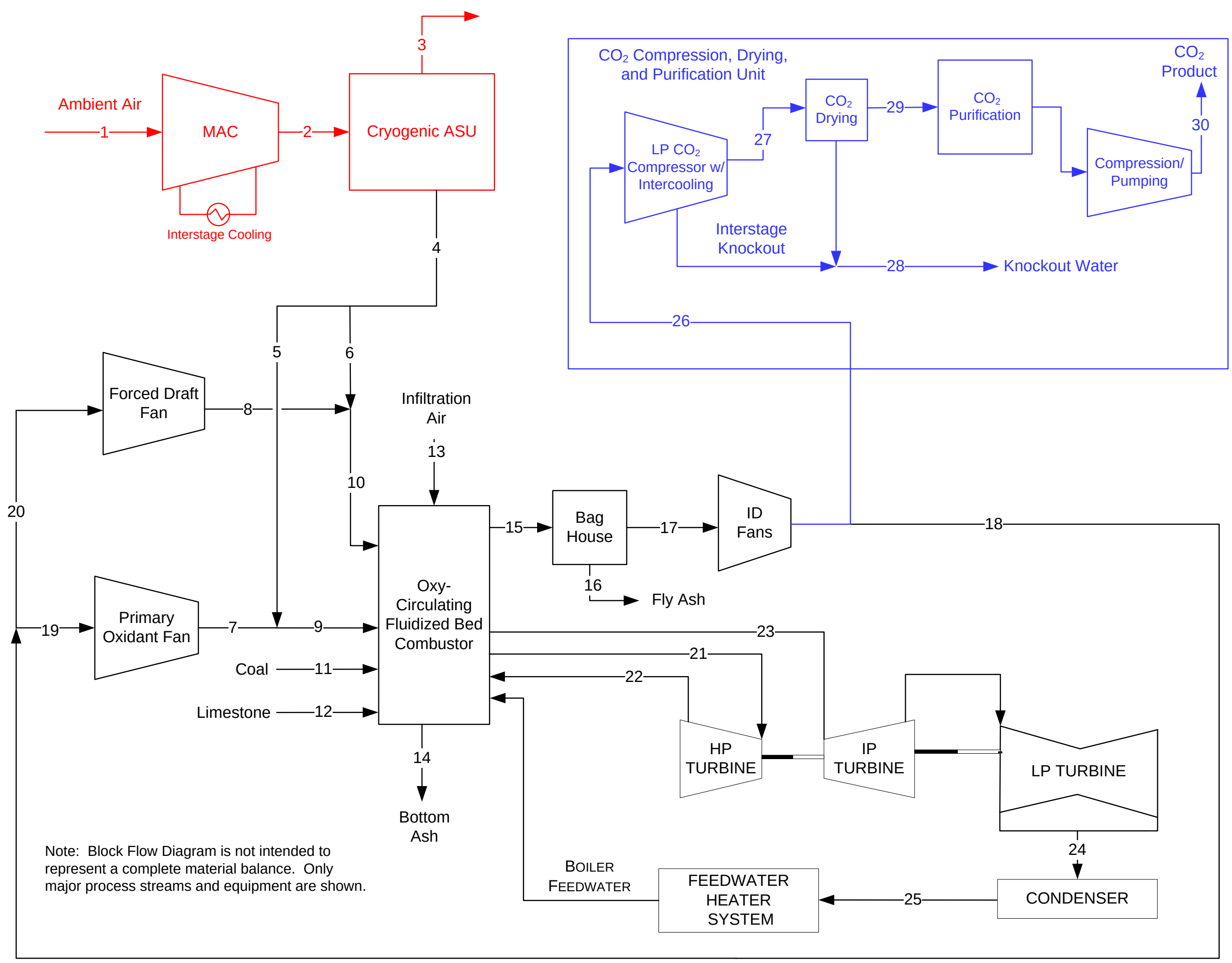
Reference Plant	Technology	COE ($/MWh)	CO_2 Emissions (tonnes/MWh)
Greenfield	Supercritical PC	81.0	0.802
Advanced Greenfield	Ultra-supercritical PC	75.1	0.741

3 Case Descriptions and Performance Results

3.1 Reference Oxy-Coal-Fired SC Rankine Case

Exhibit 3-1 shows a block flow diagram (BFD) for the oxy-coal-fired supercritical (SC) Rankine power plant. [11] The oxy-CFB plant has a net plant output of 550 MW and an overall higher heating value (HHV) plant efficiency of 33.6 percent. A cryogenic air separation unit (ASU) supplies the O_2 (95 mole percent O_2) required to combust coal in the CFB combustor, which generates the supercritical steam that drives a steam generator to produce electric power. Limestone is injected into the CFB combustor bed to remove sulfur present in the coal. A combination of solids recycle rate and single-pass carbon conversion is used to maximize the overall carbon conversion in the CFB. A high solids recycle rate is used to give an overall carbon conversion of ~99 percent. The CFB heat loss is assumed to be 1 percent of the thermal input of the coal.

Exhibit 3-1 Reference oxy-coal-fired SC Rankine power plant



Source: NETL

The flue gas from the CFB combustor passes through a bag house to remove particulate matter and is split into two streams. A portion of the flue gas stream (45 percent) is recirculated to the CFB to maintain CFB operating temperature of 1,600 °F and the remaining exhaust flue gas is sent to the CO_2 purification unit (CPU). The CPU purifies the CO_2 product stream to obtain a CO_2 purity of 95 percent or greater, and a maximum O_2 content of 10 ppmv to comply with EOR O_2 content specification. The CPU also compresses the CO_2 to a pressure of 2,200 psi. The feed to the plant is Illinois No. 6 coal. A single reheat Rankine SC steam cycle at steam conditions: 3,500 psig/1,110 °F/ 1,150 °F (24.1MPa/ 599 °C/ 621 °C) is used to generate power.

3.1.1 Reference SC Rankine Case Performance Results

The Reference SC Rankine Case produces a net output of 550 MW at a net plant efficiency of 33.6 percent (HHV basis). The stream tables that correspond to the block flow diagram in Exhibit 3-1 are shown in Exhibit 3-2. Overall plant performance is summarized in Exhibit 3-3, and a detailed breakdown of auxiliary power requirements is provided in Exhibit 3-4.

Exhibit 3-2 Reference SC Rankine Case stream table results

Stream	1	2	3	4	5	6	7	8	9	10
V-L Mole Fraction										
Ar	0.0092	0.0092	0.0024	0.0340	0.0340	0.0340	0.0309	0.0309	0.0325	0.0325
CO_2	0.0005	0.0005	0.0006	0.0000	0.0000	0.0000	0.7123	0.7123	0.3424	0.3424
H_2	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	0.1516	0.1516	0.0729	0.0729
N_2	0.7729	0.7729	0.9778	0.0162	0.0162	0.0162	0.0858	0.0858	0.0497	0.0497
O_2	0.2074	0.2074	0.0063	0.9498	0.9498	0.9498	0.0190	0.0190	0.5024	0.5024
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002
Total	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)	67,527	67,527	53,134	14,393	3,382	11,010	3,130	10,189	6,512	21,199
V-L Flowrate (kg/hr)	1,948,566	1,948,566	1,485,051	463,514	108,926	354,588	120,026	390,723	228,952	745,311
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	24	17	13	13	13	67	61	44	43
Pressure (MPa, abs)	0.10	0.59	0.10	0.16	0.16	0.16	0.11	0.11	0.11	0.11
Enthalpy (kJ/kg)[A]	30.57	32.00	38.64	11.49	10.99	10.99	239.11	233.63	130.58	127.71
Density (kg/m^3)	1.2	7.0	1.2	2.2	2.2	2.2	1.5	1.5	1.5	1.4
V-L Molecular Weight	28.856	28.856	27.949	32.205	32.205	32.205	38.349	38.349	35.158	35.158
V-L Flowrate (lb_{mol}/hr)	148,872	148,872	117,142	31,730	7,457	24,274	6,900	22,462	14,357	46,736
V-L Flowrate (lb/hr)	4,295,852	4,295,852	3,273,977	1,021,874	240,140	781,734	264,612	861,397	504,753	1,643,131
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	75	63	55	55	55	152	142	112	109
Pressure (psia)	14.7	86.1	14.7	23.2	23.2	23.2	16.2	15.3	16.2	15.3
Enthalpy (Btu/lb)[A]	13.1	13.8	16.6	4.9	4.7	4.7	102.8	100.4	56.1	54.9
Density (lb/ft^3)	0.076	0.435	0.073	0.135	0.136	0.136	0.095	0.091	0.093	0.089
	A - Reference conditions are 32.02 F & 0.089 PSIA									
Enthalpy (Btu/lb)	-43.5	-42.9	-54.7	-4.7	-5.0	-5.0	-3,538.2	-3,540.6	-1,857.2	-1,858.5

[A] - Steam Table Reference conditions are 32.02°F and 0.089 psia
* - AspenPlus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm

Exhibit 3-2 Reference SC Rankine Case stream table results (continued)

Stream	11	12	13	14	15	16	17	18	19	20
V-L Mole Fraction										
Ar	0.0000	0.0000	0.0092	0.0000	0.0277	0.0000	0.0277	0.0309	0.0309	0.0309
CO_2	0.0000	0.0000	0.0005	0.0000	0.6393	0.0000	0.6393	0.7123	0.7123	0.7123
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0101	0.0000	0.2386	0.0000	0.2386	0.1516	0.1516	0.1516
N_2	0.0000	0.0000	0.7729	0.0000	0.0770	0.0000	0.0770	0.0858	0.0858	0.0858
O_2	0.0000	0.0000	0.2074	0.0000	0.0171	0.0000	0.0171	0.0190	0.0190	0.0190
SO_2	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0004	0.0004	0.0004
Total	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	0	1,351	0	32,979	0	32,979	13,318	3,130	10,189
V-L Flowrate (kg/hr)	0	0	38,971	0	1,195,937	0	1,195,937	510,749	120,026	390,723
Solids Flowrate (kg/hr)	216,944	52,157	0	84,429	2,001	2,001	0	0	0	0
Temperature (°C)	15	15	15	15	127	15	127	57	57	57
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)^A	---	---	30.57	---	416.76	---	422.74	230.18	230.18	230.18
Density (kg/m^3)	---	---	1.2	---	1.1	---	1.1	1.4	1.4	1.4
V-L Molecular Weight	---	---	28.856	---	36.264	---	36.264	38.349	38.349	38.349
V-L Flowrate (lb_{mol}/hr)	0	0	2,977	0	72,706	0	72,706	29,362	6,900	22,462
V-L Flowrate (lb/hr)	0	0	85,917	0	2,636,590	0	2,636,590	1,126,009	264,612	861,397
Solids Flowrate (lb/hr)	478,280	114,987	0	186,134	4,411	4,411	0	0	0	0
Temperature (°F)	59	59	59	59	260	59	260	135	135	135
Pressure (psia)	14.7	14.7	14.7	14.7	14.4	14.7	14.2	14.8	14.7	14.7
Enthalpy (Btu/lb)^A	---	---	13.1	---	179.2	---	181.7	99.0	99.0	99.0
Density (lb/ft^3)	---	---	0.076	---	0.068	---	0.067	0.089	0.089	0.089
Enthalpy (Btu/lb)	-910.1	-5,421.0	-43.5	-3,909.4	-3,626.2	-5,209.5	-3,623.6	-3,542.1	-3,542.1	-3,542.1

Exhibit 3-2 Reference SC Rankine Case stream table results (continued)

Stream	21	22	23	24	25	26	27	28	29	30
V-L Mole Fraction										
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0309	0.0363	0.0000	0.0364	0.0000
CO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.7123	0.8375	0.0000	0.8400	1.0000
H_2	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	1.0000	1.0000	1.0000	0.1516	0.0025	0.9977	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0858	0.1009	0.0000	0.1012	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0190	0.0224	0.0000	0.0224	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0023	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
V-L Flowrate (kg_{mol}/hr)	110,594	92,457	92,457	82,899	83,120	16,278	13,845	2,474	13,804	10,723
V-L Flowrate (kg/hr)	1,992,377	1,665,640	1,665,640	1,493,452	1,497,436	624,249	580,419	44,831	579,418	471,909
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	593	342	593	38	39	57	38	38	38	37
Pressure (MPa, abs)	24.23	4.90	4.80	0.01	1.80	0.10	3.00	0.10	3.00	15.27
Enthalpy (kJ/kg)[A]	3,469.01	3,040.88	3,643.41	160.75	161.42	230.18	9.60	157.59	6.95	-206.54
Density (kg/m^3)	69.2	19.2	12.3	0.1	993.5	1.4	55.4	431.6	55.5	536.7
V-L Molecular Weight	18.015	18.015	18.015	18.015	18.015	38.349	41.922	18.122	41.974	44.010
V-L Flowrate (lb_{mol}/hr)	243,817	203,833	203,833	182,761	183,249	35,887	30,524	5,454	30,433	23,640
V-L Flowrate (lb/hr)	4,392,440	3,672,108	3,672,108	3,292,497	3,301,282	1,376,233	1,279,605	98,834	1,277,399	1,040,382
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	1,100	648	1,100	101	101	135	100	100	100	99
Pressure (psia)	3,514.7	710.8	696.6	1.0	261.6	14.8	435.1	14.8	435.1	2,215.0
Enthalpy (Btu/lb)[A]	1,491.4	1,307.3	1,566.4	69.1	69.4	99.0	4.1	67.8	3.0	-88.8
Density (lb/ft^3)	4.319	1.197	0.768	0.004	62.022	0.089	3.460	26.946	3.462	33.507
Enthalpy (Btu/lb)	-5,375.0	-5,559.1	-5,300.1	-6,019.5	-6,800.2	-3,542.1	-3,393.4	-6,802.4	-3,391.6	-3,941.8

Exhibit 3-3 Reference SC Rankine Case plant performance summary

Performance Summary	B22F
Total Gross Power, MWe	**721**
CPU (Purification and Compression) Auxiliaries, kWe	60,220
Balance of Plant, kWe	110,734
Total Auxiliaries, MWe	**171**
Net Power, MWe	**550**
HHV Net Plant Efficiency (%)	33.6%
HHV Net Plant Heat Rate, kJ/kWh (Btu/kWh)	10,702 (10,144)
LHV Net Plant Efficiency (%)	34.9%
LHV Net Plant Heat Rate, kJ/kWh (Btu/kWh)	10,323 (9,784)
HHV Boiler Efficiency, %	91.8%
LHV Boiler Efficiency, %	95.2%
Steam Turbine Cycle Efficiency, %	48.3%
Steam Turbine Heat Rate, kJ/kWh (Btu/kWh)	7,457 (7,068)
Condenser Duty, GJ/hr (MMBtu/hr)	2,715 (2,573)
As-Received Coal Feed, kg/hr (lb/hr)	216,944 (478,280)
Limestone Sorbent Feed, kg/hr (lb/hr)	52,157 (114,987)
HHV Thermal Input, kWt	1,635,225
LHV Thermal Input, kWt	1,577,195
Raw Water Withdrawal, $(m^3/min)/MW_{net}$ (gpm/MW_{net})	0.058 (15.3)
Raw Water Consumption, $(m^3/min)/MW_{net}$ (gpm/MW_{net})	0.044 (11.7)
O_2 Mole Percent in Boiler Exit, %	1.9%
Carbon Conversion, %	99.03%

Exhibit 3-4 Reference SC Rankine Case plant power summary

Power Summary	B22F
Steam Turbine Power, MWe	721
Gross Power, MWe	**721**
Auxiliary Load Summary	
Coal Handling and Conveying, kWe	470
Limestone Handling & Reagent Preparation, kWe	230
Pulverizers, kWe	100
Ash Handling, kWe	2,550
Primary Air Fans, kWe	320
Forced Draft Fans, kWe	400
Induced Draft Fans, kWe	1,780
Air Separation Unit, kWe	85,294
Baghouse, kWe	10
CPU (Purification and Compression) Auxiliaries, kWe	60,220
Condensate Pumps, kWe	990
Miscellaneous Balance of Plant[A,] kWe	2,000
Steam Turbine Auxiliaries, kWe	400
Circulating Water Pumps, kWe	8,560
Cooling Tower Fans, kWe	5,000
Transformer Losses, kWe	2,630
Total Auxiliaries, MWe	**171**
Net Power, MWe	**550**

3.1.2 Reference SC Rankine Case Mass Balances

The carbon input consists of carbon in the coal, carbon in the air, and carbon in the limestone reagent for in-bed SO_2 removal. Most carbon leaves the plant in the captured CO_2 stream, as well as through the CPU vent stack in the form of CO_2, with additional carbon leaving in the bottom ash because of in-bed limestone removal. The carbon capture efficiency is defined as one minus the amount of carbon in the CPU vent stack gas relative to the total carbon in, represented by Equation 4:

$$\frac{Carbon\ in\ Stack}{(Total\ Carbon\ In)} = \left(1 - \left(\frac{23{,}373}{321{,}965}\right)\right) * 100 = 92.7\% \qquad \text{Eq. 4}$$

The carbon balance for the Reference SC Rankine Case is shown in Exhibit 3-5.

Exhibit 3-5 Reference SC Rankine Case carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	138,637 (305,642)	CO_2 Product	128,789 (283,931)
Air (CO_2)	380 (837)	Bottom Ash	4,523 (9,972)
Limestone Reagent	5,292 (11,668)	Separated Air	372 (821)
		CPU Vent	10,481 (23,106)
		Fly Ash	143 (315)
Total	**144,309 (318,146)**	**Total**	**144,309 (318,146)**

Exhibit 3-6 shows the sulfur balance for the Reference SC Rankine Case. Sulfur input comes only from the sulfur present in the coal. Most sulfur leaves the plant with the bottom ash because of in-bed limestone SO_2 removal.

Exhibit 3-6 Reference SC Rankine Case sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	5,450 (12,016)	Bottom Ash	5,104 (11,253)
		CO_2 Product	2 (4)
		Fly Ash	161 (355)
		CPU Water	183 (403)
Total	**5,450 (12,016)**	**Total**	**5,450 (12,016)**

Exhibit 3-7 shows the overall water balance for the Reference SC Rankine Case.

Exhibit 3-7 Reference SC Rankine Case water balance

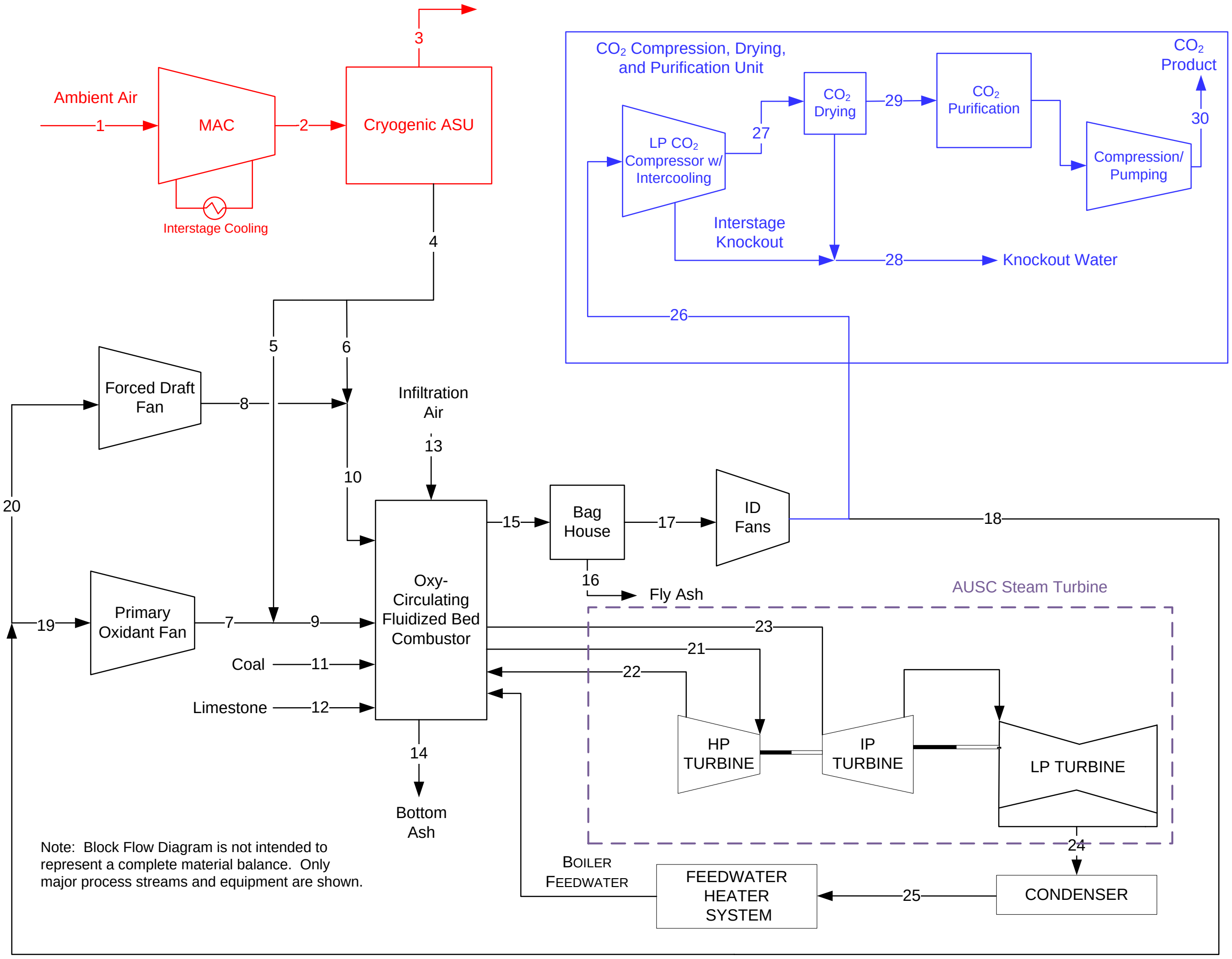
Water Use	Water Demand	Internal Recycle	Raw Water Withdrawal	Process Water Discharge	Raw Water Consumption
	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)	m^3/min (gpm)
BFW Makeup	0.33 (88)	0.0 (0)	0.33 (88)	0.00 (0)	0.33 (88)
Cooling Tower	33.4 (8,812)	1.82 (482)	31.5 (8,330)	7.50 (1982)	24.03 (6348)
Total	**33.7 (8,900)**	**1.82 (482)**	**31.9 (8,418)**	**7.50 (1,982)**	**24.36 (6,436)**

3.2 Reference Oxy-Coal-Fired AUSC Rankine Case

Exhibit 3-8 shows a BFD for the oxy-coal-fired advanced ultra-supercritical (AUSC) Rankine power plant. [11] The AUSC oxy-CFB case uses the same design basis and plant configuration as the reference oxy-coal-fired SC Rankine case except that the steam cycle conditions conform to AUSC conditions: 3,500 psig/1,400°F/1,400°F (24.1 MPa/760°C/760°C). The cost and performance for the ASU and CPU is based on the base case from the atmospheric advanced oxy-combustion study. [12] The cost and performance for the AUSC steam cycle is based on information provided by the AUSC Consortium report "Engineering and Economic Analysis of an Advanced Ultra-

Supercritical Pulverized Coal Power Plant with and without Post-Combustion Carbon Capture." [13]

Exhibit 3-8 Reference oxy-coal-fired AUSC Rankine power plant



Source: NETL

3.2.1 Reference AUSC Rankine Case Performance Results

The Reference AUSC Rankine Case produces a net output of 550 MW at a net plant efficiency of 36.9 percent (HHV basis). The stream tables that correspond to the BFD in Exhibit 3-8 are shown in Exhibit 3-9. Overall plant performance is summarized in Exhibit 3-10, and a detailed breakdown of auxiliary power requirements is provided in Exhibit 3-11.

Exhibit 3-9 Reference AUSC Rankine Case stream table results

Stream	1	2	3	4	5	6	7	8	9	10
V-L Mole Fraction										
Ar	0.0092	0.0092	0.0024	0.0340	0.0340	0.0340	0.0309	0.0309	0.0325	0.0325
CO_2	0.0005	0.0005	0.0006	0.0000	0.0000	0.0000	0.7124	0.7124	0.3424	0.3424
H_2	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	0.1516	0.1516	0.0729	0.0729
N_2	0.7729	0.7729	0.9778	0.0162	0.0162	0.0162	0.0858	0.0858	0.0497	0.0497
O_2	0.2074	0.2074	0.0063	0.9498	0.9498	0.9498	0.0190	0.0190	0.5024	0.5024
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002
Total	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)	61,576	61,577	48,453	13,124	3,084	10,040	2,854	9,290	5,938	19,331
V-L Flowrate (kg/hr)	1,776,837	1,776,867	1,354,195	422,672	99,328	323,344	109,445	356,279	208,773	679,623
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	24	17	13	13	13	67	61	44	43
Pressure (MPa, abs)	0.10	0.59	0.10	0.16	0.16	0.16	0.11	0.11	0.11	0.11
Enthalpy (kJ/kg)[A]	30.57	32.00	38.64	11.49	10.99	10.99	239.11	233.63	130.58	127.70
Density (kg/m^3)	1.2	7.0	1.2	2.2	2.2	2.2	1.5	1.5	1.5	1.4
V-L Molecular Weight	28.856	28.856	27.949	32.205	32.205	32.205	38.350	38.350	35.158	35.158
V-L Flowrate (lb_{mol}/hr)	135,752	135,754	106,820	28,935	6,800	22,135	6,292	20,482	13,091	42,617
V-L Flowrate (lb/hr)	3,917,255	3,917,321	2,985,489	931,831	218,980	712,851	241,285	785,461	460,266	1,498,312
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	75	63	55	55	55	152	142	112	109
Pressure (psia)	14.7	86.1	14.7	23.2	23.2	23.2	16.2	15.3	16.2	15.3
Enthalpy (Btu/lb)[A]	13.1	13.8	16.6	4.9	4.7	4.7	102.8	100.4	56.1	54.9
Density (lb/ft^3)	0.076	0.435	0.073	0.135	0.136	0.136	0.095	0.091	0.093	0.089
	A - Reference conditions are 32.02 F & 0.089 PSIA									
Enthalpy (Btu/lb)	-43.5	-42.9	-54.7	-4.7	-5.0	-5.0	-3,538.4	-3,540.7	-1,857.3	-1,858.5

[A] - Steam Table Reference conditions are 32.02°F and 0.089 psia

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

Exhibit 3-9 Reference AUSC Rankine Case stream table results (continued)

Stream	11	12	13	14	15	16	17	18	19	20
V-L Mole Fraction										
Ar	0.0000	0.0000	0.0092	0.0000	0.0277	0.0000	0.0277	0.0309	0.0309	0.0309
CO_2	0.0000	0.0000	0.0005	0.0000	0.6393	0.0000	0.6393	0.7124	0.7124	0.7124
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0101	0.0000	0.2386	0.0000	0.2386	0.1516	0.1516	0.1516
N_2	0.0000	0.0000	0.7729	0.0000	0.0770	0.0000	0.0770	0.0858	0.0858	0.0858
O_2	0.0000	0.0000	0.2074	0.0000	0.0170	0.0000	0.0170	0.0190	0.0190	0.0190
SO_2	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0004	0.0004	0.0004
Total	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	0	1,232	0	30,072	0	30,072	12,144	2,854	9,290
V-L Flowrate (kg/hr)	0	0	35,537	0	1,090,512	0	1,090,512	465,724	109,445	356,279
Solids Flowrate (kg/hr)	197,825	47,506	0	76,938	1,823	1,823	0	0	0	0
Temperature (°C)	15	15	15	15	127	15	127	57	57	57
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	---	---	30.57	---	416.77	---	422.74	230.18	230.09	230.09
Density (kg/m^3)	---	---	1.2	---	1.1	---	1.1	1.4	1.4	1.4
V-L Molecular Weight	---	---	28.856	---	36.264	---	36.264	38.350	38.350	38.350
V-L Flowrate (lb_{mol}/hr)	0	0	2,715	0	66,296	0	66,296	26,773	6,292	20,482
V-L Flowrate (lb/hr)	0	0	78,345	0	2,404,168	0	2,404,168	1,026,746	241,285	785,461
Solids Flowrate (lb/hr)	436,129	104,732	0	169,619	4,019	4,019	0	0	0	0
Temperature (°F)	59	59	59	59	260	59	260	135	135	135
Pressure (psia)	14.7	14.7	14.7	14.7	14.4	14.7	14.2	14.8	14.7	14.7
Enthalpy (Btu/lb)[A]	---	---	13.1	---	179.2	---	181.7	99.0	98.9	98.9
Density (lb/ft^3)	---	---	0.076	---	0.068	---	0.067	0.089	0.089	0.089
Enthalpy (Btu/lb)	-910.1	-5,421.0	-43.5	-3,909.0	-3,626.3	-5,210.5	-3,623.8	-3,542.2	-3,542.3	-3,542.3

Exhibit 3-9 Reference AUSC Rankine Case stream table results (continued)

Stream	21	22	23	24	25	26	27	28	29	30
V-L Mole Fraction										
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0309	0.0363	0.0000	0.0364	0.0000
CO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.7124	0.8375	0.0000	0.8400	1.0000
H_2	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	1.0000	1.0000	1.0000	0.1516	0.0025	0.9977	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0858	0.1009	0.0000	0.1012	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0190	0.0223	0.0000	0.0224	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0023	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
V-L Flowrate (kg_{mol}/hr)	84,794	72,868	72,868	65,958	66,128	14,843	12,625	2,256	12,587	9,778
V-L Flowrate (kg/hr)	1,527,588	1,312,738	1,312,738	1,188,255	1,191,310	569,219	529,253	40,878	528,341	430,334
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	760	483	760	38	39	57	38	38	38	37
Pressure (MPa, abs)	24.23	4.90	4.80	0.01	1.80	0.10	3.00	0.10	3.00	15.27
Enthalpy (kJ/kg)[A]	3,929.97	3,385.41	4,033.54	160.75	161.42	230.18	9.60	157.59	6.95	-206.54
Density (kg/m^3)	53.6	14.7	10.2	0.1	993.5	1.4	55.4	431.6	55.5	536.7
V-L Molecular Weight	18.015	18.015	18.015	18.015	18.015	38.350	41.922	18.122	41.974	44.010
V-L Flowrate (lb_{mol}/hr)	186,939	160,647	160,647	145,413	145,787	32,723	27,832	4,973	27,750	21,557
V-L Flowrate (lb/hr)	3,367,756	2,894,092	2,894,092	2,619,654	2,626,389	1,254,912	1,166,804	90,121	1,164,791	948,723
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	1,400	901	1,400	101	101	135	100	100	100	99
Pressure (psia)	3,514.7	710.8	696.6	1.0	261.6	14.8	435.1	14.8	435.1	2,215.0
Enthalpy (Btu/lb)[A]	1,689.6	1,455.5	1,734.1	69.1	69.4	99.0	4.1	67.8	3.0	-88.8
Density (lb/ft^3)	3.349	0.916	0.636	0.004	62.022	0.089	3.460	26.944	3.462	33.507
Enthalpy (Btu/lb)	-5,176.9	-5,411.0	-5,132.3	-5,968.3	-6,800.2	-3,542.2	-3,393.5	-6,802.4	-3,391.7	-3,941.8

Exhibit 3-10 Reference AUSC Rankine Case plant performance summary

Performance Summary	B24F
Case Description	AUSC oxy-CFB with auto refrigerated CO_2 purification firing Bituminous Coal
Total Gross Power, MWe	**706**
CPU (Purification and Compression) Auxiliaries, kWe	54,910
Balance of Plant, kWe	100,708
Total Auxiliaries, MWe	**156**
Net Power, MWe	**550**
HHV Net Plant Efficiency (%)	36.9%
HHV Net Plant Heat Rate, kJ/kWh (Btu/kWh)	9,760 (9,251)
LHV Net Plant Efficiency (%)	38.2%
LHV Net Plant Heat Rate, kJ/kWh (Btu/kWh)	9,414 (8,923)
HHV Boiler Efficiency, %	91.8%
LHV Boiler Efficiency, %	95.2%
Steam Turbine Cycle Efficiency, %	51.8%
Steam Turbine Heat Rate, kJ/kWh (Btu/kWh)	6,944 (6,582)
Condenser Duty, GJ/hr (MMBtu/hr)	2,302 (2,181)
As-Received Coal Feed, kg/hr (lb/hr)	197,825 (436,129)
Limestone Sorbent Feed, kg/hr (lb/hr)	47,506 (104,732)
HHV Thermal Input, kWt	1,491,111
LHV Thermal Input, kWt	1,438,195
Raw Water Withdrawal, $(m^3/min)/MW_{net}$ (gpm/MW_{net})	0.050 (13.3)
Raw Water Consumption, $(m^3/min)/MW_{net}$ (gpm/MW_{net})	0.038 (10.2)
O_2 Mole Percent in Boiler Exit, %	1.9%
Carbon Conversion, %	99.03%

Exhibit 3-11 Reference AUSC Rankine Case plant power summary

Power Summary	B24F
Steam Turbine Power, MWe	706
Gross Power, MWe	**706**
Auxiliary Load Summary	
Coal Handling and Conveying, kWe	450
Limestone Handling & Reagent Preparation, kWe	210
Pulverizers, kWe	90
Ash Handling, kWe	2,330
Primary Air Fans, kWe	290
Forced Draft Fans, kWe	370
Induced Draft Fans, kWe	1,620
Air Separation Unit, kWe	77,778
Baghouse, kWe	10
CPU (Purification and Compression) Auxiliaries, kWe	54,910
Condensate Pumps, kWe	790
Miscellaneous Balance of Plant[A,B] kWe	2,000
Steam Turbine Auxiliaries, kWe	400
Circulating Water Pumps, kWe	7,470
Cooling Tower Fans, kWe	4,360
Transformer Losses, kWe	2,540
Total Auxiliaries, MWe	**156**
Net Power, MWe	**550**

3.2.2 Reference AUSC Rankine Case Mass Balances

The carbon balance for the Reference AUSC Rankine Case is shown in Exhibit 3-12.

Exhibit 3-12 Reference AUSC Rankine Case carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	126,419 (278,705)	CO_2 Product	117,442 (258,916)
Air (CO_2)	346 (763)	Bottom Ash	4,137 (9,120)
Limestone Reagent	4,820 (10,627)	Separated Air	339 (748)
		CPU Vent	9,554 (21,062)
		Fly Ash	131 (288)
Total	**131,585 (290,096)**	**Total**	**131,585 (290,096)**

Exhibit 3-13 shows the sulfur balance for Reference AUSC Rankine Case. Sulfur input comes only from the sulfur present in the coal. Most sulfur leaves the plant with the bottom ash because of in-bed limestone SO_2 removal.

Exhibit 3-13 Reference AUSC Rankine Case sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	4,970 (10,957)	Bottom Ash	4,621 (10,187)
		CO_2 Product	2 (4)
		Fly Ash	146 (322)
		CPU Water	167 (368)
Total	**4,970 (10,957)**	**Total**	**4,970 (10,957)**

Exhibit 3-14 shows the overall water balance for Reference AUSC Rankine Case.

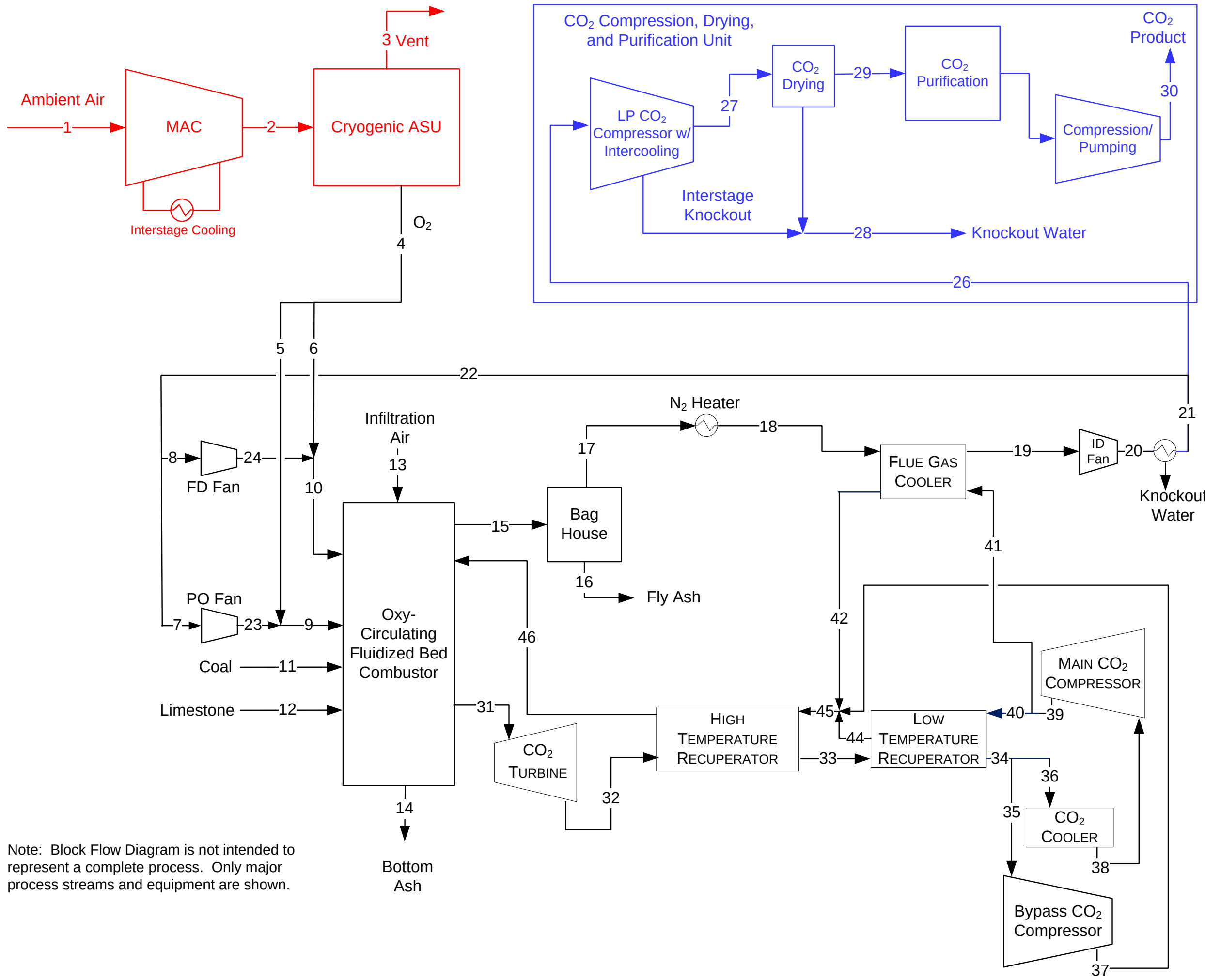
Exhibit 3-14 Reference AUSC Rankine Case water balance

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)
BFW Makeup	0.25 (67)	0.0 (0)	0.25 (67)	0.00 (0)	0.25 (67)
Cooling Tower	29.1 (7,683)	1.65 (437)	27.4 (7,246)	6.54 (1728)	20.89 (5518)
Total	**29.3 (7,751)**	**1.65 (437)**	**27.7 (7,314)**	**6.54 (1,728)**	**21.14 (5,586)**

3.3 BASELINE sCO_2

Exhibit 3-15 shows a BFD for the oxy-coal-fired baseline sCO_2 recompression Brayton cycle power plant. The performance of this conceptual commercial plant is based on an Aspen simulation of the process. Illinois No. 6 coal is fed to the atmospheric pressure CFB together with limestone that is added for sulfur capture. Oxygen is provided by a low pressure (LP) ASU. A circulating stream of CO_2 provides fluid bed mixing in the CFB. The same bed temperature as the reference plant of 1,600 °F, the same carbon conversion (~99 percent), and the same heat loss (1 percent) is used. The CFB heats sCO_2 that flows through boiler tubes. This indirectly heated sCO_2 carries heat to the power cycle, whereas supercritical steam is used in the reference plant. Flue gas from the CFB is cooled and condensate is removed in a water knockout tank. A portion of the flue gas, which consists primarily of CO_2, is recycled to the CFB as a fluidizing gas. The remainder of the dried flue gas is fed to the CPU, which operates at the same conditions and under the same specifications as the CPU used in the reference Rankine plant.

Exhibit 3-15 Block flow diagram for the baseline sCO_2 recompression Brayton cycle



Source: NETL

The CO_2 power cycle is analogous to a steam bottoming cycle, except that the working fluid is CO_2 rather than H_2O. Supercritical (~5,000 psig) CO_2 is heated to 1,148 °F in the boiler and is expanded in the turbine for power generation. The pressure ratio of the CO_2 expander is on the order of 3 to 4. Exhaust CO_2 from the expander is cooled in recuperators. The CO_2 stream is then separated into two portions; one is cooled and recompressed, and the other bypasses the cooler and is recompressed.

The pressurized CO_2 stream that passed through the CO_2 cooler is split into two streams; one portion passes through the cold side of the low-temperature recuperator (LTR) and the other portion passes through the cold side of the flue gas heat exchanger. Both streams are heated to the same temperature before joining with the compressed CO_2 bypass stream and entering the high-temperature recuperator (HTR). The CO_2 exiting the cold side of the HTR then passes through the CFB for further heating to the turbine inlet temperature (TIT) of 1,148 °F.

The flue gas cooling schema that includes the flue gas recuperator and the flue gas heat exchanger recovers a large fraction of the sensible heat in the flue gas for the sCO_2 power cycle and obviates the need for a bottoming cycle.

Two cases were run with this cycle configuration. Case Baseline620 used a TIT of 620 °C (1,148 °F). Case Baseline760 used a TIT of 760 °C (1,400 °F). Exhibit 3-16 shows the remaining operating parameters for the baseline sCO_2 Brayton cycle configuration. The inlet pressure was 4,970 psig (equal to the CO_2 compressor outlet pressure less the pressure drops through the recuperators and CFB). The sCO_2 turbine pressure ratio was 3.7, which resulted in an exit pressure of 1,350 psia. The fraction of the CO_2 cooler bypass was chosen to maximize recuperation.

Exhibit 3-16 Baseline sCO_2 Brayton cycle parameters

Parameter	Case Baseline620	Case Baseline760
Turbine inlet temperature	620 °C (1,148 °F)	760 °C (1,400 °F)
Compressor outlet pressure (psig)	5,000	5,000
Turbine exit pressure	1150 psia	1150 psia
Nominal compressor pressure ratio	3.8	3.8
CO_2 cooler temperature	35 °C (95 °F)	35 °C (95 °F)
Compressor isentropic efficiency	0.85	0.85
Turbine isentropic efficiency	0.927	0.927
Cycle pressure drop (psia)	60	60
Minimum temperature approach	6 °C (10 °F)	6 °C (10 °F)
Nominal CO_2 cooler bypass fraction	Max recuperation	Max recuperation

It should be noted that the baseline sCO_2 recompression cycle plant is a relatively simple configuration and does not reflect the maximum potential of an indirect-fired sCO_2 power plant. Similarly, the parameters in Exhibit 3-16 are based on a systems analysis of an sCO_2 recompression cycle [1] and are not intended to represent an optimum operating point for an integrated plant.

3.3.1 Baseline sCO_2 Performance Results

The stream tables that correspond to the block flow diagram in Exhibit 3-15 are shown in Exhibit 3-17 and Exhibit 3-18. Exhibit 3-17 corresponds to a TIT of 1148 °F (Case Baseline620) and Exhibit 3-18 corresponds to a TIT of 1400 °F (Case Baseline760). Overall plant performance for both Baseline cases is summarized in Exhibit 3-19. Note that the power cycle summary shows the gross turbine output, the power requirements for the main and bypass CO_2 compressors, and the generator loss. A detailed breakdown of auxiliary power requirements for both Baseline cases is provided in Exhibit 3-20. Exhibit 3-21 provides a detailed breakdown of the sCO_2 power cycle performance for the Baseline cases. The specific power shown in Exhibit 3-21 is equal to the net sCO_2 power cycle output divided by the mass flow rate of CO_2 through the turbine.

Exhibit 3-17 Case Baseline620 stream table results

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0093	0.0025	0.0343	0.0343	0.0343	0.0352	0.0352	0.0347	0.0347	0.0000
CO_2	0.0003	0.0003	0.0004	0.0000	0.0000	0.0000	0.8062	0.8062	0.3626	0.3626	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
H_2O	0.0099	0.0094	0.0000	0.0000	0.0000	0.0000	0.0397	0.0397	0.0179	0.0179	0.0000
N_2	0.7732	0.7735	0.9907	0.0162	0.0162	0.0162	0.0971	0.0971	0.0526	0.0526	0.0000
O_2	0.2074	0.2075	0.0064	0.9495	0.9495	0.9495	0.0214	0.0214	0.5321	0.5321	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002	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
V-L Flowrate (kg_{mol}/hr)	65,509	65,477	50,896	13,966	3,282	10,684	2,683	8,734	5,965	19,418	0
V-L Flowrate (kg/hr)	1,890,386	1,889,816	1,428,932	449,799	105,703	344,096	110,087	358,369	215,790	702,465	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	210,467
Temperature (°C)	15	38	19	13	13	13	32	32	27	24	15
Pressure (MPa, abs)	0.10	0.69	0.10	0.16	0.16	0.16	0.10	0.10	0.11	0.11	0.11
Enthalpy (kJ/kg)[A]	30.54	52.80	19.65	10.99	10.99	10.99	70.38	70.38	45.23	42.81	---
Density (kg/m^3)	1.2	7.7	1.2	2.2	2.2	2.2	1.6	1.6	1.6	1.5	---
V-L Molecular Weight	28.857	28.862	28.075	32.207	32.207	32.207	41.032	41.032	36.176	36.176	---
V-L Flowrate (lb_{mol}/hr)	144,422	144,353	112,207	30,790	7,236	23,554	5,915	19,255	13,150	42,809	0
V-L Flowrate (lb/hr)	4,167,587	4,166,331	3,150,256	991,637	233,035	758,602	242,701	790,068	475,735	1,548,670	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	464,000
Temperature (°F)	59	100	66	55	55	55	90	90	80	75	59
Pressure (psia)	14.7	100.5	14.7	23.2	23.2	23.2	14.7	14.7	16.2	15.3	16.1
Enthalpy (Btu/lb)[A]	13.1	22.7	8.4	4.7	4.7	4.7	30.3	30.3	19.4	18.4	---
Density (lb/ft^3)	0.076	0.483	0.073	0.136	0.136	0.136	0.103	0.103	0.101	0.097	---

A - Steam Table Reference conditions are 32.02°F and 0.089 psia
* - AspenPlus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm

Exhibit 3-17 Case Baseline620 stream table results (continued)

	12	13	14	15	16	17	18	19	20	21	22
V-L Mole Fraction											
Ar	0.0000	0.0092	0.0000	0.0293	0.0000	0.0293	0.0293	0.0293	0.0293	0.0352	0.0352
CO_2	0.0000	0.0005	0.0000	0.6707	0.0000	0.6707	0.6707	0.6707	0.6707	0.8062	0.8062
H_2	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	0.0101	0.0000	0.2010	0.0000	0.2010	0.2010	0.2010	0.2010	0.0397	0.0397
N_2	0.0000	0.7729	0.0000	0.0808	0.0000	0.0808	0.0808	0.0808	0.0808	0.0971	0.0971
O_2	0.0000	0.2074	0.0000	0.0178	0.0000	0.0178	0.0178	0.0178	0.0178	0.0214	0.0214
SO_2	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	1,310	0	30,493	0	30,493	30,493	30,493	30,493	25,371	11,417
V-L Flowrate (kg/hr)	0	37,808	0	1,133,284	0	1,133,284	1,133,284	1,133,284	1,133,284	1,041,013	468,456
Solids Flowrate (kg/hr)	50,633	0	81,905	1,941	1,941	0	0	0	0	0	0
Temperature (°C)	15	15	25	241	25	241	216	81	88	32	32
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	---	30.57	---	482.94	---	489.27	461.88	321.27	328.02	70.38	70.38
Density (kg/m^3)	---	1.2	---	0.9	---	0.8	0.9	1.2	1.3	1.7	1.7
V-L Molecular Weight	---	28.856	---	37.166	---	37.166	37.166	37.166	37.166	41.032	41.032
V-L Flowrate (lb_{mol}/hr)	0	2,889	0	67,225	0	67,225	67,225	67,225	67,225	55,933	25,170
V-L Flowrate (lb/hr)	0	83,352	0	2,498,464	0	2,498,464	2,498,464	2,498,464	2,498,464	2,295,040	1,032,768
Solids Flowrate (lb/hr)	111,627	0	180,571	4,280	4,280	0	0	0	0	0	0
Temperature (°F)	59	59	77	465	77	465	420	179	191	90	90
Pressure (psia)	14.7	14.7	14.7	14.3	14.7	14.1	14.0	13.9	14.8	14.8	14.8
Enthalpy (Btu/lb)[A]	---	13.1	---	207.6	---	210.3	198.6	138.1	141.0	30.3	30.3
Density (lb/ft^3)	---	0.076	---	0.054	---	0.053	0.055	0.076	0.079	0.103	0.103

Exhibit 3-17 Case Baseline620 stream table results (continued)

	23	24	26	27	28	29	30	31	32	33	34
V-L Mole Fraction											
Ar	0.0352	0.0352	0.0352	0.0365	0.0000	0.0367	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.8062	0.8062	0.8062	0.8359	0.0001	0.8398	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0397	0.0397	0.0397	0.0042	0.9900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0971	0.0971	0.0971	0.1007	0.0000	0.1012	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0214	0.0214	0.0214	0.0222	0.0000	0.0223	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0004	0.0004	0.0004	0.0004	0.0099	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
V-L Flowrate (kg_{mol}/hr)	2,683	8,734	13,954	13,457	560	13,394	10,402	436,025	436,025	436,025	436,025
V-L Flowrate (kg/hr)	110,087	358,369	572,557	563,604	10,337	562,220	457,779	19,189,364	19,189,364	19,189,364	19,189,364
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	41	36	32	99	35	38	37	620	453	216	81
Pressure (MPa, abs)	0.11	0.11	0.10	3.00	0.10	3.00	15.20	34.30	9.31	9.24	9.17
Enthalpy (kJ/kg)[A]	78.10	73.37	70.38	73.49	145.38	6.95	-206.34	630.16	441.39	167.29	-3.75
Density (kg/m^3)	1.8	1.7	1.7	43.4	77.9	55.5	536.8	188.5	67.6	107.2	192.2
V-L Molecular Weight	41.032	41.032	41.032	41.882	18.472	41.974	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	5,915	19,255	30,763	29,668	1,234	29,530	22,932	961,270	961,270	961,270	961,270
V-L Flowrate (lb/hr)	242,701	790,068	1,262,272	1,242,534	22,790	1,239,482	1,009,231	42,305,305	42,305,305	42,305,305	42,305,305
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	106	96	90	210	95	100	99	1,148	847	420	179
Pressure (psia)	16.2	15.3	14.8	435.1	14.8	435.1	2,205.0	4,974.7	1,350.0	1,340.0	1,330.0
Enthalpy (Btu/lb)[A]	33.6	31.5	30.3	31.6	62.5	3.0	-88.7	270.9	189.8	71.9	-1.6
Density (lb/ft^3)	0.110	0.106	0.103	2.707	4.865	3.462	33.509	11.769	4.217	6.694	12.001

Exhibit 3-17 Case Baseline620 stream table results (continued)

	35	36	37	38	39	40	41	42	44	45	46
V-L Mole Fraction											
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	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)	108,285	327,740	108,285	327,740	327,740	312,565	15,175	15,175	312,565	436,025	436,025
V-L Flowrate (kg/hr)	4,765,589	14,423,774	4,765,589	14,423,774	14,423,774	13,755,922	667,852	667,852	13,755,922	19,189,364	19,189,364
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	81	81	210	35	76	76	76	210	210	210	412
Pressure (MPa, abs)	9.17	9.17	34.58	9.10	34.64	34.64	34.64	34.58	34.58	34.58	34.51
Enthalpy (kJ/kg)[A]	-3.75	-3.75	90.17	-188.29	-148.42	-148.42	-148.42	90.18	90.17	90.17	364.28
Density (kg/m^3)	192.2	192.2	425.4	669.1	801.6	801.6	801.6	425.4	425.4	425.4	255.9
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	238,727	722,543	238,727	722,543	722,543	689,088	33,455	33,455	689,088	961,270	961,270
V-L Flowrate (lb/hr)	10,506,326	31,798,979	10,506,326	31,798,979	31,798,979	30,326,617	1,472,362	1,472,362	30,326,617	42,305,305	42,305,305
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	179	179	410	95	169	169	169	410	410	410	774
Pressure (psia)	1,330.0	1,330.0	5,014.7	1,320.0	5,024.7	5,024.7	5,024.7	5,014.7	5,014.7	5,014.7	5,004.7
Enthalpy (Btu/lb)[A]	-1.6	-1.6	38.8	-80.9	-63.8	-63.8	-63.8	38.8	38.8	38.8	156.6
Density (lb/ft^3)	12.001	12.001	26.554	41.768	50.044	50.044	50.044	26.554	26.554	26.554	15.974

Exhibit 3-18 Case Baseline760 stream table results

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0093	0.0025	0.0343	0.0343	0.0343	0.0352	0.0352	0.0347	0.0347	0.0000
CO_2	0.0003	0.0003	0.0004	0.0000	0.0000	0.0000	0.8062	0.8062	0.3626	0.3626	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
H_2O	0.0099	0.0094	0.0000	0.0000	0.0000	0.0000	0.0397	0.0397	0.0179	0.0179	0.0000
N_2	0.7732	0.7735	0.9907	0.0162	0.0162	0.0162	0.0971	0.0971	0.0526	0.0526	0.0000
O_2	0.2074	0.2075	0.0064	0.9495	0.9495	0.9495	0.0214	0.0214	0.5321	0.5321	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002	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
V-L Flowrate (kg_{mol}/hr)	57,490	57,462	44,666	12,256	2,880	9,376	2,355	7,665	5,235	17,041	0
V-L Flowrate (kg/hr)	1,658,976	1,658,476	1,254,011	394,737	92,763	301,974	96,611	314,499	189,374	616,473	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	184,703
Temperature (°C)	15	38	19	13	13	13	32	32	27	24	15
Pressure (MPa, abs)	0.10	0.69	0.10	0.16	0.16	0.16	0.10	0.10	0.11	0.11	0.11
Enthalpy (kJ/kg)^A	30.54	52.80	19.65	10.99	10.99	10.99	70.38	70.38	45.23	42.81	---
Density (kg/m^3)	1.2	7.7	1.2	2.2	2.2	2.2	1.6	1.6	1.6	1.5	---
V-L Molecular Weight	28.857	28.862	28.075	32.207	32.207	32.207	41.032	41.032	36.176	36.176	---
V-L Flowrate (lb_{mol}/hr)	126,743	126,682	98,471	27,020	6,350	20,671	5,191	16,898	11,541	37,569	0
V-L Flowrate (lb/hr)	3,657,417	3,656,314	2,764,621	870,247	204,508	665,739	212,991	693,352	417,499	1,359,091	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	407,200
Temperature (°F)	59	100	66	55	55	55	90	90	80	75	59
Pressure (psia)	14.7	100.5	14.7	23.2	23.2	23.2	14.7	14.7	16.2	15.3	16.1
Enthalpy (Btu/lb)^A	13.1	22.7	8.4	4.7	4.7	4.7	30.3	30.3	19.4	18.4	---
Density (lb/ft^3)	0.076	0.483	0.073	0.136	0.136	0.136	0.103	0.103	0.101	0.097	---

Exhibit 3-18 Case Baseline760 stream table results (continued)

	12	13	14	15	16	17	18	19	20	21	22
V-L Mole Fraction											
Ar	0.0000	0.0092	0.0000	0.0293	0.0000	0.0293	0.0293	0.0293	0.0293	0.0352	0.0352
CO_2	0.0000	0.0005	0.0000	0.6707	0.0000	0.6707	0.6707	0.6707	0.6707	0.8062	0.8062
H_2	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	0.0101	0.0000	0.2010	0.0000	0.2010	0.2010	0.2010	0.2010	0.0397	0.0397
N_2	0.0000	0.7729	0.0000	0.0808	0.0000	0.0808	0.0808	0.0808	0.0808	0.0971	0.0971
O_2	0.0000	0.2074	0.0000	0.0178	0.0000	0.0178	0.0178	0.0178	0.0178	0.0214	0.0214
SO_2	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	1,150	0	26,760	0	26,760	26,760	26,760	26,760	22,265	10,019
V-L Flowrate (kg/hr)	0	33,180	0	994,554	0	994,554	994,554	994,554	994,554	913,579	411,110
Solids Flowrate (kg/hr)	44,435	0	71,952	1,705	1,705	0	0	0	0	0	0
Temperature (°C)	15	15	25	241	25	241	216	81	88	32	32
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	---	30.57	---	482.93	---	489.27	461.88	321.27	328.02	70.38	70.38
Density (kg/m^3)	---	1.2	---	0.9	---	0.8	0.9	1.2	1.3	1.7	1.7
V-L Molecular Weight	---	28.856	---	37.166	---	37.166	37.166	37.166	37.166	41.032	41.032
V-L Flowrate (lb_{mol}/hr)	0	2,535	0	58,995	0	58,995	58,995	58,995	58,995	49,086	22,089
V-L Flowrate (lb/hr)	0	73,148	0	2,192,617	0	2,192,617	2,192,617	2,192,617	2,192,617	2,014,096	906,343
Solids Flowrate (lb/hr)	97,962	0	158,628	3,760	3,760	0	0	0	0	0	0
Temperature (°F)	59	59	77	465	77	465	420	179	191	90	90
Pressure (psia)	14.7	14.7	14.7	14.3	14.7	14.1	14.0	13.9	14.8	14.8	14.8
Enthalpy (Btu/lb)[A]	---	13.1	---	207.6	---	210.3	198.6	138.1	141.0	30.3	30.3
Density (lb/ft^3)	---	0.076	---	0.054	---	0.053	0.055	0.076	0.079	0.103	0.103

Exhibit 3-18 Case Baseline760 stream table results (continued)

	23	24	26	27	28	29	30	31	32	33	34
V-L Mole Fraction											
Ar	0.0352	0.0352	0.0352	0.0365	0.0000	0.0367	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.8062	0.8062	0.8062	0.8359	0.0001	0.8398	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0397	0.0397	0.0397	0.0042	0.9900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0971	0.0971	0.0971	0.1007	0.0000	0.1012	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0214	0.0214	0.0214	0.0222	0.0000	0.0223	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0004	0.0004	0.0004	0.0004	0.0099	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
V-L Flowrate (kg_{mol}/hr)	2,355	7,665	12,246	11,810	491	11,755	9,129	340,536	340,536	340,536	340,536
V-L Flowrate (kg/hr)	96,611	314,499	502,468	494,611	9,072	493,396	401,743	14,986,929	14,986,929	14,986,929	14,986,929
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	41	36	32	99	35	38	37	760	576	216	81
Pressure (MPa, abs)	0.11	0.11	0.10	3.00	0.10	3.00	15.20	34.30	9.31	9.24	9.17
Enthalpy (kJ/kg)[A]	78.10	73.37	70.38	73.49	145.38	6.95	-206.34	810.83	589.18	167.29	-3.75
Density (kg/m^3)	1.8	1.7	1.7	43.4	77.9	55.5	536.8	162.0	57.2	107.2	192.2
V-L Molecular Weight	41.032	41.032	41.032	41.882	18.472	41.974	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	5,191	16,898	26,997	26,036	1,083	25,915	20,125	750,754	750,754	750,754	750,754
V-L Flowrate (lb/hr)	212,991	693,352	1,107,753	1,090,430	20,000	1,087,753	885,692	33,040,523	33,040,523	33,040,523	33,040,523
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	106	96	90	210	95	100	99	1,400	1,069	420	179
Pressure (psia)	16.2	15.3	14.8	435.1	14.8	435.1	2,205.0	4,974.7	1,350.0	1,340.0	1,330.0
Enthalpy (Btu/lb)[A]	33.6	31.5	30.3	31.6	62.5	3.0	-88.7	348.6	253.3	71.9	-1.6
Density (lb/ft^3)	0.110	0.106	0.103	2.707	4.865	3.462	33.509	10.112	3.570	6.694	12.001

Exhibit 3-18 Case Baseline760 stream table results (continued)

	35	36	37	38	39	40	41	42	44	45	46
V-L Mole Fraction											
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	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)	83,105	257,432	83,105	257,432	257,432	244,114	13,318	13,318	244,114	340,536	340,536
V-L Flowrate (kg/hr)	3,657,419	11,329,510	3,657,419	11,329,510	11,329,510	10,743,394	586,116	586,116	10,743,394	14,986,929	14,986,929
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	81	81	210	35	76	76	76	210	210	210	528
Pressure (MPa, abs)	9.17	9.17	34.58	9.10	34.64	34.64	34.64	34.58	34.58	34.58	34.51
Enthalpy (kJ/kg)[A]	-3.75	-3.75	90.17	-188.29	-148.42	-148.42	-148.42	90.17	90.17	90.17	512.06
Density (kg/m^3)	192.2	192.2	425.4	669.1	801.6	801.6	801.6	425.4	425.4	425.4	213.5
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	183,214	567,539	183,214	567,539	567,539	538,179	29,361	29,361	538,179	750,754	750,754
V-L Flowrate (lb/hr)	8,063,229	24,977,295	8,063,229	24,977,295	24,977,295	23,685,130	1,292,165	1,292,165	23,685,130	33,040,523	33,040,523
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	179	179	410	95	169	169	169	410	410	410	982
Pressure (psia)	1,330.0	1,330.0	5,014.7	1,320.0	5,024.7	5,024.7	5,024.7	5,014.7	5,014.7	5,014.7	5,004.7
Enthalpy (Btu/lb)[A]	-1.6	-1.6	38.8	-80.9	-63.8	-63.8	-63.8	38.8	38.8	38.8	220.1
Density (lb/ft^3)	12.001	12.001	26.554	41.768	50.044	50.044	50.044	26.554	26.554	26.554	13.325

Exhibit 3-19 Baseline plant performance summary

Parameter	Case Baseline620	Case Baseline760
CFB Coal Flow Rate (lb/hr)	464,000	407,200
Limestone Flow Rate (lb/hr)	111,627	97,962
Oxygen Flow Rate (lb/hr)	991,637	870,247
Coal Thermal Input (MMBtu/hr)	5,413	4,750
Net Plant Power Output (kW)	549,910	549,799
Net Plant Efficiency (HHV %)	**34.67**	**39.49**
HHV Heat Rate (Btu/kWh)	9,843	8,640
Raw Water Withdrawal (gpm)	6,879	5,541

Exhibit 3-20 Plant power summary for Baseline cases

POWER SUMMARY		
Item (kW)	**Case Baseline620**	**Case Baseline760**
POWER CYCLE SUMMARY		
sCO_2 Turbine Gross Power	1,006,200	922,700
sCO_2 Main Compressor	-159,700	-125,500
sCO_2 Bypass Compressor	-124,300	-95,400
sCO_2 Generator Loss	-10,833	-10,527
TOTAL sCO_2 POWER GENERATED	**711,367**	691,273
AUXILIARY LOAD SUMMARY		
Coal Handling	-457	-434
Limestone Prep	-220	-200
Pulverizers	-100	-90
Slag Handling and Dewatering	-2,480	-2,180
Primary Oxidant Fans	-250	-220
Forced Draft Fans	-320	-280
Induced Draft Fans	-2,200	-1,930
Air Separation Unit	-82,740	-72,610
Baghouse	-10	-10
CPU (Purification and Compression) Auxiliaries	-56,430	-49,520
Turbine Auxiliaries	-400	-400
Miscellaneous Balance of Plant	-2,000	-2,000
Circulating Water Pump	-7,120	-5,770

POWER SUMMARY		
Item (kW)	**Case Baseline620**	**Case Baseline760**
Cooling Tower Fans	-4,160	-3,370
Transformer Losses	-2,570	-2,460
TOTAL AUXILIARIES	**-161,457**	**-141,474**
NET PLANT POWER	**549,910**	**549,799**

Exhibit 3-21 Baseline sCO_2 cycle performance summary

Parameter	Case Baseline620	Case Baseline760
THERMAL INPUT		
Power Cycle Thermal Input - CFB (MMBtu/hr)	4,836	4,244
Power Cycle Thermal Input – Flue gas (MMBtu/hr)	151	133
Power Cycle Thermal Input - Total (MMBtu/hr)	4,987	4,376
Fractional Thermal Input to Power Cycle	0.921	0.921
RECUPERATOR DUTY		
Recuperator Duty – HTR (MMBtu/hr)	4,985	5,993
Recuperator Duty – LTR (MMBtu/hr)	3,111	2,430
Recuperator Duty – Total (MMBtu/hr)	8,096	8,422
COOLING DUTY		
Power Cycle Cooling Duty – CO_2 cooler (MMBtu/hr)	2,523	1,982
Power Cycle Cooling Duty – Total (MMBtu/hr)	2,523	1,982
POWER OUTPUT		
Net Cycle Power Output (kW)	711,367	691,273
SPECIFIC POWER		
sCO_2 Flow Rate (lb/hr)	42,305,305	33,040,523
sCO_2 Cycle Specific Power (Wh/lb)	16.82	20.92
sCO_2 Cycle Specific Power (kJ/kg)	133.5	166.1
OVERALL CYCLE PERFORMANCE		
sCO_2 Power Cycle Efficiency (%)	48.67	53.90
sCO_2 Cycle Heat Rate (Btu/kWh)	7,010	6,331

3.3.2 Case Mass Balances

The carbon balance for Case Baseline620 is shown in Exhibit 3-22, while the corresponding carbon balance for Case Baseline760 is shown in Exhibit 3-23.

Exhibit 3-22 Case Baseline620 carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	134,180 (295,817)	CO_2 Product	124,933 (275,430)
Air (CO_2)	264 (583)	Bottom Ash	4,389 (9,676)
Limestone Reagent	5,138 (11,327)	Separated Air	257 (567)
		CPU Vent	10,178 (22,439)
		Fly Ash	139 (306)
Total	**139,582 (307,726)**	**Total**	**139,582 (307,726)**

Exhibit 3-23 Case Baseline760 carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	118,033 (260,218)	CO_2 Product	109,640 (241,715)
Air (CO_2)	232 (511)	Bottom Ash	3,855 (8,498)
Limestone Reagent	4,509 (9,940)	Separated Air	226 (497)
		CPU Vent	8,932 (19,692)
		Fly Ash	122 (268)
Total	**122,774 (270,670)**	**Total**	**122,774 (270,670)**

Exhibit 3-24 shows the sulfur balance for Case Baseline620. Sulfur input comes only from the sulfur present in the coal. As with the Reference Rankine Cases, most sulfur leaves the plant with the bottom ash because of in-bed limestone SO_2 removal. For the sCO_2 Cases, however, the in-bed sulfur capture was assumed to be 100 percent so sulfur enters or leaves the CPU.

Exhibit 3-24 Case Baseline620 sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	5,288 (11,657)	Bottom Ash	4,950 (10,914)
		CO_2 Product	2 (4)
		Fly Ash	156 (345)
		CPU Water	178 (392)
Total	**5,288 (11,657)**	**Total**	**5,288 (11,657)**

Exhibit 3-25 shows the sulfur balance for Case Baseline760.

Exhibit 3-25 Case Baseline760 sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	4,640 (10,230)	Bottom Ash	4,349 (9,587)
		CO_2 Product	2 (3)
		Fly Ash	137 (303)
		CPU Water	156 (344)
Total	**4,640 (10,230)**	**Total**	**4,640 (10,230)**

Exhibit 3-26 shows the overall water balance for Case Baseline620 and Exhibit 3-27 shows the overall water balance for Case Baseline760.

Exhibit 3-26 Case Baseline620 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	27.74 (7328)	1.7 (449)	26.04 (6879)	6.24 (1648)	19.80 (5231)
MAC knock-out	0.00 ()	0.0 (2)	0.00 ()	0.00 (0)	0.00 ()
ASU discharge	0.0 (0)	0.00 (0)	0.0 (0)	0.19 (49)	0.00 ()
Total	**27.7 (7,328)**	**1.71 (451)**	**26.0 (6,879)**	**6.42 (1,697)**	**19.80 (5,231)**

Exhibit 3-27 Case Baseline760 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	22.46 (5935)	1.5 (394)	20.97 (5541)	5.05 (1335)	15.92 (4206)
MAC knock-out	0.00 ()	0.0 (2)	0.00 ()	0.00 (0)	0.00 ()
ASU discharge	0.0 (0)	0.00 (0)	0.0 (0)	0.16 (43)	0.00 ()
Total	**22.5 (5,935)**	**1.50 (396)**	**21.0 (5,541)**	**5.21 (1,378)**	**15.92 (4,206)**

3.4 Performance Comparison Between Reference Rankine and Baseline sCO_2

Exhibit 3-28 compares the performance of the two reference Rankine cycles and the two Baseline sCO_2 cycles.

Exhibit 3-28 Performance comparison between Reference Rankine and Baseline sCO_2

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Baseline620	Case Baseline760
CFB Coal Flow Rate (lb/hr)	478,280	436,129	464,000	407,200
Limestone Flow Rate (lb/hr)	114,987	104,732	111,627	97,962
Oxygen Flow Rate (lb/hr)	1,021,874	931,831	991,637	870,247
sCO_2 Flow Rate (lb/hr)	---	---	42,305,305	33,040,523
Net Plant Efficiency (HHV %)	**33.64**	**36.88**	**34.67**	**39.49**
HHV Heat Rate (Btu/kWh)	10,144	9,251	9,843	8,640
sCO_2 Power Cycle Efficiency (%)	---	---	48.67	53.90
sCO_2 Cycle Heat Rate (Btu/kWh)	---	---	7,010	6,331
Steam Power Cycle Efficiency (%)	48.27	51.84	---	---
Steam Cycle Heat Rate (Btu/kWh)	7,068	6,582	---	---
Coal Thermal Input (MMBtu/hr)	5,580	5,088	5,413	4,750
Power Cycle Thermal Input (MMBtu/hr)	5,122	4,672	4,987	4,376
Fractional Thermal Input to Power Cycle	0.918	0.918	0.921	0.921
sCO2 Cycle Specific Power (Wh/lb)			16.82	20.92
Raw Water Withdrawal (gpm)	8,418	7,314	6,879	5,541
Power Summary				
Steam Turbine Power Output	721,000	705,600	---	---
sCO_2 Cycle Power Output	---	---	711,367	691,273
Gross Power Output	721,000	705,600	711,367	691,273
Total Auxiliary Power Load	170,954	155,618	**161,457**	**141,474**
Net Power Output	550,046	549,982	549,910	549,799

3.4.1 Reference SC Rankine Compared to Case Baseline620

Referring to Exhibit 3-28 and the results for Case Baseline620, the net plant HHV efficiency for the sCO_2 cycle is 1.03 percentage points higher than the Reference SC Rankine cycle plant. The higher process efficiency of the baseline sCO_2 plant compared to the reference SC Rankine plant is due both to the higher power cycle efficiency for the sCO_2 Brayton cycle compared to the SC Rankine cycle (48.67 versus 48.27 percent) and the lower auxiliary power requirement for the sCO_2 plant compared to the Reference SC Rankine plant at the same net power output.

A systems analysis of a sCO_2 power cycle without thermal integration and operating at the same process conditions shown in Exhibit 3-16 yields a cycle efficiency of 49.04 percent. The thermal integration with the flue gas heat exchanger used in the baseline sCO_2 recompression plant increases the total fraction of coal thermal input that can be utilized in the power cycle (by 3.1 percent), but decreases the cycle efficiency because it lowers the amount of CO_2 that bypasses the cooler. In the balance, the thermal integration is worthwhile because the increase in recovered heat more than offsets the drop in cycle efficiency.

The water demand for Case Baseline620 was 18 percent lower than the Reference SC Rankine plant because it had less process cooling duty requirement and because it eliminated water loses in the Rankine cycle.

3.4.2 Reference AUSC Rankine Compared to Case Baseline760

Comparing the results of Case Baseline760 and the Reference AUSC Rankine cycle plant, the net plant efficiency for the sCO_2 cycle plant is 2.61 percentage points higher than the AUSC Rankine plant. As with Case Baseline620, The higher process efficiency of the baseline sCO_2 plant compared to the reference AUSC Rankine plant is due both to the higher power cycle efficiency for the sCO_2 Brayton cycle compared to the SC Rankine cycle (53.90 versus 51.84 percent) and the lower auxiliary power requirement for the sCO_2 plant compared to the Reference AUSC Rankine plant at the same net power output. The relatively higher increase in efficiency of the sCO_2 cycle plant over the Rankine cycle plant is due to the larger increase in power cycle efficiency for the sCO_2 cycle (5.23 percentage points) compared to the Rankine cycle (3.57 percentage points) in going from SC to AUSC conditions. This is consistent with other studies that show that the sensitivity of the sCO_2 cycle to TIT is significantly greater than the corresponding sensitivity for the Rankine cycle. [14] [15] The differences in auxiliary power requirement and water usage for Case Baseline760 compared to the Reference AUSC Rankine Case are similar in relative magnitude to the corresponding differences in Case Baseline620 and the Reference SC Rankine Case.

3.4.3 Comparison Between Baseline sCO_2 Cases

Comparing the results of Case Baseline620 and Baseline760, Case Baseline 760 attained an increase of 4.82 percentage points in process efficiency and a 5.23 percentage points in sCO_2 cycle efficiency. These improvements, and the secondary impacts such as reduced water withdrawal, resulted entirely from the increase in TIT. This is also reflected in the greater turbine:compressor power ratio and greater specific power of the sCO_2 cycle for Case Baseline760 compared to Case Baseline620.

3.5 Alternative Cycle Configurations Examined to Improve Performance

Additional analyses were conducted to determine if further improvement in the sCO_2 Brayton cycle performance could be obtained by altering the cycle configuration. Three additional configurations were analyzed for the baseline sCO_2 conceptual commercial power plant. These were:

- Recompression cycle with reheat
- Recompression cycle with main compressor intercooling

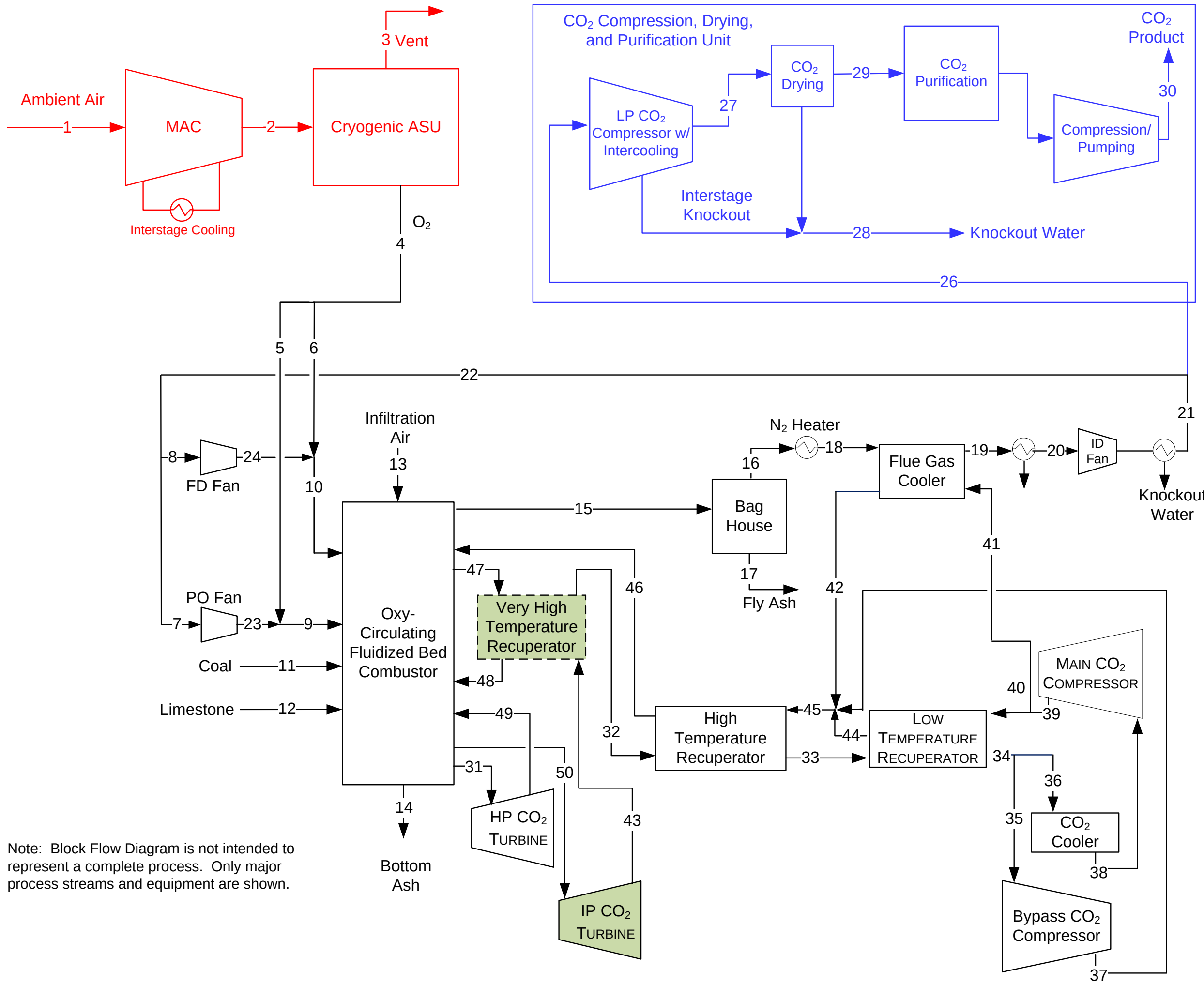
- Recompression cycle with combination of reheat and intercooling

These process modifications are intended to either 1) increase the fraction of plant thermal input that is captured in the sCO_2 cycle, 2) increase the sCO_2 power cycle efficiency, 3) decrease the sCO_2 plant auxiliary power requirement, or 4) provide some combination of these three effects.

3.6 Recompression Cycle with Reheat

Exhibit 3-29 shows a BFD of the sCO_2 recompression Brayton power plant with reheat. The new units for this configuration are shown in green. In this configuration, the sCO_2 exiting the high pressure (HP) expansion turbine is returned to the CFB furnace to be reheated before it is expanded in the intermediate pressure (IP) turbine. The pressure ratios in the two turbines are approximately equal. If the temperature exiting the IP turbine is sufficiently high, an additional recuperation step, shown in Exhibit 3-29, is included. All other aspects of the plant configuration are the same as for the baseline sCO_2 recompression power plant.

Exhibit 3-29 Block flow diagram for the sCO_2 recompression Brayton cycle with reheat



Source: NETL

3.6.1 Recompression Cycle with Reheat Performance Results

The stream tables that correspond to the BFD in Exhibit 3-29 are shown in Exhibit 3-30 and Exhibit 3-31. Exhibit 3-30 corresponds to a TIT of 1148 °F (Case Reheat620) and Exhibit 3-31 corresponds to a TIT of 1400 °F (Case Reheat760). Overall plant performance for both Reheat cases is summarized in Exhibit 3-32, and a detailed breakdown of auxiliary power requirements for both Reheat cases is provided in Exhibit 3-33. Exhibit 3-34 provides a detailed breakdown of the sCO_2 power cycle performance for the Reheat cases.

Exhibit 3-30 Case Reheat620 stream table results

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0093	0.0025	0.0343	0.0343	0.0343	0.0352	0.0352	0.0347	0.0347	0.0000
CO_2	0.0003	0.0003	0.0004	0.0000	0.0000	0.0000	0.8062	0.8062	0.3626	0.3626	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
H_2O	0.0099	0.0094	0.0000	0.0000	0.0000	0.0000	0.0397	0.0397	0.0179	0.0179	0.0000
N_2	0.7732	0.7735	0.9907	0.0162	0.0162	0.0162	0.0971	0.0971	0.0526	0.0526	0.0000
O_2	0.2074	0.2075	0.0064	0.9495	0.9495	0.9495	0.0214	0.0214	0.5321	0.5321	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002	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
V-L Flowrate (kg_{mol}/hr)	62,713	62,683	48,724	13,370	3,142	10,228	2,568	8,361	5,710	18,589	0
V-L Flowrate (kg/hr)	1,809,718	1,809,173	1,367,956	430,605	101,192	329,413	105,389	343,076	206,582	672,489	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	201,486
Temperature (°C)	15	38	19	13	13	13	32	32	27	24	15
Pressure (MPa, abs)	0.10	0.69	0.10	0.16	0.16	0.16	0.10	0.10	0.11	0.11	0.11
Enthalpy (kJ/kg)[A]	30.54	52.80	19.65	10.99	10.99	10.99	70.38	70.38	45.23	42.81	---
Density (kg/m^3)	1.2	7.7	1.2	2.2	2.2	2.2	1.6	1.6	1.6	1.5	---
V-L Molecular Weight	28.857	28.862	28.075	32.207	32.207	32.207	41.032	41.032	36.176	36.176	---
V-L Flowrate (lb_{mol}/hr)	138,259	138,193	107,419	29,476	6,927	22,549	5,663	18,433	12,589	40,982	0
V-L Flowrate (lb/hr)	3,989,746	3,988,543	3,015,827	949,321	223,090	726,231	232,344	756,354	455,434	1,482,584	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	444,200
Temperature (°F)	59	100	66	55	55	55	90	90	80	75	59
Pressure (psia)	14.7	100.5	14.7	23.2	23.2	23.2	14.7	14.7	16.2	15.3	16.1
Enthalpy (Btu/lb)[A]	13.1	22.7	8.4	4.7	4.7	4.7	30.3	30.3	19.4	18.4	---
Density (lb/ft^3)	0.076	0.483	0.073	0.136	0.136	0.136	0.103	0.103	0.101	0.097	---

A - Steam Table Reference conditions are 32.02°F and 0.089 psia
* - AspenPlus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm

Exhibit 3-30 Case Reheat620 stream table results (continued)

	12	13	14	15	16	17	18	19	20	21	22
V-L Mole Fraction											
Ar	0.0000	0.0092	0.0000	0.0293	0.0000	0.0293	0.0293	0.0293	0.0293	0.0352	0.0352
CO_2	0.0000	0.0005	0.0000	0.6707	0.0000	0.6707	0.6707	0.6707	0.6707	0.8062	0.8062
H_2	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	0.0101	0.0000	0.2010	0.0000	0.2010	0.2010	0.2010	0.2010	0.0397	0.0397
N_2	0.0000	0.7729	0.0000	0.0808	0.0000	0.0808	0.0808	0.0808	0.0808	0.0971	0.0971
O_2	0.0000	0.2074	0.0000	0.0178	0.0000	0.0178	0.0178	0.0178	0.0178	0.0214	0.0214
SO_2	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	1,254	0	29,191	0	29,191	29,191	29,191	29,191	24,288	10,930
V-L Flowrate (kg/hr)	0	36,194	0	1,084,924	0	1,084,924	1,084,924	1,084,924	1,084,924	996,590	448,466
Solids Flowrate (kg/hr)	48,472	0	78,485	1,860	1,860	0	0	0	0	0	0
Temperature (°C)	15	15	25	243	25	243	218	82	89	32	32
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	---	30.57	---	485.04	---	491.37	463.98	321.86	328.63	70.38	70.38
Density (kg/m^3)	---	1.2	---	0.9	---	0.8	0.9	1.2	1.3	1.7	1.7
V-L Molecular Weight	---	28.856	---	37.166	---	37.166	37.166	37.166	37.166	41.032	41.032
V-L Flowrate (lb_{mol}/hr)	0	2,765	0	64,356	0	64,356	64,356	64,356	64,356	53,546	24,096
V-L Flowrate (lb/hr)	0	79,795	0	2,391,848	0	2,391,848	2,391,848	2,391,848	2,391,848	2,197,106	988,697
Solids Flowrate (lb/hr)	106,863	0	173,030	4,101	4,101	0	0	0	0	0	0
Temperature (°F)	59	59	77	469	77	469	424	180	192	90	90
Pressure (psia)	14.7	14.7	14.7	14.3	14.7	14.1	14.0	13.9	14.8	14.8	14.8
Enthalpy (Btu/lb)[A]	---	13.1	---	208.5	---	211.3	199.5	138.4	141.3	30.3	30.3
Density (lb/ft^3)	---	0.076	---	0.053	---	0.053	0.055	0.076	0.079	0.103	0.103

Exhibit 3-30 Case Reheat620 stream table results (continued)

	23	24	26	27	28	29	30	31	32	33	34
V-L Mole Fraction											
Ar	0.0352	0.0352	0.0352	0.0365	0.0000	0.0367	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.8062	0.8062	0.8062	0.8359	0.0001	0.8398	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0397	0.0397	0.0397	0.0042	0.9900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0971	0.0971	0.0971	0.1007	0.0000	0.1012	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0214	0.0214	0.0214	0.0222	0.0000	0.0223	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0004	0.0004	0.0004	0.0004	0.0099	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
V-L Flowrate (kg_{mol}/hr)	2,568	8,361	13,359	12,883	536	12,823	9,958	402,053	402,053	402,053	402,053
V-L Flowrate (kg/hr)	105,389	343,076	548,125	539,553	9,896	538,228	438,245	17,694,251	17,694,251	17,694,251	17,694,251
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	41	36	32	99	35	38	37	620	398	218	82
Pressure (MPa, abs)	0.11	0.11	0.10	3.00	0.10	3.00	15.20	34.30	9.24	9.17	9.10
Enthalpy (kJ/kg)[A]	78.10	73.37	70.38	73.49	145.38	6.95	-206.34	630.19	377.53	169.74	-2.06
Density (kg/m^3)	1.8	1.7	1.7	43.4	77.9	55.5	536.8	188.5	73.0	105.8	189.2
V-L Molecular Weight	41.032	41.032	41.032	41.882	18.472	41.974	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	5,663	18,433	29,451	28,402	1,181	28,269	21,953	886,374	886,374	886,374	886,374
V-L Flowrate (lb/hr)	232,344	756,354	1,208,408	1,189,512	21,817	1,186,591	966,165	39,009,147	39,009,147	39,009,147	39,009,147
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	106	96	90	210	95	100	99	1,148	749	424	180
Pressure (psia)	16.2	15.3	14.8	435.1	14.8	435.1	2,205.0	4,974.7	1,340.0	1,330.0	1,320.0
Enthalpy (Btu/lb)[A]	33.6	31.5	30.3	31.6	62.5	3.0	-88.7	270.9	162.3	73.0	-0.9
Density (lb/ft^3)	0.110	0.106	0.103	2.707	4.865	3.462	33.509	11.769	4.560	6.605	11.812

Exhibit 3-30 Case Reheat620 stream table results (continued)

	35	36	37	38	39	40	41	42	43	44	45
V-L Mole Fraction											
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	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)	100,120	301,933	100,120	301,933	301,933	287,357	14,576	14,576	402,053	287,357	402,053
V-L Flowrate (kg/hr)	4,406,241	13,288,010	4,406,241	13,288,010	13,288,010	12,646,544	641,467	641,467	17,694,251	12,646,544	17,694,251
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	82	82	212	35	76	76	76	212	545	212	212
Pressure (MPa, abs)	9.10	9.10	34.58	9.03	34.64	34.64	34.64	34.58	9.31	34.58	34.58
Enthalpy (kJ/kg)[A]	-2.06	-2.06	93.11	-187.40	-147.27	-147.27	-147.27	93.10	551.63	93.11	93.11
Density (kg/m^3)	189.2	189.2	422.4	664.4	799.4	799.4	799.4	422.4	59.5	422.4	422.4
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	220,726	665,648	220,726	665,648	665,648	633,515	32,134	32,134	886,374	633,515	886,374
V-L Flowrate (lb/hr)	9,714,099	29,295,048	9,714,099	29,295,048	29,295,048	27,880,856	1,414,192	1,414,192	39,009,147	27,880,856	39,009,147
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	180	180	414	95	170	170	170	414	1,013	414	414
Pressure (psia)	1,320.0	1,320.0	5,014.7	1,310.0	5,024.7	5,024.7	5,024.7	5,014.7	1,350.0	5,014.7	5,014.7
Enthalpy (Btu/lb)[A]	-0.9	-0.9	40.0	-80.6	-63.3	-63.3	-63.3	40.0	237.2	40.0	40.0
Density (lb/ft^3)	11.812	11.812	26.367	41.477	49.904	49.904	49.904	26.367	3.712	26.367	26.367

Exhibit 3-30 Case Reheat620 stream table results (continued)

	46	47	48	49	50
V-L Mole Fraction					
Ar	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	402,053	402,053	402,053	402,053	402,053
V-L Flowrate (kg/hr)	17,694,251	17,694,251	17,694,251	17,694,251	17,694,251
Solids Flowrate (kg/hr)	0	0	0	0	0
Temperature (°C)	363	393	529	522	620
Pressure (MPa, abs)	34.51	34.44	34.37	16.51	16.44
Enthalpy (kJ/kg)^A	300.90	339.57	513.68	517.63	638.38
Density (kg/m^3)	280.9	264.6	212.3	107.4	94.5
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	886,374	886,374	886,374	886,374	886,374
V-L Flowrate (lb/hr)	39,009,147	39,009,147	39,009,147	39,009,147	39,009,147
Solids Flowrate (lb/hr)	0	0	0	0	0
Temperature (°F)	685	739	984	972	1,148
Pressure (psia)	5,004.7	4,994.7	4,984.7	2,395.0	2,385.0
Enthalpy (Btu/lb)^A	129.4	146.0	220.8	222.5	274.5
Density (lb/ft^3)	17.536	16.516	13.255	6.703	5.897

Exhibit 3-31 Case Reheat760 stream table results

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0093	0.0025	0.0343	0.0343	0.0343	0.0352	0.0352	0.0347	0.0347	0.0000
CO_2	0.0003	0.0003	0.0004	0.0000	0.0000	0.0000	0.8062	0.8062	0.3626	0.3626	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
H_2O	0.0099	0.0094	0.0000	0.0000	0.0000	0.0000	0.0397	0.0397	0.0179	0.0179	0.0000
N_2	0.7732	0.7735	0.9907	0.0162	0.0162	0.0162	0.0971	0.0971	0.0526	0.0526	0.0000
O_2	0.2074	0.2075	0.0064	0.9495	0.9495	0.9495	0.0214	0.0214	0.5321	0.5321	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002	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
V-L Flowrate (kg_{mol}/hr)	55,626	55,599	43,218	11,859	2,787	9,072	2,278	7,416	5,065	16,488	0
V-L Flowrate (kg/hr)	1,605,198	1,604,714	1,213,360	381,941	89,756	292,185	93,479	304,304	183,235	596,490	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	178,715
Temperature (°C)	15	38	19	13	13	13	32	32	27	24	15
Pressure (MPa, abs)	0.10	0.69	0.10	0.16	0.16	0.16	0.10	0.10	0.11	0.11	0.11
Enthalpy (kJ/kg)^A	30.54	52.80	19.65	10.99	10.99	10.99	70.38	70.38	45.23	42.81	---
Density (kg/m^3)	1.2	7.7	1.2	2.2	2.2	2.2	1.6	1.6	1.6	1.5	---
V-L Molecular Weight	28.857	28.862	28.075	32.207	32.207	32.207	41.032	41.032	36.176	36.176	---
V-L Flowrate (lb_{mol}/hr)	122,634	122,575	95,279	26,145	6,144	20,001	5,023	16,350	11,167	36,351	0
V-L Flowrate (lb/hr)	3,538,856	3,537,789	2,675,002	842,036	197,879	644,158	206,086	670,876	403,965	1,315,034	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	394,000
Temperature (°F)	59	100	66	55	55	55	90	90	80	75	59
Pressure (psia)	14.7	100.5	14.7	23.2	23.2	23.2	14.7	14.7	16.2	15.3	16.1
Enthalpy (Btu/lb)^A	13.1	22.7	8.4	4.7	4.7	4.7	30.3	30.3	19.4	18.4	---
Density (lb/ft^3)	0.076	0.483	0.073	0.136	0.136	0.136	0.103	0.103	0.101	0.097	---

Exhibit 3-31 Case Reheat760 stream table results (continued)

	12	13	14	15	16	17	18	19	20	21	22
V-L Mole Fraction											
Ar	0.0000	0.0092	0.0000	0.0293	0.0000	0.0293	0.0293	0.0293	0.0293	0.0352	0.0352
CO_2	0.0000	0.0005	0.0000	0.6707	0.0000	0.6707	0.6707	0.6707	0.6707	0.8062	0.8062
H_2	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	0.0101	0.0000	0.2010	0.0000	0.2010	0.2010	0.2010	0.2010	0.0397	0.0397
N_2	0.0000	0.7729	0.0000	0.0808	0.0000	0.0808	0.0808	0.0808	0.0808	0.0971	0.0971
O_2	0.0000	0.2074	0.0000	0.0178	0.0000	0.0178	0.0178	0.0178	0.0178	0.0214	0.0214
SO_2	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	1,113	0	25,892	0	25,892	25,892	25,892	25,892	21,543	9,695
V-L Flowrate (kg/hr)	0	32,104	0	962,314	0	962,314	962,314	962,314	962,314	883,963	397,784
Solids Flowrate (kg/hr)	42,994	0	69,620	1,650	1,650	0	0	0	0	0	0
Temperature (°C)	15	15	25	243	25	243	218	82	89	32	32
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	---	30.57	---	485.04	---	491.37	463.98	321.87	328.63	70.38	70.38
Density (kg/m^3)	---	1.2	---	0.9	---	0.8	0.9	1.2	1.3	1.7	1.7
V-L Molecular Weight	---	28.856	---	37.166	---	37.166	37.166	37.166	37.166	41.032	41.032
V-L Flowrate (lb_{mol}/hr)	0	2,453	0	57,083	0	57,083	57,083	57,083	57,083	47,495	21,373
V-L Flowrate (lb/hr)	0	70,777	0	2,121,540	0	2,121,540	2,121,540	2,121,540	2,121,540	1,948,806	876,963
Solids Flowrate (lb/hr)	94,787	0	153,486	3,638	3,638	0	0	0	0	0	0
Temperature (°F)	59	59	77	469	77	469	424	180	192	90	90
Pressure (psia)	14.7	14.7	14.7	14.3	14.7	14.1	14.0	13.9	14.8	14.8	14.8
Enthalpy (Btu/lb)[A]	---	13.1	---	208.5	---	211.3	199.5	138.4	141.3	30.3	30.3
Density (lb/ft^3)	---	0.076	---	0.053	---	0.053	0.055	0.076	0.079	0.103	0.103

Exhibit 3-31 Case Reheat760 stream table results (continued)

	23	24	26	27	28	29	30	31	32	33	34
V-L Mole Fraction											
Ar	0.0352	0.0352	0.0352	0.0365	0.0000	0.0367	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.8062	0.8062	0.8062	0.8359	0.0001	0.8398	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0397	0.0397	0.0397	0.0042	0.9900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0971	0.0971	0.0971	0.1007	0.0000	0.1012	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0214	0.0214	0.0214	0.0222	0.0000	0.0223	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0004	0.0004	0.0004	0.0004	0.0099	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
V-L Flowrate (kg_{mol}/hr)	2,278	7,416	11,849	11,427	475	11,374	8,833	318,125	318,125	318,125	318,125
V-L Flowrate (kg/hr)	93,479	304,304	486,180	478,577	8,778	477,402	388,721	14,000,618	14,000,618	14,000,618	14,000,618
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	41	36	32	99	35	38	37	760	423	218	82
Pressure (MPa, abs)	0.11	0.11	0.10	3.00	0.10	3.00	15.20	34.30	9.24	9.17	9.10
Enthalpy (kJ/kg)[A]	78.10	73.37	70.38	73.49	145.38	6.95	-206.34	811.08	406.64	169.74	-2.06
Density (kg/m^3)	1.8	1.7	1.7	43.4	77.9	55.5	536.8	162.0	70.2	105.8	189.2
V-L Molecular Weight	41.032	41.032	41.032	41.882	18.472	41.974	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	5,023	16,350	26,122	25,192	1,048	25,075	19,473	701,346	701,346	701,346	701,346
V-L Flowrate (lb/hr)	206,086	670,876	1,071,843	1,055,082	19,352	1,052,491	856,982	30,866,079	30,866,079	30,866,079	30,866,079
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	106	96	90	210	95	100	99	1,400	794	424	180
Pressure (psia)	16.2	15.3	14.8	435.1	14.8	435.1	2,205.0	4,974.7	1,340.0	1,330.0	1,320.0
Enthalpy (Btu/lb)[A]	33.6	31.5	30.3	31.6	62.5	3.0	-88.7	348.7	174.8	73.0	-0.9
Density (lb/ft^3)	0.110	0.106	0.103	2.707	4.865	3.462	33.509	10.112	4.381	6.605	11.812

Exhibit 3-31 Case Reheat760 stream table results (continued)

	35	36	37	38	39	40	41	42	43	44	45
V-L Mole Fraction											
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	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)	77,825	240,300	77,825	240,300	240,300	227,372	12,928	12,928	318,125	227,372	318,125
V-L Flowrate (kg/hr)	3,425,073	10,575,545	3,425,073	10,575,545	10,575,545	10,006,596	568,950	568,950	14,000,618	10,006,596	14,000,618
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	82	82	212	35	76	76	76	212	677	212	212
Pressure (MPa, abs)	9.10	9.10	34.58	9.03	34.64	34.64	34.64	34.58	9.31	34.58	34.58
Enthalpy (kJ/kg)[A]	-2.06	-2.06	93.11	-187.40	-147.27	-147.27	-147.27	93.11	713.52	93.11	93.11
Density (kg/m^3)	189.2	189.2	422.4	664.4	799.4	799.4	799.4	422.4	50.9	422.4	422.4
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	171,575	529,770	171,575	529,770	529,770	501,269	28,501	28,501	701,346	501,269	701,346
V-L Flowrate (lb/hr)	7,550,992	23,315,087	7,550,992	23,315,087	23,315,087	22,060,767	1,254,320	1,254,320	30,866,079	22,060,767	30,866,079
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	180	180	414	95	170	170	170	414	1,251	414	414
Pressure (psia)	1,320.0	1,320.0	5,014.7	1,310.0	5,024.7	5,024.7	5,024.7	5,014.7	1,350.0	5,014.7	5,014.7
Enthalpy (Btu/lb)[A]	-0.9	-0.9	40.0	-80.6	-63.3	-63.3	-63.3	40.0	306.8	40.0	40.0
Density (lb/ft^3)	11.812	11.812	26.367	41.477	49.904	49.904	49.904	26.366	3.177	26.367	26.367

Exhibit 3-31 Case Reheat760 stream table results (continued)

	46	47	48	49	50
V-L Mole Fraction					
Ar	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	318,125	318,125	318,125	318,125	318,125
V-L Flowrate (kg/hr)	14,000,618	14,000,618	14,000,618	14,000,618	14,000,618
Solids Flowrate (kg/hr)	0	0	0	0	0
Temperature (°C)	385	418	658	653	760
Pressure (MPa, abs)	34.51	34.44	34.37	16.51	16.44
Enthalpy (kJ/kg)[A]	330.01	371.57	678.45	679.30	814.66
Density (kg/m^3)	268.7	252.9	180.8	91.3	81.2
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	701,346	701,346	701,346	701,346	701,346
V-L Flowrate (lb/hr)	30,866,079	30,866,079	30,866,079	30,866,079	30,866,079
Solids Flowrate (lb/hr)	0	0	0	0	0
Temperature (°F)	726	784	1,216	1,207	1,400
Pressure (psia)	5,004.7	4,994.7	4,984.7	2,395.0	2,385.0
Enthalpy (Btu/lb)[A]	141.9	159.7	291.7	292.0	350.2
Density (lb/ft^3)	16.777	15.788	11.287	5.700	5.069

Exhibit 3-32 Reheat sCO_2 plant performance summary

Parameter	Case Reheat620	Case Reheat760
CFB Coal Flow Rate (lb/hr)	444,200	394,000
Limestone Flow Rate (lb/hr)	106,863	94,787
Oxygen Flow Rate (lb/hr)	949,321	842,036
Coal Thermal Input (MMBtu/hr)	5,182	4,596
Net Plant Power Output (kW)	549,780	550,117
Net Plant Efficiency (HHV %)	**36.20**	**40.84**
HHV Heat Rate (Btu/kWh)	9,425	8,356
Raw Water Withdrawal (gpm)	6,414	5,235

Exhibit 3-33 Plant power summary for Reheat cases

POWER SUMMARY		
Item (kW)	**Case Reheat620**	**Case Reheat760**
POWER CYCLE SUMMARY		
sCO_2 Turbine Gross Power	979,600	905,800
sCO_2 Main Compressor	-148,100	-117,900
sCO_2 Bypass Compressor	-116,500	-90,500
sCO_2 Generator Loss	-10,725	-10,461
TOTAL sCO_2 POWER GENERATED	**704,275**	**686,939**
AUXILIARY LOAD SUMMARY		
Coal Handling	-455	-432
Limestone Prep	-210	-190
Pulverizers	-100	-80
Slag Handling and Dewatering	-2,370	-2,110
Primary Air Fans	-240	-210
Forced Draft Fans	-310	-270
Induced Draft Fans	-2,110	-1,870
Air Separation Unit	-79,210	-70,260
Baghouse	-10	-10
CPU (Purification and Compression) Auxiliaries	-54,020	-47,910
Turbine Auxiliaries	-400	-400
Miscellaneous Balance of Plant	-2,000	-2,000
Circulating Water Pump	-6,650	-5,460

POWER SUMMARY		
Item (kW)	**Case Reheat620**	**Case Reheat760**
Cooling Tower Fans	-3,880	-3,190
Transformer Losses	-2,530	-2,430
TOTAL AUXILIARIES	**-154,495**	**-136,822**
NET POWER	**549,780**	**550,117**

Exhibit 3-34 Reheat sCO_2 cycle performance summary

Parameter	Case Reheat620	Case Reheat760
THERMAL INPUT		
Power Cycle Thermal Input - CFB (MMBtu/hr)	4,627	4,104
Power Cycle Thermal Input – Flue gas (MMBtu/hr)	146	130
Power Cycle Thermal Input - Total (MMBtu/hr)	4,774	4,234
Fractional Thermal Input to Power Cycle	0.921	0.921
RECUPERATOR DUTY		
Recuperator Duty – VTR (MMBtu/hr)	2,920	4,072
Recuperator Duty – HTR (MMBtu/hr)	3,485	3,144
Recuperator Duty – LTR (MMBtu/hr)	2,881	2,280
Recuperator Duty – Total (MMBtu/hr)	9,286	9,496
COOLING DUTY		
Power Cycle Cooling Duty – CO_2 cooler (MMBtu/hr)	2,334	1,858
Power Cycle Cooling Duty – Total (MMBtu/hr)	2,334	1,858
POWER OUTPUT		
Net Cycle Power Output (kW)	704,275	686,939
SPECIFIC POWER		
sCO_2 Flow Rate (lb/hr)	39,009,147	30,866,079
sCO_2 Cycle Specific Power (Wh/lb)	18.05	22.25
sCO_2 Cycle Specific Power (kJ/kg)	143.3	176.6
OVERALL CYCLE PERFORMANCE		
sCO_2 Power Cycle Efficiency (%)	50.34	55.36
sCO_2 Cycle Heat Rate (Btu/kWh)	6,778	6,164

3.6.2 Effect of Reheat on the sCO_2 Power Cycle

Reheat is expected to increase the specific gross output of the sCO_2 turbine because the expansion more closely approaches an isothermal expansion, which will generate more power than either an isentropic or polytropic expansion. Reheat also increases the final turbine exit temperature allowing a greater HTR duty and increasing the temperature of the HP CO_2 stream entering the CFB, which again increases turbine output. Reheat is not expected to have a significant impact on the cooling and compression portions of the sCO_2 power cycle.

Comparing the results in Exhibit 3-33 and Exhibit 3-34 with the corresponding Baseline Case results in Exhibit 3-20 and Exhibit 3-21 shows that the net effect of reheat on the Baseline Cases follows these qualitative trends. For both TITs, adding reheat increased the gross specific turbine output and relative recuperator duties compared to the Baseline cases, thus increasing the power cycle and process efficiencies.

3.6.3 Case Mass Balances

The carbon balance for Case Reheat620 is shown in Exhibit 3-35 while the corresponding carbon balance for Case Reheat760 is shown in

Exhibit 3-36.

Exhibit 3-35 Case Reheat620 carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	128,758 (283,863)	CO_2 Product	119,602 (263,677)
Air (CO_2)	253 (558)	Bottom Ash	4,205 (9,270)
Limestone Reagent	4,919 (10,843)	Separated Air	246 (543)
		CPU Vent	9,744 (21,482)
		Fly Ash	133 (293)
Total	**133,929 (295,264)**	**Total**	**133,929 (295,264)**

Exhibit 3-36 Case Reheat760 carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	114,207 (251,783)	CO_2 Product	106,086 (233,880)
Air (CO_2)	224 (495)	Bottom Ash	3,730 (8,223)
Limestone Reagent	4,363 (9,618)	Separated Air	218 (481)
		CPU Vent	8,643 (19,054)
		Fly Ash	118 (260)
Total	**118,794 (261,896)**	**Total**	**118,794 (261,896)**

Exhibit 3-37 shows the sulfur balance for Case Reheat620.

Exhibit 3-37 Case Reheat620 sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	5,062 (11,160)	Bottom Ash	4,744 (10,459)
		CO_2 Product	2 (4)
		Fly Ash	150 (330)
		CPU Water	170 (375)
Total	**5,062 (11,160)**	**Total**	**5,062 (11,160)**

Exhibit 3-38 shows the sulfur balance for Case Reheat760.

Exhibit 3-38 Case Reheat760 sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	4,490 (9,899)	Bottom Ash	4,208 (9,276)
		CO_2 Product	2 (3)
		Fly Ash	133 (293)
		CPU Water	151 (332)
Total	**4,490 (9,899)**	**Total**	**4,490 (9,899)**

Exhibit 3-39 shows the overall water balance for Case Reheat620 and Exhibit 3-40 shows the overall water balance for Case Reheat760.

Exhibit 3-39 Case Reheat620 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	25.91 (6844)	1.6 (430)	24.28 (6414)	5.83 (1539)	18.45 (4875)
MAC knock-out	0.00 ()	0.0 (2)	0.00 ()	0.00 (0)	0.00 ()
ASU discharge	0.0 (0)	0.00 (0)	0.0 (0)	0.18 (47)	0.00 ()
Total	**25.9 (6,844)**	**1.64 (432)**	**24.3 (6,414)**	**6.00 (1,586)**	**18.45 (4,875)**

Exhibit 3-40 Case Reheat760 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	21.26 (5616)	1.4 (381)	19.82 (5235)	4.78 (1263)	15.04 (3972)
MAC knock-out	0.00 ()	0.0 (2)	0.00 ()	0.00 (0)	0.00 ()
Flue gas conden	0.0 (0)	0.00 (0)	0.0 (0)	0.16 (42)	0.00 ()
Total	**21.3 (5,616)**	**1.45 (383)**	**19.8 (5,235)**	**4.94 (1,305)**	**15.04 (3,972)**

3.7 Performance Comparison Between Reference Rankine, Baseline sCO_2 and Reheat sCO_2

Exhibit 3-41 compares the performance of the two reference Rankine cycles and the two Reheat sCO_2 cycles.

Exhibit 3-41 Performance comparison between Reference Rankine and Baseline sCO_2

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Reheat620	Case Reheat760
CFB Coal Flow Rate (lb/hr)	478,280	436,129	444,200	394,000
Limestone Flow Rate (lb/hr)	114,987	104,732	106,863	94,787
Oxygen Flow Rate (lb/hr)	1,021,874	931,831	949,321	842,036
sCO_2 Flow Rate (lb/hr)	---	---	39,009,147	30,866,079
Net Plant Efficiency (HHV %)	**33.64**	**36.88**	**36.20**	**40.84**
HHV Heat Rate (Btu/kWh)	10,144	9,251	9,425	8,356
sCO_2 Power Cycle Efficiency (%)	---	---	50.34	55.36
sCO_2 Cycle Heat Rate (Btu/kWh)	---	---	6,778	6,164
Steam Power Cycle Efficiency (%)	48.27	51.84	---	---
Steam Cycle Heat Rate (Btu/kWh)	7,068	6,582	---	---
Coal Thermal Input (MMBtu/hr)	5,580	5,088	5,182	4,596
Power Cycle Thermal Input (MMBtu/hr)	5,122	4,672	4,774	4,234
Fractional Thermal Input to Power Cycle	0.918	0.918	0.921	0.921
sCO2 Cycle Specific Power (Wh/lb)			18.05	22.25
Raw Water Withdrawal (gpm)	8,418	7,314	6,414	5,235

Power Summary				
Steam Turbine Power Output	721,000	705,600	---	---
sCO_2 Cycle Power Output	---	---	704,275	686,939
Gross Power Output	721,000	705,600	704,275	686,939
Total Auxiliary Power Load	**170,954**	**155,618**	**154,495**	**136,822**
Net Power Output	**550,046**	**549,982**	**549,780**	**550,117**

3.7.1 Performance Comparison Between Reference SC Rankine, Case Baseline620 and Case Reheat620

Exhibit 3-42 compares the performance of the SC Rankine and the sCO_2 Brayton cycles with and without reheat with a TIT of 620 °C. Because of reheat, the sCO_2 power cycle efficiency has increased from 48.67 to 50.34 percent, and the overall plant efficiency has increased from 34.67 to 36.20 percent for a 1.53 percentage point increase. The process efficiency for the sCO_2 reheat plant is 2.56 percentage points higher than the reference SC Rankine plant.

Exhibit 3-42 Performance comparison between Reference, Baseline, and Reheat sCO_2 at 620 °C

Parameter	Reference SC Rankine	Case Baseline620	Case Reheat620
CFB Coal Flow Rate (lb/hr)	478,280	464,000	444,200
Limestone Flow Rate (lb/hr)	114,987	111,627	106,863
Oxygen Flow Rate (lb/hr)	1,021,874	991,637	949,321
sCO_2 Flow Rate (lb/hr)	---	42,305,305	39,009,147
Net Plant Efficiency (HHV %)	**33.64**	**34.67**	**36.20**
HHV Heat Rate (Btu/kWh)	10,144	9,843	9,425
sCO_2 Power Cycle Efficiency (%)	---	48.67	50.34
sCO_2 Cycle Heat Rate (Btu/kWh)	---	7,010	6,778
Steam Power Cycle Efficiency (%)	48.27	---	---
Steam Cycle Heat Rate (Btu/kWh)	7,068	---	---
Coal Thermal Input (MMBtu/hr)	5,580	5,413	5,182
Power Cycle Thermal Input (MMBtu/hr)	5,122	4,987	4,774
Fractional Thermal Input to Power Cycle	0.918	0.921	0.921
sCO2 Cycle Specific Power (kJ/kg)		16.82	18.05
Raw Water Withdrawal (gpm)	8,418	6,879	6,414
Power Summary			
Steam Turbine Power Output	721,000	---	---
sCO_2 Cycle Power Output	---	711,367	704,275

Gross Power Output	721,000	711,367	704,275
Total Auxiliary Power Load	**170,954**	**161,457**	**154,495**
Net Power Output	**550,046**	**549,910**	**549,780**

3.7.2 Performance Comparison Between Reference AUSC Rankine, Case Baseline760 and Case Reheat760

Exhibit 3-43 compares the performance of the AUSC Rankine and the sCO_2 Brayton cycles with and without reheat with a TIT of 760 °C. In this case, the use of reheat increases the sCO_2 power cycle efficiency from 53.90 to 55.36 percent, and the overall plant efficiency from 39.49 to 40.84 percent for a 1.35 percentage point increase. The process efficiency for the sCO_2 reheat plant is 3.96 percentage points higher than the reference AUSC Rankine plant.

Exhibit 3-43 Performance comparison between Reference, Baseline, and Reheat sCO_2 at 760 °C

Parameter	Reference AUSC Rankine	Case Baseline760	Case Reheat760
CFB Coal Flow Rate (lb/hr)	436,129	407,200	394,000
Limestone Flow Rate (lb/hr)	104,732	97,962	94,787
Oxygen Flow Rate (lb/hr)	931,831	870,247	842,036
sCO_2 Flow Rate (lb/hr)	---	33,040,523	30,866,079
Net Plant Efficiency (HHV %)	**36.88**	**39.49**	**40.84**
HHV Heat Rate (Btu/kWh)	9,251	8,640	8,356
sCO_2 Power Cycle Efficiency (%)	---	53.90	55.36
sCO_2 Cycle Heat Rate (Btu/kWh)	---	6,331	6,164
Steam Power Cycle Efficiency (%)	51.84	---	---
Steam Cycle Heat Rate (Btu/kWh)	6,582	---	---
Coal Thermal Input (MMBtu/hr)	5,088	4,750	4,596
Power Cycle Thermal Input (MMBtu/hr)	4,672	4,376	4,234
Fractional Thermal Input to Power Cycle	0.918	0.921	0.921
sCO2 Cycle Specific Power (kJ/kg)		20.92	22.25
Raw Water Withdrawal (gpm)	7,314	5,541	5,235
Power Summary			
Steam Turbine Power Output	705,600	---	---
sCO_2 Cycle Power Output	---	691,273	686,939
Gross Power Output	705,600	691,273	686,939
Total Auxiliary Power Load	**155,618**	**141,474**	**136,822**
Net Power Output	**549,982**	**549,799**	**550,117**

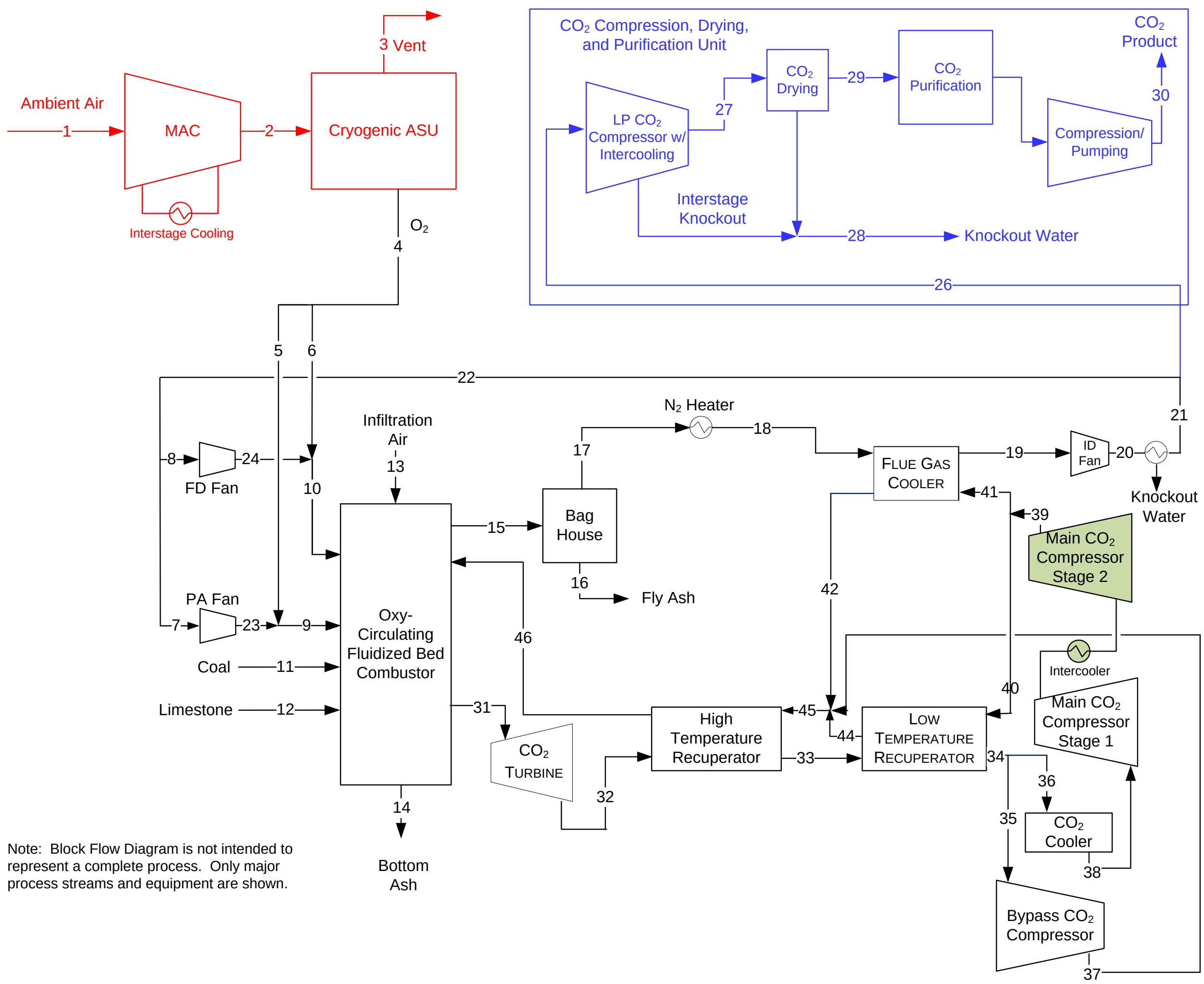
3.7.3 Comparison Between Reheat Cases

The use of reheat yielded significant increases in cycle efficiency and process efficiency for both reheat cases, but the magnitude of these increases was about 13-14 percent greater for Case Reheat620 compared to Case Reheat760. The drop in the relative magnitude of the increase in cycle performance with TIT is an expected trend for a recuperated Brayton cycle.

3.8 Recompression Cycle with Main Compressor Intercooling

Exhibit 3-44 shows the BFD for the sCO_2 plant with main compressor intercooling. This BFD is the same as for Exhibit 3-15 except for the intercooler between the two main compressor stages. There is no intercooler on the bypass compressor.

Exhibit 3-44 Block flow diagram for the sCO_2 recompression Brayton cycle with main compressor intercooling



Source: NETL

3.8.1 Recompression Cycle with Intercooling Performance Results

The stream tables that correspond to the block flow diagram in Exhibit 3-44 are shown in Exhibit 3-45 and Exhibit 3-46. Exhibit 3-45 corresponds to a TIT of 1148 °F (Case IC620) and Exhibit 3-46 corresponds to a TIT of 1400 °F (Case IC760). Overall plant performance for both Intercooled cases is summarized in Exhibit 3-47, and a detailed breakdown of auxiliary power requirements for both Intercooled cases is provided in Exhibit 3-48. Exhibit 3-49 provides a detailed breakdown of the sCO_2 power cycle performance for the Intercooled cases.

Exhibit 3-45 Case IC620 stream table results

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0093	0.0025	0.0343	0.0343	0.0343	0.0352	0.0352	0.0347	0.0347	0.0000
CO_2	0.0003	0.0003	0.0004	0.0000	0.0000	0.0000	0.8062	0.8062	0.3626	0.3626	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
H_2O	0.0099	0.0094	0.0000	0.0000	0.0000	0.0000	0.0397	0.0397	0.0179	0.0179	0.0000
N_2	0.7732	0.7735	0.9907	0.0162	0.0162	0.0162	0.0971	0.0971	0.0526	0.0526	0.0000
O_2	0.2074	0.2075	0.0064	0.9495	0.9495	0.9495	0.0214	0.0214	0.5321	0.5321	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002	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
V-L Flowrate (kg_{mol}/hr)	64,309	64,278	49,964	13,710	3,222	10,488	2,634	8,574	5,856	19,062	0
V-L Flowrate (kg/hr)	1,855,756	1,855,196	1,402,755	441,559	103,766	337,793	108,070	351,804	211,837	689,596	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	206,611
Temperature (°C)	15	38	19	13	13	13	32	32	27	24	15
Pressure (MPa, abs)	0.10	0.69	0.10	0.16	0.16	0.16	0.10	0.10	0.11	0.11	0.11
Enthalpy (kJ/kg)[A]	30.54	52.80	19.65	10.99	10.99	10.99	70.38	70.38	45.23	42.81	---
Density (kg/m^3)	1.2	7.7	1.2	2.2	2.2	2.2	1.6	1.6	1.6	1.5	---
V-L Molecular Weight	28.857	28.862	28.075	32.207	32.207	32.207	41.032	41.032	36.176	36.176	---
V-L Flowrate (lb_{mol}/hr)	141,777	141,708	110,151	30,226	7,103	23,123	5,807	18,902	12,910	42,025	0
V-L Flowrate (lb/hr)	4,091,241	4,090,008	3,092,546	973,471	228,766	744,705	238,255	775,595	467,020	1,520,300	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	455,500
Temperature (°F)	59	100	66	55	55	55	90	90	80	75	59
Pressure (psia)	14.7	100.5	14.7	23.2	23.2	23.2	14.7	14.7	16.2	15.3	16.1
Enthalpy (Btu/lb)[A]	13.1	22.7	8.4	4.7	4.7	4.7	30.3	30.3	19.4	18.4	---
Density (lb/ft^3)	0.076	0.483	0.073	0.136	0.136	0.136	0.103	0.103	0.101	0.097	---

A - Steam Table Reference conditions are 32.02°F and 0.089 psia
* - AspenPlus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm

Exhibit 3-45 Case IC620 stream table results (continued)

	12	13	14	15	16	17	18	19	20	21	22
V-L Mole Fraction											
Ar	0.0000	0.0092	0.0000	0.0293	0.0000	0.0293	0.0293	0.0293	0.0307	0.0352	0.0352
CO_2	0.0000	0.0005	0.0000	0.6707	0.0000	0.6707	0.6707	0.6707	0.7042	0.8062	0.8062
H_2	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	0.0101	0.0000	0.2010	0.0000	0.2010	0.2010	0.2010	0.1612	0.0397	0.0397
N_2	0.0000	0.7729	0.0000	0.0808	0.0000	0.0808	0.0808	0.0808	0.0848	0.0971	0.0971
O_2	0.0000	0.2074	0.0000	0.0178	0.0000	0.0178	0.0178	0.0178	0.0187	0.0214	0.0214
SO_2	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0003	0.0003	0.0004	0.0004	0.0004
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	1,286	0	29,934	0	29,934	29,934	29,934	28,512	24,906	11,208
V-L Flowrate (kg/hr)	0	37,115	0	1,112,523	0	1,112,523	1,112,523	1,112,523	1,086,905	1,021,943	459,874
Solids Flowrate (kg/hr)	49,706	0	80,418	1,906	1,906	0	0	0	0	0	0
Temperature (°C)	15	15	25	198	25	198	173	57	64	32	32
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	---	30.57	---	436.87	---	443.20	415.81	240.55	248.94	70.38	70.38
Density (kg/m^3)	---	1.2	---	0.9	---	0.9	1.0	1.4	1.4	1.7	1.7
V-L Molecular Weight	---	28.856	---	37.166	---	37.166	37.166	37.166	38.121	41.032	41.032
V-L Flowrate (lb_{mol}/hr)	0	2,836	0	65,993	0	65,993	65,993	65,993	62,858	54,909	24,709
V-L Flowrate (lb/hr)	0	81,825	0	2,452,694	0	2,452,694	2,452,694	2,452,694	2,396,216	2,252,998	1,013,849
Solids Flowrate (lb/hr)	109,582	0	177,291	4,202	4,202	0	0	0	0	0	0
Temperature (°F)	59	59	77	389	77	389	343	135	146	90	90
Pressure (psia)	14.7	14.7	14.7	14.3	14.7	14.1	14.0	13.9	14.8	14.8	14.8
Enthalpy (Btu/lb)[A]	---	13.1	---	187.8	---	190.5	178.8	103.4	107.0	30.3	30.3
Density (lb/ft^3)	---	0.076	---	0.058	---	0.058	0.061	0.086	0.087	0.103	0.103

Exhibit 3-45 Case IC620 stream table results (continued)

	23	24	26	27	28	29	30	31	32	33	34
V-L Mole Fraction											
Ar	0.0352	0.0352	0.0352	0.0365	0.0000	0.0367	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.8062	0.8062	0.8062	0.8359	0.0001	0.8398	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0397	0.0397	0.0397	0.0042	0.9900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0971	0.0971	0.0971	0.1007	0.0000	0.1012	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0214	0.0214	0.0214	0.0222	0.0000	0.0223	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0004	0.0004	0.0004	0.0004	0.0099	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
V-L Flowrate (kg_{mol}/hr)	2,634	8,574	13,698	13,211	549	13,149	10,211	404,248	404,248	404,248	404,248
V-L Flowrate (kg/hr)	108,070	351,804	562,068	553,279	10,148	551,920	449,396	17,790,852	17,790,852	17,790,852	17,790,852
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	41	36	32	99	35	38	37	620	453	173	57
Pressure (MPa, abs)	0.11	0.11	0.10	3.00	0.10	3.00	15.20	34.30	9.31	9.24	9.17
Enthalpy (kJ/kg)[A]	78.10	73.37	70.38	73.49	145.38	6.95	-206.34	630.17	441.40	117.32	-53.17
Density (kg/m^3)	1.8	1.7	1.7	43.4	77.9	55.5	536.8	188.5	67.6	122.3	255.0
V-L Molecular Weight	41.032	41.032	41.032	41.882	18.472	41.974	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	5,807	18,902	30,200	29,124	1,211	28,989	22,512	891,213	891,213	891,213	891,213
V-L Flowrate (lb/hr)	238,255	775,595	1,239,149	1,219,772	22,373	1,216,776	990,749	39,222,114	39,222,114	39,222,114	39,222,114
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	106	96	90	210	95	100	99	1,148	847	343	135
Pressure (psia)	16.2	15.3	14.8	435.1	14.8	435.1	2,205.0	4,974.7	1,350.0	1,340.0	1,330.0
Enthalpy (Btu/lb)[A]	33.6	31.5	30.3	31.6	62.5	3.0	-88.7	270.9	189.8	50.4	-22.9
Density (lb/ft^3)	0.110	0.106	0.103	2.707	4.865	3.462	33.509	11.769	4.217	7.633	15.922

Exhibit 3-45 Case IC620 stream table results (continued)

	35	36	37	38	39	40	41	42	44	45	46
V-L Mole Fraction											
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	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)	65,694	338,553	65,694	338,553	338,553	318,105	20,449	20,449	318,105	404,248	404,248
V-L Flowrate (kg/hr)	2,891,192	14,899,660	2,891,192	14,899,660	14,899,660	13,999,725	899,935	899,935	13,999,725	17,790,852	17,790,852
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	57	57	167	35	52	52	52	167	167	167	398
Pressure (MPa, abs)	9.17	9.17	34.58	9.10	34.64	34.64	34.64	34.58	34.58	34.58	34.51
Enthalpy (kJ/kg)[A]	-53.17	-53.17	21.70	-188.29	-194.96	-194.96	-194.96	21.70	21.70	21.70	345.77
Density (kg/m^3)	255.0	255.0	507.1	669.1	891.2	891.2	891.2	507.1	507.1	507.1	262.7
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	144,831	746,382	144,831	746,382	746,382	701,301	45,081	45,081	701,301	891,213	891,213
V-L Flowrate (lb/hr)	6,373,987	32,848,127	6,373,987	32,848,127	32,848,127	30,864,111	1,984,016	1,984,016	30,864,111	39,222,114	39,222,114
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	135	135	333	95	125	125	125	333	333	333	748
Pressure (psia)	1,330.0	1,330.0	5,014.7	1,320.0	5,024.7	5,024.7	5,024.7	5,014.7	5,014.7	5,014.7	5,004.7
Enthalpy (Btu/lb)[A]	-22.9	-22.9	9.3	-80.9	-83.8	-83.8	-83.8	9.3	9.3	9.3	148.7
Density (lb/ft^3)	15.922	15.922	31.659	41.768	55.637	55.637	55.637	31.659	31.659	31.659	16.397

Exhibit 3-46 Case IC760 stream table results

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0093	0.0025	0.0343	0.0343	0.0343	0.0352	0.0352	0.0347	0.0347	0.0000
CO_2	0.0003	0.0003	0.0004	0.0000	0.0000	0.0000	0.8062	0.8062	0.3626	0.3626	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
H_2O	0.0099	0.0094	0.0000	0.0000	0.0000	0.0000	0.0397	0.0397	0.0179	0.0179	0.0000
N_2	0.7732	0.7735	0.9907	0.0162	0.0162	0.0162	0.0971	0.0971	0.0526	0.0526	0.0000
O_2	0.2074	0.2075	0.0064	0.9495	0.9495	0.9495	0.0214	0.0214	0.5321	0.5321	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002	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
V-L Flowrate (kg_{mol}/hr)	56,939	56,912	44,238	12,139	2,853	9,286	2,332	7,591	5,185	16,878	0
V-L Flowrate (kg/hr)	1,643,087	1,642,592	1,242,001	390,957	91,875	299,082	95,686	311,487	187,560	610,569	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	182,934
Temperature (°C)	15	38	19	13	13	13	32	32	27	24	15
Pressure (MPa, abs)	0.10	0.69	0.10	0.16	0.16	0.16	0.10	0.10	0.11	0.11	0.11
Enthalpy (kJ/kg)[A]	30.54	52.80	19.65	10.99	10.99	10.99	70.38	70.38	45.23	42.81	---
Density (kg/m^3)	1.2	7.7	1.2	2.2	2.2	2.2	1.6	1.6	1.6	1.5	---
V-L Molecular Weight	28.857	28.862	28.075	32.207	32.207	32.207	41.032	41.032	36.176	36.176	---
V-L Flowrate (lb_{mol}/hr)	125,529	125,469	97,528	26,762	6,289	20,473	5,141	16,736	11,430	37,209	0
V-L Flowrate (lb/hr)	3,622,387	3,621,296	2,738,143	861,912	202,549	659,363	210,951	686,712	413,500	1,346,074	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	403,300
Temperature (°F)	59	100	66	55	55	55	90	90	80	75	59
Pressure (psia)	14.7	100.5	14.7	23.2	23.2	23.2	14.7	14.7	16.2	15.3	16.1
Enthalpy (Btu/lb)[A]	13.1	22.7	8.4	4.7	4.7	4.7	30.3	30.3	19.4	18.4	---
Density (lb/ft^3)	0.076	0.483	0.073	0.136	0.136	0.136	0.103	0.103	0.101	0.097	---

Exhibit 3-46 Case IC760 stream table results (continued)

	12	13	14	15	16	17	18	19	20	21	22
V-L Mole Fraction											
Ar	0.0000	0.0092	0.0000	0.0293	0.0000	0.0293	0.0293	0.0293	0.0307	0.0352	0.0352
CO_2	0.0000	0.0005	0.0000	0.6707	0.0000	0.6707	0.6707	0.6707	0.7042	0.8062	0.8062
H_2	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	0.0101	0.0000	0.2010	0.0000	0.2010	0.2010	0.2010	0.1612	0.0397	0.0397
N_2	0.0000	0.7729	0.0000	0.0808	0.0000	0.0808	0.0808	0.0808	0.0848	0.0971	0.0971
O_2	0.0000	0.2074	0.0000	0.0178	0.0000	0.0178	0.0178	0.0178	0.0187	0.0214	0.0214
SO_2	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0003	0.0003	0.0004	0.0004	0.0004
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	1,139	0	26,504	0	26,504	26,504	26,504	25,245	22,052	9,923
V-L Flowrate (kg/hr)	0	32,862	0	985,029	0	985,029	985,029	985,029	962,352	904,829	407,173
Solids Flowrate (kg/hr)	44,009	0	71,268	1,689	1,689	0	0	0	0	0	0
Temperature (°C)	15	15	25	198	25	198	173	57	64	32	32
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	---	30.57	---	436.87	---	443.20	415.81	240.57	248.96	70.38	70.38
Density (kg/m^3)	---	1.2	---	0.9	---	0.9	1.0	1.4	1.4	1.7	1.7
V-L Molecular Weight	---	28.856	---	37.166	---	37.166	37.166	37.166	38.121	41.032	41.032
V-L Flowrate (lb_{mol}/hr)	0	2,511	0	58,430	0	58,430	58,430	58,430	55,655	48,616	21,877
V-L Flowrate (lb/hr)	0	72,448	0	2,171,617	0	2,171,617	2,171,617	2,171,617	2,121,624	1,994,806	897,663
Solids Flowrate (lb/hr)	97,024	0	157,120	3,724	3,724	0	0	0	0	0	0
Temperature (°F)	59	59	77	389	77	389	343	135	146	90	90
Pressure (psia)	14.7	14.7	14.7	14.3	14.7	14.1	14.0	13.9	14.8	14.8	14.8
Enthalpy (Btu/lb)[A]	---	13.1	---	187.8	---	190.5	178.8	103.4	107.0	30.3	30.3
Density (lb/ft^3)	---	0.076	---	0.058	---	0.058	0.061	0.086	0.087	0.103	0.103

Exhibit 3-46 Case IC760 stream table results (continued)

	23	24	26	27	28	29	30	31	32	33	34
V-L Mole Fraction											
Ar	0.0352	0.0352	0.0352	0.0365	0.0000	0.0367	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.8062	0.8062	0.8062	0.8359	0.0001	0.8398	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0397	0.0397	0.0397	0.0042	0.9900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0971	0.0971	0.0971	0.1007	0.0000	0.1012	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0214	0.0214	0.0214	0.0222	0.0000	0.0223	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0004	0.0004	0.0004	0.0004	0.0099	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
V-L Flowrate (kg_{mol}/hr)	2,332	7,591	12,129	11,697	486	11,642	9,041	320,818	320,818	320,818	320,818
V-L Flowrate (kg/hr)	95,686	311,487	497,656	489,874	8,985	488,671	397,895	14,119,115	14,119,115	14,119,115	14,119,115
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	41	36	32	99	35	38	37	760	576	173	57
Pressure (MPa, abs)	0.11	0.11	0.10	3.00	0.10	3.00	15.20	34.30	9.31	9.24	9.17
Enthalpy (kJ/kg)[A]	78.10	73.37	70.38	73.49	145.38	6.95	-206.34	810.83	589.18	117.32	-53.17
Density (kg/m^3)	1.8	1.7	1.7	43.4	77.9	55.5	536.8	162.0	57.2	122.3	255.0
V-L Molecular Weight	41.032	41.032	41.032	41.882	18.472	41.974	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	5,141	16,736	26,739	25,787	1,072	25,667	19,932	707,282	707,282	707,282	707,282
V-L Flowrate (lb/hr)	210,951	686,712	1,097,143	1,079,987	19,809	1,077,335	877,208	31,127,321	31,127,321	31,127,321	31,127,321
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	106	96	90	210	95	100	99	1,400	1,069	343	135
Pressure (psia)	16.2	15.3	14.8	435.1	14.8	435.1	2,205.0	4,974.7	1,350.0	1,340.0	1,330.0
Enthalpy (Btu/lb)[A]	33.6	31.5	30.3	31.6	62.5	3.0	-88.7	348.6	253.3	50.4	-22.9
Density (lb/ft^3)	0.110	0.106	0.103	2.707	4.865	3.462	33.509	10.112	3.570	7.633	15.922

Exhibit 3-46 Case IC760 stream table results (continued)

	35	36	37	38	39	40	41	42	44	45	46
V-L Mole Fraction											
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	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)	50,260	270,558	50,260	270,558	270,558	252,453	18,105	18,105	252,453	320,818	320,818
V-L Flowrate (kg/hr)	2,211,922	11,907,193	2,211,922	11,907,193	11,907,193	11,110,414	796,779	796,779	11,110,414	14,119,115	14,119,115
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	57	57	167	35	52	52	52	167	167	167	513
Pressure (MPa, abs)	9.17	9.17	34.58	9.10	34.64	34.64	34.64	34.58	34.58	34.58	34.51
Enthalpy (kJ/kg)[A]	-53.17	-53.17	21.70	-188.29	-194.96	-194.96	-194.96	21.68	21.70	21.69	493.55
Density (kg/m^3)	255.0	255.0	507.1	669.1	891.2	891.2	891.2	507.1	507.1	507.1	217.9
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	110,804	596,478	110,804	596,478	596,478	556,564	39,914	39,914	556,564	707,282	707,282
V-L Flowrate (lb/hr)	4,876,454	26,250,867	4,876,454	26,250,867	26,250,867	24,494,271	1,756,597	1,756,597	24,494,271	31,127,321	31,127,321
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	135	135	333	95	125	125	125	333	333	333	956
Pressure (psia)	1,330.0	1,330.0	5,014.7	1,320.0	5,024.7	5,024.7	5,024.7	5,014.7	5,014.7	5,014.7	5,004.7
Enthalpy (Btu/lb)[A]	-22.9	-22.9	9.3	-80.9	-83.8	-83.8	-83.8	9.3	9.3	9.3	212.2
Density (lb/ft^3)	15.922	15.922	31.659	41.768	55.637	55.637	55.637	31.660	31.659	31.659	13.601

Exhibit 3-47 Intercooled sCO_2 plant performance summary

Parameter	Case IC620	Case IC760
CFB Coal Flow Rate (lb/hr)	455,500	403,300
Limestone Flow Rate (lb/hr)	109,582	97,024
Oxygen Flow Rate (lb/hr)	973,471	861,912
Coal Thermal Input (MMBtu/hr)	5,314	4,705
Net Plant Power Output (kW)	550,097	550,121
Net Plant Efficiency (HHV %)	**35.32**	**39.90**
HHV Heat Rate (Btu/kWh)	9,660	8,552
Raw Water Withdrawal (gpm)	6,675	5,445

Exhibit 3-48 Plant power summary for Intercooled cases

POWER SUMMARY		
Item (kW)	**Case IC620**	**Case IC760**
POWER CYCLE SUMMARY		
sCO_2 Turbine Gross Power	932,900	869,300
sCO_2 Main Compressor	-153,700	-122,800
sCO_2 Bypass Compressor	-60,100	-46,000
sCO_2 Generator Loss	-10,787	-10,508
TOTAL sCO_2 POWER GENERATED	**708,314**	**689,993**
AUXILIARY LOAD SUMMARY		
Coal Handling	-457	-432
Limestone Prep	-220	-190
Pulverizers	-100	-90
Slag Handling and Dewatering	-2,430	-2,160
Primary Air Fans	-250	-220
Forced Draft Fans	-310	-280
Induced Draft Fans	-1,920	-1,700
Air Separation Unit	-81,230	-71,920
Baghouse	-10	-10
CPU (Purification and Compression) Auxiliaries	-55,390	-49,040
Turbine Auxiliaries	-400	-400
Miscellaneous Balance of Plant	-2,000	-2,000
Circulating Water Pump	-6,910	-5,670

POWER SUMMARY		
Item (kW)	**Case IC620**	**Case IC760**
Cooling Tower Fans	-4,040	-3,310
Transformer Losses	-2,550	-2,450
TOTAL AUXILIARIES	**-158,217**	**-139,872**
NET POWER	**550,097**	**550,121**

Exhibit 3-49 Intercooled sCO_2 cycle performance summary

Parameter	Case IC620	Case IC760
THERMAL INPUT		
Power Cycle Thermal Input - CFB (MMBtu/hr)	4,796	4,246
Power Cycle Thermal Input – Flue gas (MMBtu/hr)	185	164
Power Cycle Thermal Input - Total (MMBtu/hr)	4,980	4,409
Fractional Thermal Input to Power Cycle	0.937	0.937
RECUPERATOR DUTY		
Recuperator Duty – HTR (MMBtu/hr)	5,465	6,315
Recuperator Duty – LTR (MMBtu/hr)	2,875	2,282
Recuperator Duty – Total (MMBtu/hr)	8,340	8,596
COOLING DUTY		
Power Cycle Cooling Duty – CO_2 cooler (MMBtu/hr)	1,908	1,525
Power Cycle Cooling Duty – CO_2 intercooler (MMBtu/hr)	619	494
Power Cycle Cooling Duty – Total (MMBtu/hr)	2,527	2,019
POWER OUTPUT		
Net Cycle Power Output (kW)	708,314	689,993
SPECIFIC POWER		
sCO_2 Flow Rate (lb/hr)	39,222,114	31,127,321
sCO_2 Cycle Specific Power (Wh/lb)	18.06	22.17
sCO_2 Cycle Specific Power (kJ/kg)	143.3	175.9
OVERALL CYCLE PERFORMANCE		
sCO_2 Power Cycle Efficiency (%)	48.53	53.39
sCO_2 Cycle Heat Rate (Btu/kWh)	7,031	6,391

3.8.2 Effect of Intercooling on the sCO_2 Power Cycle

The expected effect of main compressor intercooling on the sCO_2 power cycle is analogous to the effect of reheat. Compressor intercooling reduces the specific compression power requirement because the compression more closely approaches an isothermal compression, which requires less power than either an isentropic or polytropic compression. Intercooling also lowers the temperature of the CO_2 entering the HP side of the LTR. Because the LP hot side of the recuperator has a lower thermal capacitance than the HP cold side, the reduction in the HP cold end temperature also leads to a reduction in the HP hot end exit temperature which can lead to a decrease in cycle efficiency. The effect of intercooling on the plant cooling duty is difficult to predict as there are offsetting factors. All other factors being the same, intercooling tends to increase the total cooling duty. However, intercooling lowers the cold end temperature of both the hot side and cold side of the LTR and the lower temperature of the cold end of the hot side of the LTR lowers the CO_2 cooler duty.

Comparing the results in Exhibit 3-48 and Exhibit 3-49 with the corresponding Baseline Case results in Exhibit 3-20 and Exhibit 3-21 shows that the net effect of intercooling on the Baseline cases is qualitatively consistent with the expected trends. For both TITs, adding main compressor intercooling resulted in a significant drop in the cycle compression power requirement but this positive impact on cycle efficiency was offset by a reduction in the bypass compressor split fraction and a reduction in the recuperator HP hot end exit temperature resulting in a small drop in cycle efficiency.

One interesting aspect of main compressor intercooling is its effect on the bypass compressor power requirements, apart from the change in bypass compressor split fraction noted above. The reduced temperature at the HP, cold end of the LTR due to main compressor intercooling also reduces the cold end outlet temperature on the LP side of the LTR, given a constant approach temperature at this location. This temperature changes from 179 °F in the Baseline Cases to 135 °F in the intercooled cases, irrespective of the turbine inlet temperatures. This reduces the inlet temperature entering the bypass compressor, and the resulting increased inlet density significantly reduces its power consumption. The specific power required of the bypass compressor (power input divided by mass flow) decreases 25.5 percent with intercooling of the main compressor, from 9.43 Wh/lb in the Baseline Cases, to 11.83 Wh/lb in the intercooled cases. By comparison, intercooling of the main compressor itself only decreases its specific power requirements by 7.3 percent, from 5.02 Wh/lb in the Baseline Cases, to 4.68 Wh/lb in the intercooled cases. Hence, it could be argued that the main purpose for intercooling the main compressor is to reduce the power requirements of the bypass compressor.

Comparing the results of Exhibits 3-20 and 3-48, gross auxiliary power savings for the bypass compressor are an order of magnitude greater than that of the main compressor between the baseline and intercooled cases, due both to the increased efficiency of compressing colder sCO_2, and to the reduced split fraction of flow to the bypass compressor for the intercooled cases. It is anticipated that additional process efficiency and specific power benefits may be realized by incorporating additional stages of intercooling to the main compressor to further decrease its exit temperature.

The impact of intercooling on overall process efficiency and cycle specific power was greater than the impact on cycle efficiency because the lower compressor exit temperature allowed for greater heat recovery from the flue gas cooler and a significant increase in the fraction of thermal input to the plant that could be harvested in the sCO_2

power cycle. The overall cooling duty of the cycle did not change significantly with intercooling and hence it had no significant impact on cycle and process efficiency.

3.8.3 Case Mass Balances

The carbon balance for Case IC620 is shown in Exhibit 3-50 while the corresponding carbon balance for Case IC760 is shown in Exhibit 3-51.

Exhibit 3-50 Case IC620 carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	132,033 (291,084)	CO_2 Product	122,645 (270,386)
Air (CO_2)	259 (572)	Bottom Ash	4,308 (9,498)
Limestone Reagent	5,044 (11,119)	Separated Air	252 (556)
		CPU Vent	9,992 (22,028)
		Fly Ash	136 (300)
Total	**137,337 (302,775)**	**Total**	**137,337 (302,775)**

Exhibit 3-51 Case IC760 carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	116,902 (257,726)	CO_2 Product	108,590 (239,399)
Air (CO_2)	230 (506)	Bottom Ash	3,818 (8,418)
Limestone Reagent	4,466 (9,845)	Separated Air	223 (493)
		CPU Vent	8,847 (19,504)
		Fly Ash	121 (266)
Total	**121,598 (268,077)**	**Total**	**121,598 (268,077)**

Exhibit 3-52 shows the sulfur balance for Case IC620.

Exhibit 3-52 Case IC620 sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	5,191 (11,444)	Bottom Ash	4,863 (10,721)

		CO_2 Product	2 (4)
		Fly Ash	154 (339)
		CPU Water	174 (384)
Total	**5,191 (11,444)**	**Total**	**5,191 (11,444)**

Exhibit 3-53 shows the sulfur balance for Case IC760.

Exhibit 3-53 Case IC760 sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	4,596 (10,132)	Bottom Ash	4,307 (9,496)
		CO_2 Product	2 (3)
		Fly Ash	136 (300)
		CPU Water	154 (340)
Total	**4,596 (10,132)**	**Total**	**4,596 (10,132)**

Exhibit 3-54 shows the overall water balance for Case IC620 and Exhibit 3-55 shows the overall water balance for Case IC760.

Exhibit 3-54 Case IC620 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	26.94 (7116)	1.7 (441)	25.27 (6675)	6.06 (1600)	19.21 (5075)
MAC knock-out	0.00 ()	0.0 (2)	0.00 ()	0.00 (0)	0.00 ()
ASU discharge	0.0 (0)	0.00 (0)	0.0 (0)	0.18 (48)	0.00 ()
Total	**26.9 (7,116)**	**1.68 (443)**	**25.3 (6,675)**	**6.24 (1,648)**	**19.21 (5,075)**

Exhibit 3-55 Case IC760 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	22.09 (5835)	1.5 (390)	20.61 (5445)	4.97 (1312)	15.64 (4133)
MAC knock-out	0.00 ()	0.0 (2)	0.00 ()	0.00 (0)	0.00 ()

ASU discharge	0.0 (0)	0.00 (0)	0.0 (0)	0.16 (42)	0.00 ()
Total	**22.1 (5,835)**	**1.48 (392)**	**20.6 (5,445)**	**5.13 (1,355)**	**15.64 (4,133)**

3.9 Performance Comparison Between Reference Rankine, Baseline sCO_2 and Intercooled sCO_2

Exhibit 3-56 compares the performance of the two reference Rankine cycles and the two Intercooled sCO_2 cycles.

Exhibit 3-56 Performance comparison between Reference Rankine and Baseline sCO_2

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case IC620	Case IC760
CFB Coal Flow Rate (lb/hr)	478,280	436,129	455,500	403,300
Limestone Flow Rate (lb/hr)	114,987	104,732	109,582	97,024
Oxygen Flow Rate (lb/hr)	1,021,874	931,831	973,471	861,912
sCO_2 Flow Rate (lb/hr)	---	---	39,222,114	31,127,321
Net Plant Efficiency (HHV %)	**33.64**	**36.88**	**35.32**	**39.90**
HHV Heat Rate (Btu/kWh)	10,144	9,251	9,660	8,552
sCO_2 Power Cycle Efficiency (%)	---	---	48.53	53.39
sCO_2 Cycle Heat Rate (Btu/kWh)	---	---	7,031	6,391
Steam Power Cycle Efficiency (%)	48.27	51.84	---	---
Steam Cycle Heat Rate (Btu/kWh)	7,068	6,582	---	---
Coal Thermal Input (MMBtu/hr)	5,580	5,088	5,314	4,705
Power Cycle Thermal Input (MMBtu/hr)	5,122	4,672	4,980	4,409
Fractional Thermal Input to Power Cycle	0.918	0.918	0.937	0.937
sCO_2 Cycle Specific Power (Wh/lb)			18.06	22.17
Raw Water Withdrawal (gpm)	8,418	7,314	6,675	5,445
Power Summary				
Steam Turbine Power Output	721,000	705,600	---	---
sCO_2 Cycle Power Output	---	---	708,314	689,993
Gross Power Output	721,000	705,600	708,314	689,993
Total Auxiliary Power Load	**170,954**	**155,618**	**158,217**	**139,872**
Net Power Output	**550,046**	**549,982**	**550,097**	**550,121**

3.9.1 Performance Comparison Between Reference SC Rankine, Case Baseline620 and Case IC620

Exhibit 3-57 shows the comparative performance of the SC Rankine and the baseline sCO_2 Brayton cycles with and without main compressor intercooling at a TIT of 620 °C. The overall plant HHV efficiency increases from 34.67 to 35.32 percent, despite a small drop in the cycle efficiency from 48.67 to 48.53 percent. This is due to an increase in the fraction of coal thermal input recovered in the sCO_2 power cycle, because additional heat enters the sCO_2 cycle from the flue gas exchanger due to the lower HP cold side entrance temperature. Specific power of the sCO_2 cycle also increases 7.3 percent for the intercooled case relative to the baseline, which translates to a more compact sCO_2 power cycle with intercooling.

Exhibit 3-57 Performance comparison between Reference, Baseline, and Intercooled sCO_2 at 620 °C

Parameter	Reference SC Rankine	Case Baseline620	Case IC620
CFB Coal Flow Rate (lb/hr)	478,280	464,000	455,500
Limestone Flow Rate (lb/hr)	114,987	111,627	109,582
Oxygen Flow Rate (lb/hr)	1,021,874	991,637	973,471
sCO_2 Flow Rate (lb/hr)	---	42,305,305	39,222,114
Net Plant Efficiency (HHV %)	**33.64**	**34.67**	**35.32**
HHV Heat Rate (Btu/kWh)	10,144	9,843	9,660
sCO_2 Power Cycle Efficiency (%)	---	48.67	48.53
sCO_2 Cycle Heat Rate (Btu/kWh)	---	7,010	7,031
Steam Power Cycle Efficiency (%)	48.27	---	---
Steam Cycle Heat Rate (Btu/kWh)	7,068	---	---
Coal Thermal Input (MMBtu/hr)	5,580	5,413	5,314
Power Cycle Thermal Input (MMBtu/hr)	5,122	4,987	4,980
Fractional Thermal Input to Power Cycle	0.918	0.921	0.937
sCO_2 Cycle Specific Power (Wh/lb)		16.82	18.06
Raw Water Withdrawal (gpm)	8,418	6,879	6,675
Power Summary			
Steam Turbine Power Output	721,000	---	---
sCO_2 Cycle Power Output	---	711,367	708,314
Gross Power Output	721,000	711,367	708,314
Total Auxiliary Power Load	**170,954**	**161,457**	**158,217**
Net Power Output	**550,046**	**549,910**	**550,097**

3.9.2 Performance Comparison Between Reference AUSC Rankine, Case Baseline760 and Case IC760

Exhibit 3-58 shows the comparative performance of the AUSC Rankine and the baseline sCO_2 Brayton cycles with and without main compressor intercooling at a TIT of 760 °C. The overall plant HHV efficiency increases from 39.49 to 39.90 percent, despite the drop in cycle efficiency from 53.90 to 53.39 percent. As with the lower TIT cases, this is due to an increase in the total amount of heat recovered in the cycle. The drop in cycle efficiency results from offsetting influences on the cycle efficiency. Intercooling reduces the power requirement for compression but offsetting this is a reduction in the temperature of the HP CO_2 leaving the HTR. The sCO_2 cycle specific power is 6 percent higher than in the Baseline case, improving the cycle's power density. The process efficiency for the sCO_2 with main compressor intercooling plant is 3.02 percentage points higher than the reference AUSC Rankine plant.

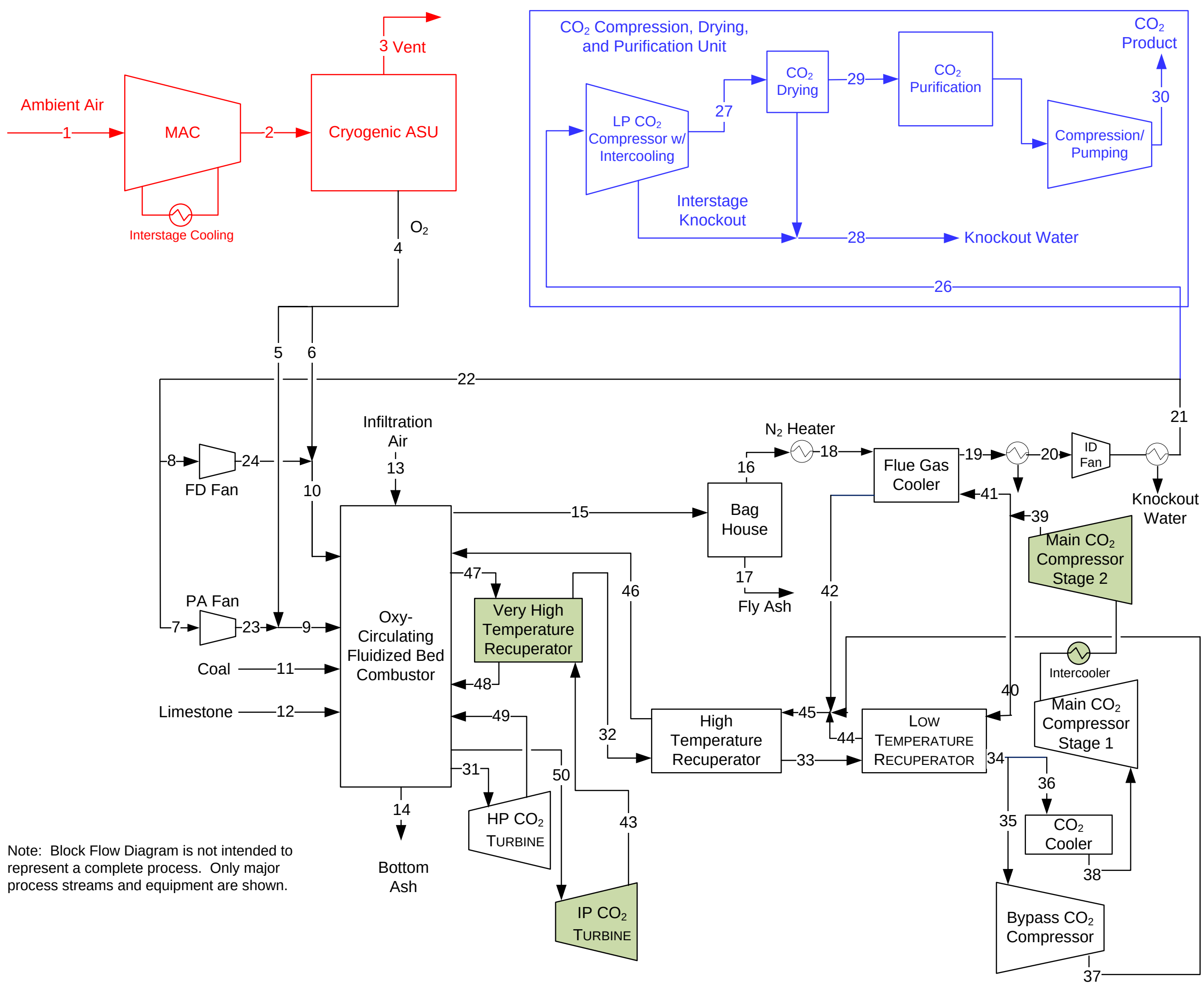
Exhibit 3-58 Performance comparison between Reference, Baseline, and Intercooled sCO_2 at 760 °C

Parameter	Reference AUSC Rankine	Case Baseline760	Case IC760
CFB Coal Flow Rate (lb/hr)	436,129	407,200	403,300
Limestone Flow Rate (lb/hr)	104,732	97,962	97,024
Oxygen Flow Rate (lb/hr)	931,831	870,247	861,912
sCO_2 Flow Rate (lb/hr)	---	33,040,523	31,127,321
Net Plant Efficiency (HHV %)	**36.88**	**39.49**	**39.90**
HHV Heat Rate (Btu/kWh)	9,251	8,640	8,552
sCO_2 Power Cycle Efficiency (%)	---	53.90	53.39
sCO_2 Cycle Heat Rate (Btu/kWh)	---	6,331	6,391
Steam Power Cycle Efficiency (%)	51.84	---	---
Steam Cycle Heat Rate (Btu/kWh)	6,582	---	---
Coal Thermal Input (MMBtu/hr)	5,088	4,750	4,705
Power Cycle Thermal Input (MMBtu/hr)	4,672	4,376	4,409
Fractional Thermal Input to Power Cycle	0.918	0.921	0.937
sCO_2 Cycle Specific Power (Wh/lb)		20.92	22.17
Raw Water Withdrawal (gpm)	7,314	5,541	5,445
Power Summary			
Steam Turbine Power Output	705,600	---	---
sCO_2 Cycle Power Output	---	691,273	689,993
Gross Power Output	705,600	691,273	689,993
Total Auxiliary Power Load	**155,618**	**141,474**	**139,872**
Net Power Output	**549,982**	**549,799**	**550,121**

3.10 RECOMPRESSION CYCLE WITH COMBINATION OF REHEAT AND INTERCOOLING

Exhibit 3-59 shows the BFD for the sCO_2 plant with both reheat and main compressor intercooling. As in the case of Exhibit 3-29, there is a third recuperator stage. In this configuration, the cold side effluent from the HTR is partially heated in the freeboard section of the CFB and then further heated using the effluent from the IP turbine in a very high-temperature recuperator (VTR).

Exhibit 3-59 Block flow diagram for the sCO_2 recompression Brayton cycle with reheat and main compressor intercooling



Source: NETL

3.10.1 Recompression Cycle with Reheat and Intercooling Performance Results

The stream tables that correspond to the BFD in Exhibit 3-59 are shown in Exhibit 3-60 and Exhibit 3-61. Exhibit 3-60 corresponds to a TIT of 1148 °F (Case RhtIC620) and

Exhibit 3-61 corresponds to a TIT of 1400 °F (Case RhtIC760). Overall plant performance for both Reheat and Intercooled cases is summarized in Exhibit 3-62, and a detailed breakdown of auxiliary power requirements for both Reheat and Intercooled cases is provided in Exhibit 3-63. Exhibit 3-63 provides a detailed breakdown of the sCO_2 power cycle performance for the Reheat and Intercooled cases.

Exhibit 3-60 Case RhtIC620 stream table results

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0093	0.0025	0.0343	0.0343	0.0343	0.0352	0.0352	0.0347	0.0347	0.0000
CO_2	0.0003	0.0003	0.0004	0.0000	0.0000	0.0000	0.8062	0.8062	0.3626	0.3626	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
H_2O	0.0099	0.0094	0.0000	0.0000	0.0000	0.0000	0.0397	0.0397	0.0179	0.0179	0.0000
N_2	0.7732	0.7735	0.9907	0.0162	0.0162	0.0162	0.0971	0.0971	0.0526	0.0526	0.0000
O_2	0.2074	0.2075	0.0064	0.9495	0.9495	0.9495	0.0214	0.0214	0.5321	0.5321	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002	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
V-L Flowrate (kg_{mol}/hr)	61,697	61,667	47,934	13,153	3,091	10,062	2,527	8,226	5,618	18,288	0
V-L Flowrate (kg/hr)	1,780,385	1,779,848	1,345,783	423,625	99,552	324,073	103,681	337,515	203,233	661,589	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	198,220
Temperature (°C)	15	38	19	13	13	13	32	32	27	24	15
Pressure (MPa, abs)	0.10	0.69	0.10	0.16	0.16	0.16	0.10	0.10	0.11	0.11	0.11
Enthalpy (kJ/kg)[A]	30.54	52.80	19.65	10.99	10.99	10.99	70.38	70.38	45.23	42.81	---
Density (kg/m^3)	1.2	7.7	1.2	2.2	2.2	2.2	1.6	1.6	1.6	1.5	---
V-L Molecular Weight	28.857	28.862	28.075	32.207	32.207	32.207	41.032	41.032	36.176	36.176	---
V-L Flowrate (lb_{mol}/hr)	136,018	135,953	105,677	28,998	6,815	22,183	5,571	18,135	12,385	40,318	0
V-L Flowrate (lb/hr)	3,925,076	3,923,893	2,966,944	933,934	219,474	714,459	228,578	744,094	448,052	1,458,553	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	437,000
Temperature (°F)	59	100	66	55	55	55	90	90	80	75	59
Pressure (psia)	14.7	100.5	14.7	23.2	23.2	23.2	14.7	14.7	16.2	15.3	16.1
Enthalpy (Btu/lb)[A]	13.1	22.7	8.4	4.7	4.7	4.7	30.3	30.3	19.4	18.4	---
Density (lb/ft^3)	0.076	0.483	0.073	0.136	0.136	0.136	0.103	0.103	0.101	0.097	---

A - Steam Table Reference conditions are 32.02°F and 0.089 psia
* - AspenPlus thermodynamic reference state is the component's constituent elements in an ideal gas state at 25°C and 1 atm

Exhibit 3-60 Case RhtIC620 stream table results (continued)

	12	13	14	15	16	17	18	19	20	21	22
V-L Mole Fraction											
Ar	0.0000	0.0092	0.0000	0.0293	0.0000	0.0293	0.0293	0.0293	0.0307	0.0352	0.0352
CO_2	0.0000	0.0005	0.0000	0.6707	0.0000	0.6707	0.6707	0.6707	0.7036	0.8062	0.8062
H_2	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	0.0101	0.0000	0.2010	0.0000	0.2010	0.2010	0.2010	0.1619	0.0397	0.0397
N_2	0.0000	0.7729	0.0000	0.0808	0.0000	0.0808	0.0808	0.0808	0.0848	0.0971	0.0971
O_2	0.0000	0.2074	0.0000	0.0178	0.0000	0.0178	0.0178	0.0178	0.0187	0.0214	0.0214
SO_2	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	1,234	0	28,718	0	28,718	28,718	28,718	27,379	23,895	10,753
V-L Flowrate (kg/hr)	0	35,608	0	1,067,339	0	1,067,339	1,067,339	1,067,339	1,043,216	980,437	441,197
Solids Flowrate (kg/hr)	47,687	0	77,211	1,830	1,830	0	0	0	0	0	0
Temperature (°C)	15	15	25	200	25	200	174	57	64	32	32
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	---	30.57	---	438.48	---	444.81	417.42	241.70	250.07	70.38	70.38
Density (kg/m^3)	---	1.2	---	0.9	---	0.9	1.0	1.4	1.4	1.7	1.7
V-L Molecular Weight	---	28.856	---	37.166	---	37.166	37.166	37.166	38.102	41.032	41.032
V-L Flowrate (lb_{mol}/hr)	0	2,720	0	63,313	0	63,313	63,313	63,313	60,361	52,678	23,705
V-L Flowrate (lb/hr)	0	78,502	0	2,353,079	0	2,353,079	2,353,079	2,353,079	2,299,897	2,161,493	972,672
Solids Flowrate (lb/hr)	105,131	0	170,220	4,035	4,035	0	0	0	0	0	0
Temperature (°F)	59	59	77	392	77	392	346	135	147	90	90
Pressure (psia)	14.7	14.7	14.7	14.3	14.7	14.1	14.0	13.9	14.8	14.8	14.8
Enthalpy (Btu/lb)[A]	---	13.1	---	188.5	---	191.2	179.5	103.9	107.5	30.3	30.3
Density (lb/ft^3)	---	0.076	---	0.058	---	0.057	0.060	0.085	0.087	0.103	0.103

Exhibit 3-60 Case RhtIC620 stream table results (continued)

	23	24	26	27	28	29	30	31	32	33	34
V-L Mole Fraction											
Ar	0.0352	0.0352	0.0352	0.0365	0.0000	0.0367	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.8062	0.8062	0.8062	0.8359	0.0001	0.8398	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0397	0.0397	0.0397	0.0042	0.9900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0971	0.0971	0.0971	0.1007	0.0000	0.1012	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0214	0.0214	0.0214	0.0222	0.0000	0.0223	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0004	0.0004	0.0004	0.0004	0.0099	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
V-L Flowrate (kg_{mol}/hr)	2,527	8,226	13,142	12,674	527	12,615	9,797	374,652	374,652	374,652	374,652
V-L Flowrate (kg/hr)	103,681	337,515	539,240	530,808	9,736	529,504	431,143	16,488,338	16,488,338	16,488,338	16,488,338
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	41	36	32	99	35	38	37	620	326	174	57
Pressure (MPa, abs)	0.11	0.11	0.10	3.00	0.10	3.00	15.20	34.30	9.24	9.17	9.10
Enthalpy (kJ/kg)[A]	78.10	73.37	70.38	73.49	145.38	6.95	-206.34	630.37	293.56	119.40	-51.63
Density (kg/m^3)	1.8	1.7	1.7	43.4	77.9	55.5	536.8	188.5	83.2	120.6	250.8
V-L Molecular Weight	41.032	41.032	41.032	41.882	18.472	41.974	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	5,571	18,135	28,973	27,941	1,162	27,811	21,598	825,965	825,965	825,965	825,965
V-L Flowrate (lb/hr)	228,578	744,094	1,188,821	1,170,231	21,464	1,167,357	950,507	36,350,564	36,350,564	36,350,564	36,350,564
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	106	96	90	210	95	100	99	1,148	618	346	135
Pressure (psia)	16.2	15.3	14.8	435.1	14.8	435.1	2,205.0	4,974.7	1,340.0	1,330.0	1,320.0
Enthalpy (Btu/lb)[A]	33.6	31.5	30.3	31.6	62.5	3.0	-88.7	271.0	126.2	51.3	-22.2
Density (lb/ft^3)	0.110	0.106	0.103	2.707	4.865	3.462	33.509	11.769	5.194	7.532	15.655

Exhibit 3-60 Case RhtIC620 stream table results (continued)

	35	36	37	38	39	40	41	42	43	44	45
V-L Mole Fraction											
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	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)	62,628	312,024	62,628	312,024	312,024	292,567	19,457	19,457	374,652	292,567	374,652
V-L Flowrate (kg/hr)	2,756,235	13,732,103	2,756,235	13,732,103	13,732,103	12,875,810	856,293	856,293	16,488,338	12,875,810	16,488,338
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	57	57	169	35	52	52	52	169	545	169	169
Pressure (MPa, abs)	9.10	9.10	34.58	9.03	34.64	34.64	34.64	34.58	9.31	34.58	34.58
Enthalpy (kJ/kg)[A]	-51.63	-51.63	24.23	-187.40	-194.77	-194.77	-194.77	24.25	551.63	24.23	24.23
Density (kg/m^3)	250.8	250.8	503.7	664.4	890.9	890.9	890.9	503.7	59.5	503.7	503.7
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	138,071	687,895	138,071	687,895	687,895	645,000	42,895	42,895	825,965	645,000	825,965
V-L Flowrate (lb/hr)	6,076,458	30,274,106	6,076,458	30,274,106	30,274,106	28,386,303	1,887,803	1,887,803	36,350,564	28,386,303	36,350,564
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	135	135	336	95	125	125	125	336	1,013	336	336
Pressure (psia)	1,320.0	1,320.0	5,014.7	1,310.0	5,024.7	5,024.7	5,024.7	5,014.7	1,350.0	5,014.7	5,014.7
Enthalpy (Btu/lb)[A]	-22.2	-22.2	10.4	-80.6	-83.7	-83.7	-83.7	10.4	237.2	10.4	10.4
Density (lb/ft^3)	15.655	15.655	31.444	41.477	55.614	55.614	55.614	31.442	3.712	31.444	31.443

Exhibit 3-60 Case RhtIC620 stream table results (continued)

	46	47	48	49	50
V-L Mole Fraction					
Ar	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	374,652	374,652	374,652	374,652	374,652
V-L Flowrate (kg/hr)	16,488,338	16,488,338	16,488,338	16,488,338	16,488,338
Solids Flowrate (kg/hr)	0	0	0	0	0
Temperature (°C)	286	320	521	522	620
Pressure (MPa, abs)	34.51	34.44	34.37	16.51	16.44
Enthalpy (kJ/kg)[A]	198.39	244.92	502.99	517.79	638.37
Density (kg/m^3)	335.7	307.6	214.8	107.4	94.5
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	825,965	825,965	825,965	825,965	825,965
V-L Flowrate (lb/hr)	36,350,564	36,350,564	36,350,564	36,350,564	36,350,564
Solids Flowrate (lb/hr)	0	0	0	0	0
Temperature (°F)	546	608	969	972	1,148
Pressure (psia)	5,004.7	4,994.7	4,984.7	2,395.0	2,385.0
Enthalpy (Btu/lb)[A]	85.3	105.3	216.2	222.6	274.4
Density (lb/ft^3)	20.956	19.205	13.411	6.702	5.897

Exhibit 3-61 Case RhtIC760 stream table results

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0093	0.0025	0.0343	0.0343	0.0343	0.0352	0.0352	0.0347	0.0347	0.0000
CO_2	0.0003	0.0003	0.0004	0.0000	0.0000	0.0000	0.8062	0.8062	0.3626	0.3626	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
H_2O	0.0099	0.0094	0.0000	0.0000	0.0000	0.0000	0.0397	0.0397	0.0179	0.0179	0.0000
N_2	0.7732	0.7735	0.9907	0.0162	0.0162	0.0162	0.0971	0.0971	0.0526	0.0526	0.0000
O_2	0.2074	0.2075	0.0064	0.9495	0.9495	0.9495	0.0214	0.0214	0.5321	0.5321	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0002	0.0002	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
V-L Flowrate (kg_{mol}/hr)	55,174	55,148	42,867	11,763	2,764	8,998	2,260	7,356	5,024	16,355	0
V-L Flowrate (kg/hr)	1,592,161	1,591,681	1,203,506	378,839	89,027	289,812	92,720	301,833	181,747	591,645	0
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	177,264
Temperature (°C)	15	38	19	13	13	13	32	32	27	24	15
Pressure (MPa, abs)	0.10	0.69	0.10	0.16	0.16	0.16	0.10	0.10	0.11	0.11	0.11
Enthalpy (kJ/kg)[A]	30.54	52.80	19.65	10.99	10.99	10.99	70.38	70.38	45.23	42.81	---
Density (kg/m^3)	1.2	7.7	1.2	2.2	2.2	2.2	1.6	1.6	1.6	1.5	---
V-L Molecular Weight	28.857	28.862	28.075	32.207	32.207	32.207	41.032	41.032	36.176	36.176	---
V-L Flowrate (lb_{mol}/hr)	121,638	121,580	94,505	25,932	6,094	19,838	4,982	16,217	11,076	36,056	0
V-L Flowrate (lb/hr)	3,510,114	3,509,056	2,653,276	835,197	196,271	638,926	204,412	665,428	400,684	1,304,354	0
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	390,800
Temperature (°F)	59	100	66	55	55	55	90	90	80	75	59
Pressure (psia)	14.7	100.5	14.7	23.2	23.2	23.2	14.7	14.7	16.2	15.3	16.1
Enthalpy (Btu/lb)[A]	13.1	22.7	8.4	4.7	4.7	4.7	30.3	30.3	19.4	18.4	---
Density (lb/ft^3)	0.076	0.483	0.073	0.136	0.136	0.136	0.103	0.103	0.101	0.097	---

Exhibit 3-61 Case RhtIC760 stream table results (continued)

	12	13	14	15	16	17	18	19	20	21	22
V-L Mole Fraction											
Ar	0.0000	0.0092	0.0000	0.0293	0.0000	0.0293	0.0293	0.0293	0.0307	0.0352	0.0352
CO_2	0.0000	0.0005	0.0000	0.6707	0.0000	0.6707	0.6707	0.6707	0.7036	0.8062	0.8062
H_2	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	0.0101	0.0000	0.2010	0.0000	0.2010	0.2010	0.2010	0.1619	0.0397	0.0397
N_2	0.0000	0.7729	0.0000	0.0808	0.0000	0.0808	0.0808	0.0808	0.0848	0.0971	0.0971
O_2	0.0000	0.2074	0.0000	0.0178	0.0000	0.0178	0.0178	0.0178	0.0187	0.0214	0.0214
SO_2	0.0000	0.0000	0.0000	0.0003	0.0000	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	0	1,104	0	25,682	0	25,682	25,682	25,682	24,485	21,368	9,616
V-L Flowrate (kg/hr)	0	31,843	0	954,499	0	954,499	954,499	954,499	932,926	876,784	394,553
Solids Flowrate (kg/hr)	42,645	0	69,056	1,637	1,637	0	0	0	0	0	0
Temperature (°C)	15	15	25	200	25	200	174	57	64	32	32
Pressure (MPa, abs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enthalpy (kJ/kg)[A]	---	30.57	---	438.48	---	444.81	417.42	241.70	250.07	70.38	70.38
Density (kg/m^3)	---	1.2	---	0.9	---	0.9	1.0	1.4	1.4	1.7	1.7
V-L Molecular Weight	---	28.856	---	37.166	---	37.166	37.166	37.166	38.102	41.032	41.032
V-L Flowrate (lb_{mol}/hr)	0	2,433	0	56,619	0	56,619	56,619	56,619	53,980	47,109	21,199
V-L Flowrate (lb/hr)	0	70,202	0	2,104,310	0	2,104,310	2,104,310	2,104,310	2,056,750	1,932,978	869,840
Solids Flowrate (lb/hr)	94,017	0	152,243	3,608	3,608	0	0	0	0	0	0
Temperature (°F)	59	59	77	392	77	392	346	135	147	90	90
Pressure (psia)	14.7	14.7	14.7	14.3	14.7	14.1	14.0	13.9	14.8	14.8	14.8
Enthalpy (Btu/lb)[A]	---	13.1	---	188.5	---	191.2	179.5	103.9	107.5	30.3	30.3
Density (lb/ft^3)	---	0.076	---	0.058	---	0.057	0.060	0.085	0.087	0.103	0.103

Exhibit 3-61 Case RhtIC760 stream table results (continued)

	23	24	26	27	28	29	30	31	32	33	34
V-L Mole Fraction											
Ar	0.0352	0.0352	0.0352	0.0365	0.0000	0.0367	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.8062	0.8062	0.8062	0.8359	0.0001	0.8398	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0397	0.0397	0.0397	0.0042	0.9900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0971	0.0971	0.0971	0.1007	0.0000	0.1012	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0214	0.0214	0.0214	0.0222	0.0000	0.0223	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0004	0.0004	0.0004	0.0004	0.0099	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
V-L Flowrate (kg_{mol}/hr)	2,260	7,356	11,753	11,334	471	11,281	8,761	300,521	300,521	300,521	300,521
V-L Flowrate (kg/hr)	92,720	301,833	482,231	474,690	8,707	473,525	385,564	13,225,889	13,225,889	13,225,889	13,225,889
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	41	36	32	99	35	38	37	760	348	174	57
Pressure (MPa, abs)	0.11	0.11	0.10	3.00	0.10	3.00	15.20	34.30	9.24	9.17	9.10
Enthalpy (kJ/kg)[A]	78.10	73.37	70.38	73.49	145.38	6.95	-206.34	810.79	319.69	119.40	-51.63
Density (kg/m^3)	1.8	1.7	1.7	43.4	77.9	55.5	536.8	162.0	79.7	120.6	250.8
V-L Molecular Weight	41.032	41.032	41.032	41.882	18.472	41.974	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	4,982	16,217	25,910	24,987	1,039	24,871	19,314	662,536	662,536	662,536	662,536
V-L Flowrate (lb/hr)	204,412	665,428	1,063,138	1,046,513	19,195	1,043,943	850,022	29,158,094	29,158,094	29,158,094	29,158,094
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	106	96	90	210	95	100	99	1,400	659	346	135
Pressure (psia)	16.2	15.3	14.8	435.1	14.8	435.1	2,205.0	4,974.7	1,340.0	1,330.0	1,320.0
Enthalpy (Btu/lb)[A]	33.6	31.5	30.3	31.6	62.5	3.0	-88.7	348.6	137.4	51.3	-22.2
Density (lb/ft^3)	0.110	0.106	0.103	2.707	4.865	3.462	33.509	10.112	4.975	7.532	15.655

Exhibit 3-61 Case RhtIC760 stream table results (continued)

	35	36	37	38	39	40	41	42	43	44	45
V-L Mole Fraction											
Ar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	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)	48,441	252,081	48,441	252,081	252,081	234,679	17,401	17,401	300,521	234,679	300,521
V-L Flowrate (kg/hr)	2,131,876	11,094,013	2,131,876	11,094,013	11,094,013	10,328,184	765,830	765,830	13,225,889	10,328,184	13,225,889
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	57	57	169	35	52	52	52	169	677	169	169
Pressure (MPa, abs)	9.10	9.10	34.58	9.03	34.64	34.64	34.64	34.58	9.31	34.58	34.58
Enthalpy (kJ/kg)[A]	-51.63	-51.63	24.23	-187.40	-194.77	-194.77	-194.77	24.23	713.53	24.23	24.23
Density (kg/m^3)	250.8	250.8	503.7	664.4	890.9	890.9	890.9	503.7	50.9	503.7	503.7
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	106,794	555,742	106,794	555,742	555,742	517,379	38,363	38,363	662,536	517,379	662,536
V-L Flowrate (lb/hr)	4,699,981	24,458,113	4,699,981	24,458,113	24,458,113	22,769,747	1,688,366	1,688,366	29,158,094	22,769,747	29,158,094
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	135	135	336	95	125	125	125	336	1,251	336	336
Pressure (psia)	1,320.0	1,320.0	5,014.7	1,310.0	5,024.7	5,024.7	5,024.7	5,014.7	1,350.0	5,014.7	5,014.7
Enthalpy (Btu/lb)[A]	-22.2	-22.2	10.4	-80.6	-83.7	-83.7	-83.7	10.4	306.8	10.4	10.4
Density (lb/ft^3)	15.655	15.655	31.444	41.477	55.614	55.614	55.614	31.444	3.177	31.444	31.444

Exhibit 3-61 Case RhtIC760 stream table results (continued)

	46	47	48	49	50
V-L Mole Fraction					
Ar	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	1.0000	1.0000	1.0000	1.0000	1.0000
H_2	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000
N_2	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.0000	0.0000	0.0000	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	300,521	300,521	300,521	300,521	300,521
V-L Flowrate (kg/hr)	13,225,889	13,225,889	13,225,889	13,225,889	13,225,889
Solids Flowrate (kg/hr)	0	0	0	0	0
Temperature (°C)	305	343	650	653	760
Pressure (MPa, abs)	34.51	34.44	34.37	16.51	16.44
Enthalpy (kJ/kg)[A]	224.52	274.83	668.67	679.04	814.67
Density (kg/m^3)	319.6	292.4	182.4	91.3	81.2
V-L Molecular Weight	44.010	44.010	44.010	44.010	44.010
V-L Flowrate (lb_{mol}/hr)	662,536	662,536	662,536	662,536	662,536
V-L Flowrate (lb/hr)	29,158,094	29,158,094	29,158,094	29,158,094	29,158,094
Solids Flowrate (lb/hr)	0	0	0	0	0
Temperature (°F)	581	649	1,202	1,207	1,400
Pressure (psia)	5,004.7	4,994.7	4,984.7	2,395.0	2,385.0
Enthalpy (Btu/lb)[A]	96.5	118.2	287.5	291.9	350.2
Density (lb/ft^3)	19.952	18.254	11.385	5.702	5.069

Exhibit 3-62 Reheat and Intercooled sCO_2 plant performance summary

Parameter	Case RhtIC620	Case RhtIC760
CFB Coal Flow Rate (lb/hr)	437,000	390,800
Limestone Flow Rate (lb/hr)	105,131	94,017
Oxygen Flow Rate (lb/hr)	933,934	835,197
Coal Thermal Input (MMBtu/hr)	5,098	4,559
Net Plant Power Output (kW)	550,075	549,802
Net Plant Efficiency (HHV %)	**36.82**	**41.15**
HHV Heat Rate (Btu/kWh)	9,268	8,292
Raw Water Withdrawal (gpm)	6,246	5,152

Exhibit 3-63 Plant power summary for Reheat and Intercooled cases

POWER SUMMARY		
Item (kW)	**Case RhtIC620**	**Case RhtIC760**
POWER CYCLE SUMMARY		
sCO_2 Turbine Gross Power	912,900	855,600
sCO_2 Main Compressor	-142,300	-115,000
sCO_2 Bypass Compressor	-58,100	-44,900
sCO_2 Generator Loss	-10,688	-10,436
TOTAL sCO_2 POWER GENERATED	**701,813**	**685,265**
AUXILIARY LOAD SUMMARY		
Coal Handling	-446	-422
Limestone Prep	-210	-190
Pulverizers	-90	-80
Slag Handling and Dewatering	-2,340	-2,090
Primary Air Fans	-240	-210
Forced Draft Fans	-300	-270
Induced Draft Fans	-1,840	-1,650
Air Separation Unit	-77,930	-69,690
Baghouse	-10	-10
CPU (Purification and Compression) Auxiliaries	-53,140	-47,520
Turbine Auxiliaries	-400	-400
Miscellaneous Balance of Plant	-2,000	-2,000
Circulating Water Pump	-6,480	-5,370

POWER SUMMARY		
Item (kW)	**Case RhtIC620**	**Case RhtIC760**
Cooling Tower Fans	-3,780	-3,140
Transformer Losses	-2,520	-2,420
TOTAL AUXILIARIES	**-151,726**	**-135,462**
NET POWER	**550,075**	**549,802**

Exhibit 3-64 Reheat and Intercooled sCO_2 cycle performance summary

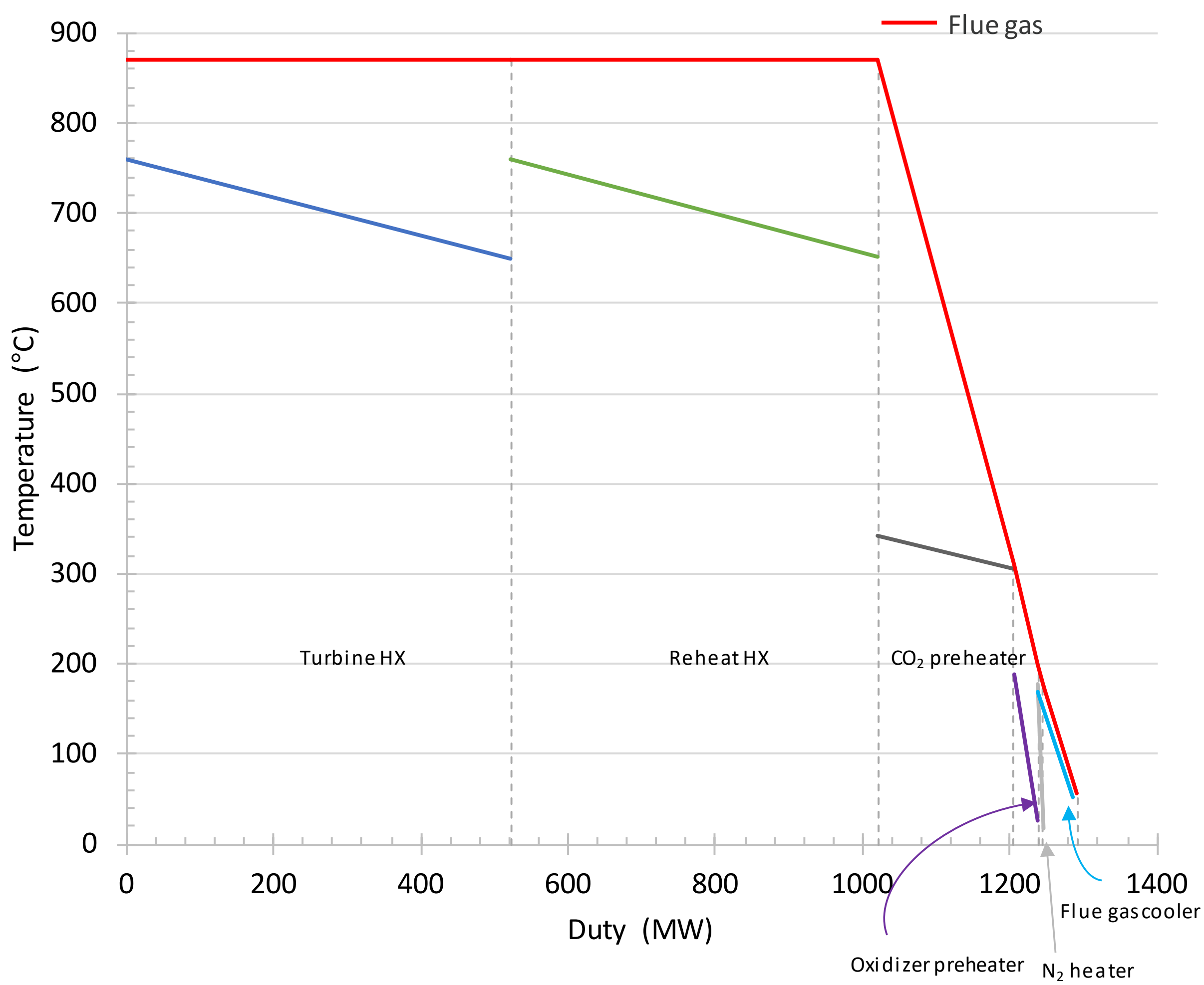
Parameter	Case RhtIC620	Case RhtIC760
THERMAL INPUT		
Power Cycle Thermal Input - CFB (MMBtu/hr)	4,599	4,113
Power Cycle Thermal Input – Flue gas (MMBtu/hr)	178	159
Power Cycle Thermal Input - Total (MMBtu/hr)	4,777	4,272
Fractional Thermal Input to Power Cycle	0.937	0.937
RECUPERATOR DUTY		
Recuperator Duty – VTR (MMBtu/hr)	4,033	4,937
Recuperator Duty – HTR (MMBtu/hr)	2,722	2,511
Recuperator Duty – LTR (MMBtu/hr)	2,673	2,144
Recuperator Duty – Total (MMBtu/hr)	9,428	9,592
COOLING DUTY		
Power Cycle Cooling Duty – CO_2 cooler (MMBtu/hr)	1,767	1,428
Power Cycle Cooling Duty – CO_2 intercooler (MMBtu/hr)	582	470
Power Cycle Cooling Duty – Total (MMBtu/hr)	2,349	1,898
POWER OUTPUT		
Net Cycle Power Output (kW)	701,813	685,265
SPECIFIC POWER		
sCO_2 Flow Rate (lb/hr)	36,350,564	29,158,094
sCO_2 Cycle Specific Power (Wh/lb)	19.31	23.50
sCO_2 Cycle Specific Power (kJ/kg)	153.2	186.5
OVERALL CYCLE PERFORMANCE		
sCO_2 Power Cycle Efficiency (%)	50.13	54.74
sCO_2 Cycle Heat Rate (Btu/kWh)	6,807	6,233

3.10.2 T-Q Diagram for Case RhtIC760

Exhibit 3-65 displays the temperature versus duty (T-Q) diagram for Case RhtIC760. The red line denotes the heating stream from CFB. Approximately 79 percent of the heat absorbed from the CFB is done in the fluidized bed region with the remaining heat absorbed from the flue gas. The segmented lines below the red line are cold source streams heated by the CFB or flue gas. Note that there is nearly

equal heat duty and driving force in the heaters for the main and reheat turbines. The minimum temperature approach specification was applied to the cold end of the oxidant preheater as well as the hot and cold ends of the flue gas cooler.

Exhibit 3-65 T-Q Diagram for Case RhtIC760



Source: NETL

3.10.3 Effect of Reheat and Intercooling on the sCO_2 Power Cycle

The use of reheat and main compressor intercooling predominantly impact opposite ends of the sCO_2 power cycle with reheat acting to increase turbine output and intercooling acting to decrease compression power. Hence, reheat and intercooling could be expected to act in an additive manner to increase cycle and process efficiency. However, this additive impact is partially offset by the nonlinear interactions that reheat and intercooling have on recuperator effectiveness and total heat recovery by the cycle.

Comparing the results in Exhibit 3-63 and Exhibit 3-64 with the corresponding Baseline Case results in Exhibit 3-20 and Exhibit 3-21 shows that the net effect of reheat and intercooling on the Baseline cases shows the expected impact on turbine and compressor power. For both TITs, the gain in process efficiency from using reheat and intercooling are nearly independent. The increase in overall plant efficiency from using both reheat and intercooling is almost the same as the sum of the increases in process efficiency from using each separately. A similar additive effect is seen in the increase in cycle efficiency. In all cases main compressor intercooling increases the sCO_2 cycle's specific power and compactness.

3.10.4 Case Mass Balances

The carbon balance for Case RhtIC620 is shown in Exhibit 3-66 while the corresponding carbon balance for Case RhtIC760 is shown in Exhibit 3-67.

Exhibit 3-66 Case RhtIC620 carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	126,671 (279,262)	CO_2 Product	117,664 (259,404)
Air (CO_2)	249 (549)	Bottom Ash	4,137 (9,119)
Limestone Reagent	4,839 (10,668)	Separated Air	242 (534)
		CPU Vent	9,586 (21,134)
		Fly Ash	131 (288)
Total	**131,759 (290,478)**	**Total**	**131,759 (290,478)**

Exhibit 3-67 Case RhtIC760 carbon balance

Carbon In		Carbon Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	113,279 (249,738)	CO_2 Product	105,224 (231,980)
Air (CO_2)	223 (491)	Bottom Ash	3,700 (8,157)
Limestone Reagent	4,327 (9,540)	Separated Air	217 (477)
		CPU Vent	8,573 (18,899)

		Fly Ash	117 (258)
Total	**117,829 (259,769)**	**Total**	**117,829 (259,769)**

Exhibit 3-68 shows the sulfur balance for Case RhtIC620.

Exhibit 3-68 Case RhtIC620 sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	4,980 (10,979)	Bottom Ash	4,667 (10,288)
		CO_2 Product	2 (4)
		Fly Ash	147 (325)
		CPU Water	167 (369)
Total	**4,980 (10,979)**	**Total**	**4,980 (10,979)**

Exhibit 3-69 shows the sulfur balance for Case RhtIC760.

Exhibit 3-69 Case RhtIC760 sulfur balance

Sulfur In		Sulfur Out	
kg/hr (lb/hr)		kg/hr (lb/hr)	
Coal	4,453 (9,818)	Bottom Ash	4,173 (9,201)
		CO_2 Product	2 (3)
		Fly Ash	132 (291)
		CPU Water	150 (330)
Total	**4,453 (9,818)**	**Total**	**4,453 (9,818)**

Exhibit 3-70 shows the overall water balance for Case RhtIC620 and Exhibit 3-71 shows the overall water balance for Case RhtIC760.

Exhibit 3-70 Case RhtIC620 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	25.24 (6668)	1.6 (423)	23.64 (6246)	5.68 (1500)	17.97 (4746)

MAC knock-out	0.00 ()	0.0 (2)	0.00 ()	0.00 (0)	0.00 ()
ASU discharge	0.0 (0)	0.00 (0)	0.0 (0)	0.17 (46)	0.00 ()
Total	**25.2 (6,668)**	**1.61 (425)**	**23.6 (6,246)**	**5.85 (1,546)**	**17.97 (4,746)**

Exhibit 3-71 Case RhtIC760 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	20.93 (5530)	1.4 (378)	19.50 (5152)	4.71 (1244)	14.80 (3909)
MAC knock-out	0.00 ()	0.0 (2)	0.00 ()	0.00 (0)	0.00 ()
ASU discharge	0.0 (0)	0.00 (0)	0.0 (0)	0.16 (41)	0.00 ()
Total	**20.9 (5,530)**	**1.44 (380)**	**19.5 (5,152)**	**4.86 (1,285)**	**14.80 (3,909)**

3.11 Performance Comparison Between Reference Rankine, Baseline sCO_2 and Reheat/Intercooled sCO_2

Exhibit 3-72 compares the performance of the two reference Rankine cycles and the two Reheat sCO_2 cycles.

Exhibit 3-72 Performance comparison between Reference Rankine and RhtIC sCO_2

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case RhtIC620	Case RhtIC760
CFB Coal Flow Rate (lb/hr)	478,280	436,129	437,000	390,800
Limestone Flow Rate (lb/hr)	114,987	104,732	105,131	94,017
Oxygen Flow Rate (lb/hr)	1,021,874	931,831	933,934	835,197
sCO_2 Flow Rate (lb/hr)	---	---	36,350,564	29,158,094
Net Plant Efficiency (HHV %)	**33.64**	**36.88**	**36.82**	**41.15**
HHV Heat Rate (Btu/kWh)	10,144	9,251	9,268	8,292
sCO_2 Power Cycle Efficiency (%)	---	---	50.13	54.74
sCO_2 Cycle Heat Rate (Btu/kWh)	---	---	6,807	6,233
Steam Power Cycle Efficiency (%)	48.27	51.84	---	---
Steam Cycle Heat Rate (Btu/kWh)	7,068	6,582	---	---
Coal Thermal Input (MMBtu/hr)	5,580	5,088	5,098	4,559
Power Cycle Thermal Input (MMBtu/hr)	5,122	4,672	4,777	4,272
Fractional Thermal Input to Power Cycle	0.918	0.918	0.937	0.937

sCO2 Cycle Specific Power (Wh/lb)			19.31	23.50
Raw Water Withdrawal (gpm)	8,418	7,314	6,246	5,152
Power Summary				
Steam Turbine Power Output	721,000	705,600	---	---
sCO_2 Cycle Power Output	---	---	701,813	685,265
Gross Power Output	721,000	705,600	701,813	685,265
Total Auxiliary Power Load	**170,954**	**155,618**	**151,726**	**135,462**
Net Power Output	**550,046**	**549,982**	**550,075**	**549,802**

3.11.1 Performance Comparison Between Reference SC Rankine, Case Baseline620 and Case RhtIC620

Exhibit 3-73 shows the performance comparison between the SC Rankine cycle, the baseline sCO_2 recompression cycle, and the sCO_2 recompression cycle with the combination of reheat and main compressor intercooling with a TIT temperature of 620 °C. The reheat and intercooling combination acts synergistically to increase the power cycle efficiency (from 48.67 to 50.13 percent), the sCO_2 cycle specific power (from 16.82 to 19.31 Wh/lb), and the overall process efficiency (from 34.67 to 36.82 percent).

Compared to the reference SC Rankine cycle plant, the sCO_2 cycle plant configured with reheat and main compressor intercooling has a 3.18 percentage point increase in overall process efficiency.

Exhibit 3-73 Performance comparison between Reference, Baseline, and Reheat/Intercooled sCO_2 at 620 °C

Parameter	Reference SC Rankine	Case Baseline620	Case RhtIC620
CFB Coal Flow Rate (lb/hr)	478,280	464,000	437,000
Limestone Flow Rate (lb/hr)	114,987	111,627	105,131
Oxygen Flow Rate (lb/hr)	1,021,874	991,637	933,934
sCO_2 Flow Rate (lb/hr)	---	42,305,305	36,350,564
Net Plant Efficiency (HHV %)	**33.64**	**34.67**	**36.82**
HHV Heat Rate (Btu/kWh)	10,144	9,843	9,268
sCO_2 Power Cycle Efficiency (%)	---	48.67	50.13
sCO_2 Cycle Heat Rate (Btu/kWh)	---	7,010	6,807
Steam Power Cycle Efficiency (%)	48.27	---	---
Steam Cycle Heat Rate (Btu/kWh)	7,068	---	---
Coal Thermal Input (MMBtu/hr)	5,580	5,413	5,098

Power Cycle Thermal Input (MMBtu/hr)	5,122	4,987	4,777
Fractional Thermal Input to Power Cycle	0.918	0.921	0.937
sCO2 Cycle Specific Power (Wh/lb)		16.82	19.31
Raw Water Withdrawal (gpm)	8,418	6,879	6,246
Power Summary			
Steam Turbine Power Output	721,000	---	---
sCO_2 Cycle Power Output	---	711,367	701,813
Gross Power Output	721,000	711,367	701,813
Total Auxiliary Power Load	**170,954**	**161,457**	**151,726**
Net Power Output	**550,046**	**549,910**	**550,075**

3.11.2 Performance Comparison Between Reference AUSC Rankine, Case Baseline760 and Case RhtIC760

Exhibit 3-74 shows the performance comparison between the AUSC Rankine cycle, the baseline sCO_2 recompression cycle, and the sCO_2 recompression cycle with the combination of reheat and main compressor intercooling with a TIT temperature of 760 °C. Again, the reheat and intercooling combination acts synergistically to increase both the overall process efficiency (from 39.49 to 41.15 percent), the sCO_2 cycle specific power (from 20.92 to 23.50 Wh/lb), and the cycle efficiency (increase from 53.90 to 54.74 percent).

Compared to the reference AUSC Rankine cycle plant, the sCO_2 cycle plant configured with reheat and main compressor intercooling has a 4.27 percentage point increase in overall process efficiency.

Exhibit 3-74 Performance comparison between Reference, Baseline, and Reheat/Intercooled sCO_2 at 760 °C

Parameter	Reference AUSC Rankine	Case Baseline760	Case RhtIC760
CFB Coal Flow Rate (lb/hr)	436,129	407,200	390,800
Limestone Flow Rate (lb/hr)	104,732	97,962	94,017
Oxygen Flow Rate (lb/hr)	931,831	870,247	835,197
sCO_2 Flow Rate (lb/hr)	---	33,040,523	29,158,094
Net Plant Efficiency (HHV %)	**36.88**	**39.49**	**41.15**
HHV Heat Rate (Btu/kWh)	9,251	8,640	8,292
sCO_2 Power Cycle Efficiency (%)	---	53.90	54.74
sCO_2 Cycle Heat Rate (Btu/kWh)	---	6,331	6,233

Steam Power Cycle Efficiency (%)	51.84	---	---
Steam Cycle Heat Rate (Btu/kWh)	6,582	---	---
Coal Thermal Input (MMBtu/hr)	5,088	4,750	4,559
Power Cycle Thermal Input (MMBtu/hr)	4,672	4,376	4,272
Fractional Thermal Input to Power Cycle	0.918	0.921	0.937
sCO2 Cycle Specific Power (Wh/lb)		20.92	23.50
Raw Water Withdrawal (gpm)	7,314	5,541	5,152
Power Summary			
Steam Turbine Power Output	705,600	---	---
sCO_2 Cycle Power Output	---	691,273	685,265
Gross Power Output	705,600	691,273	685,265
Total Auxiliary Power Load	**155,618**	**141,474**	**135,462**
Net Power Output	**549,982**	**549,799**	**549,802**

4 ECONOMIC ANALYSIS – CAPITAL COST ESTIMATE METHODOLOGY

Aside from the thermal power cycle and extra heat recovery units, the BOP unit operations and equipment items are analogous to those found in the reference Rankine plant. The cost estimates for these items were based on power law scaling algorithms using the same scaling methodology used in the reference plant. The components in the sCO_2 power cycle are not present in the reference plant and new cost algorithms had to be derived for these units. These algorithms needed to also reflect the expected cost impacts of reheat and main compressor intercooling. In addition, an adjustment was made to the CFB cost algorithm to account for differences in the working fluid between supercritical steam and CO_2. The following sections describe the approaches used for each section.

4.1 CFB BOILER COSTS

The reference SC Rankine case cost was taken from Case B22F in the NETL CFB study. [11] The cost adjustment for AUSC conditions was derived from simulations using the Thermoflow products STEAM PRO and PEACE. Simulations were prepared for a 550 MW air-fired CFB plant with a SC Rankine cycle and another plant of the same size with an AUSC Rankine cycle. The ratio of the estimated cost for the AUSC plant to the SC plant was used to scale the reference SC Rankine case cost to AUSC conditions.

For the CFB cost estimates for the sCO_2 cases, a cost algorithm was derived that consisted of two components: the oxidant preheater and the remainder of the CFB and auxiliaries. The total heat transfer area and the capital cost of the oxidant preheater were determined from STEAM PRO and PEACE from which a cost per unit area could be derived.

The cost algorithm for the balance of the CFB and auxiliaries is comprised of two components: a heat duty dependent component and a driving force dependent component. A series of sensitivity analyses were performed in STEAM PRO and PEACE varying the plant capacity and steam TIT (driving force). Correlations of the results provided the necessary scaling coefficients for heat duty and driving force. The same CFB installation factor as used in the reference SC case was used for the other cases.

Note that detailed designs of the oxy-fired CFBs for the sCO_2 cases were not performed and, hence, direct estimates of the driving force in the CFB, including driving force adjustments due to reheat, were not possible. Using the steam TIT as a surrogate variable for driving force introduces a significant uncertainty in the cost estimate.

In this regard, a sensitivity analysis to the estimated COE as a function of uncertainty in the capital cost was performed. The results of this sensitivity analysis are shown in Section 6. An additional sensitivity analysis was performed using STEAM PRO and PEACE on an air-fired CFB without a reheat steam turbine. The results of that sensitivity analysis showed that the use of reheat in the steam turbine increase the CFB cost by only 1.3 percent at a turbine inlet temperature of 760 °C. Hence, neglecting the effect of reheat on the CFB cost in this study is not expected to introduce a significant error.

4.2 Flue Gas Cooler

This cooler has a heat duty of 233 MMBtu/hr in Case Baseline760. The cost of an analogous syngas cooler from IGCC pathway studies was used to estimate a scaled cost for this exchanger. The reference cooler used for scaling had a heat duty of 267 MMBtu/hr and a BEC of $18,614,000.

4.3 Water Knockout

Water knockout has a heat duty of 333 MMBtu/hr in Case Baseline760. The cost of an analogous knockout drum from IGCC pathway studies was used to estimate a scaled cost for this exchanger. The reference knockout drum used for scaling had a heat duty of 371 MMBtu/hr and a BEC of $2,251,000.

4.4 CO_2 Recycle Compressor

The CO_2 recycle compressor has a power load of 5,400 kW in Case Baseline760. A previous NETL report [16] for a 10 MW sCO_2 pilot plant used a cost basis of $1,450/kW for an analogous compressor of about 1/5 the scale.

4.5 sCO_2 Cycle Main CO_2 Compressor

Original information from a proprietary vendor quote indicated that the main CO_2 compressor would use three identical compressors in parallel at a price of around $10 MM each. The current sCO_2 Case Baseline760 has a different CO_2 flow from the original, now requiring four compressors in parallel at a power load of 35.5 MW each with discharge temperature of 89 °C. An adjusted vendor quote recommended a cost reduction to $9 MM per compressor for this case. This cost represents equipment only; an installation factor of 60 percent was assumed.

To reflect expected changes in the compressor cost with intercooling, the scaling algorithm was divided into three components with one component dependent on required power (60 percent), another component dependent on volumetric flow rate to the compressor (20 percent), and the final component dependent on the temperature of the stream entering the main compressor stage (20 percent).

4.6 sCO_2 Cycle Bypass CO_2 Compressor

Original information from a proprietary vendor quote recommended six bypass CO_2 compressors in parallel at a price of around $10 MM each. Again, the current sCO_2 Case Baseline760 has a different CO_2 flow, requiring only three compressors in parallel at a power load of 31 MW each and a discharge temperature of 230 °C. An adjusted vendor quote recommended a cost increase to $11 MM per compressor. Again, an installation factor of 60 percent was assumed. The cost algorithm was adjusted to reflect dependence on power requirement, flow rate, and temperature in the same manner as described for the main CO_2 compressor.

4.7 Recuperators

Equipment costs of the CO_2 recuperators are based on a report by Aerojet Rocketdyne. [17] This report contained quotes from two vendors. For the vendor designated Vendor A, the recuperators were a microchannel heat exchanger based on a shell and tube design that used a small number (17) of extremely large units. The HTR was broken up into two HTRs made of different materials. The high temperature (HT) HTR (hot side temperature ≥ 500 °F) consisted of 5 units while the low temperature (LT) HTR consisted of 4 units. The unit duties for the three recuperator types were 463 MW, 170 MW, and 94 MW for the HT HTR, LT HTR, and LTR, respectively. The estimated unit costs were $44,531,000 (2011$) for HT HTR units and $7,422,000 for LTR and LT HTR units. The cost was based on material and manufacturing only (BEC). The cost algorithm derived for this study adjusts the BEC for change in duty and log mean temperature difference (LMTD) driving force. The cost estimate for the VTR uses the cost algorithm for the HT HTR.

For the vendor designated Vendor B, the recuperator design was based on a counterflow “Extended-Surface Unit-Cell Design Concept”. [17] This design uses a large number (629) of relatively small units. A single material was used for the HTR. The unit duties were 8 MW and 3 MW for the HTR and LTR, respectively. The unit costs were $97,625 (2011$) for HTR units and $152,000 for LTR units. The cost was based on material and manufacturing only (BEC). The cost algorithm derived for this study adjusts the BEC for change in duty and log mean temperature difference (LMTD) driving force. The cost estimate for the VTR uses the cost algorithm for the HTR.

Except for the sensitivity analysis described in Section 6.1, all economic analysis results for the sCO_2 power cycle cases in this study used the cost algorithm based on the Vendor B design.

4.8 CO_2 Cooler

The CO_2 cooler is analogous to a steam cycle condenser; its heat is rejected to a water cooling tower. The cost algorithm for a condenser from IGCC pathway studies is used to estimate the cost of the CO_2 cooler. For Case Baseline760, the duty of the cooler is 2,045 MMBtu/hr, which is roughly the same as that of a bottoming cycle condenser.

4.9 CO_2 Turbine

The BEC of the CO_2 turbine is based on a paper by Le Moullec [18] that cites a turbine cost of 102 €2010/kW including civil works, piping, etc. for a turbine in the 1 GWe range. This cost was assumed to include installation. Indexing that cost to June 2011 dollars provided a BEC cost of $109.3/kW for each turbine. The sCO_2 plant has two turbines. One (235,205 kW) is tied to the two CO_2 compressors, and the other (692,810 kW) is the power turbine.

The algorithm was further adjusted to cost variation based on the expected impacts of reheat. The algorithm base was broken into three components: one based on the gross turbine output (30 percent), another based on the ratio of cross sectional areas needed (37 percent), and the last based on the average turbine gas temperature (33 percent). The weighting factors were adjusted such that the calculated BEC for Case Baseline760 and Case Baseline620 would be the same based on a rough order of magnitude (ROM) estimate from General Electric (GE).

4.10 CO_2 System Piping

The pipes that transport CO_2 working fluid between the heat source and turbine are very expensive due to the large flowrate of CO_2 and the elevated temperature and pressure of the fluid. For the purposes of this economic assessment, the pipe lengths between the HTR and heat source and between the heat source and turbine are assumed to be 150 ft. The pipe inside diameter was calculated based on the actual working fluid volumetric flow rate and an assumed fluid velocity of 150 ft/sec. The selection of pipe material and thickness was based on a NETL report. [19] The material capable of meeting the service temperature and pressure with the lowest estimated pipe cost was selected. A 30 percent installation factor was assumed.

5 Economic Analysis – Results

5.1 Reference SC Rankine Case Cost Estimate Results

Exhibit 5-1 shows a detailed breakdown of the capital costs. The cost estimating methodology was described previously in Section 2, and reflects the methodology used in the Bituminous Baseline [3] and atmospheric advanced oxy-combustion study [12]. The reference Alstom case from the oxy-CFB study was the basis for the CFB cost. [20] The reference SC case scales the oxy-CFB combustor cost from the reference Alstom Case 1B oxy-CFB cost. [11]

Exhibit 5-2 shows the owner's costs, TOC, and TASC; Exhibit 5-3 shows the initial and annual O&M costs.

Exhibit 5-1 Reference SC Rankine Case total plant cost details

Total Plant Cost Summary											
	Case:	B22F – Supercritical Oxy-CFB w/ CPU					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550					Cost Base ($x1,000):			Jun 2011	
Item No.	Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $/1000	Total Plant Cost $/kW
	1	Coal & Sorbent Handling									
1.1	Coal Receive & Unload	$4,501	$0	$2,028	$0	$6,529	$566	$0	$1,064	$8,159	$15
1.2	Coal Stackout & Reclaim	$5,817	$0	$1,300	$0	$7,117	$603	$0	$1,158	$8,878	$16
1.3	Coal Conveyors	$5,408	$0	$1,286	$0	$6,694	$568	$0	$1,089	$8,352	$15
1.4	Other Coal Handling	$1,415	$0	$298	$0	$1,713	$145	$0	$279	$2,136	$4
1.5	Sorbent Receive & Unload	$318	$0	$95	$0	$413	$35	$0	$67	$515	$1
1.6	Sorbent Stackout & Reclaim	$5,138	$0	$929	$0	$6,067	$511	$0	$987	$7,565	$14
1.7	Sorbent Conveyors	$1,834	$398	$443	$0	$2,675	$224	$0	$435	$3,334	$6
1.8	Other Sorbent Handling	$1,107	$261	$573	$0	$1,941	$166	$0	$316	$2,423	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$5,616	$7,405	$0	$13,021	$1,221	$0	$2,136	$16,379	$30
	Subtotal	**$25,539**	**$6,275**	**$14,356**	**$0**	**$46,169**	**$4,039**	**$0**	**$7,531**	**$57,740**	**$105**
	2	Coal & Sorbent Prep & Feed									
2.1	Coal Crushing & Drying	$2,594	$0	$499	$0	$3,093	$261	$0	$503	$3,857	$7
2.2	Coal Conveyor to Storage	$6,642	$0	$1,430	$0	$8,071	$683	$0	$1,313	$10,068	$18
2.5	Sorbent Prep Equipment	$8,819	$382	$1,806	$0	$11,007	$927	$0	$1,790	$13,724	$25
2.6	Sorbent Storage & Feed	$1,062	$0	$401	$0	$1,464	$126	$0	$238	$1,828	$3
2.9	Coal & Sorbent Feed Foundation	$0	$662	$581	$0	$1,244	$116	$0	$204	$1,563	$3
	Subtotal	**$19,117**	**$1,044**	**$4,718**	**$0**	**$24,878**	**$2,113**	**$0**	**$4,049**	**$31,040**	**$56**
	3	Feedwater & Miscellaneous BOP Systems									
3.1	Feedwater System	$24,990	$0	$8,057	$0	$33,048	$2,824	$0	$5,381	$41,253	$75
3.2	Water Makeup & Pretreating	$7,506	$0	$2,374	$0	$9,881	$903	$0	$2,157	$12,940	$24
3.3	Other Feedwater Subsystems	$7,861	$0	$3,227	$0	$11,089	$953	$0	$1,806	$13,848	$25
3.4	Service Water Systems	$1,503	$0	$787	$0	$2,290	$206	$0	$499	$2,995	$5
3.5	Other Boiler Plant Systems	$9,805	$0	$9,270	$0	$19,076	$1,736	$0	$3,122	$23,933	$44
3.6	FO Supply Sys & Nat Gas	$339	$0	$396	$0	$735	$66	$0	$120	$921	$2
3.7	Waste Treatment Equipment	$1,218	$0	$705	$0	$1,923	$185	$0	$422	$2,529	$5
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,321	$0	$1,027	$0	$4,349	$413	$0	$952	$5,715	$10
	Subtotal	**$56,545**	**$0**	**$25,845**	**$0**	**$82,390**	**$7,286**	**$0**	**$14,459**	**$104,134**	**$189**
	4	Boiler & Accessories									
4.1	CFB Boiler & Accessories	w/ BEC	$0	w/ BEC	$0	$384,979	$37,052	$0	$42,203	$464,234	$844
4.5	ASU/Oxidant Compression	$171,171	$0	$140,049	$0	$311,220	$30,166	$0	$34,139	$375,525	$683
4.6	Secondary Air System	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0
4.8	Major Component Rigging	$0	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0
4.9	Boiler Foundations	$0	w/14.1	w/14.1	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$171,171**	**$0**	**$140,049**	**$0**	**$696,198**	**$67,218**	**$0**	**$76,342**	**$839,758**	**$1,527**

Exhibit 5-1 Reference SC Rankine Case total plant cost details (continued)

Total Plant Cost Summary											
	Case:	B22F – Supercritical Oxy-CFB w/ CPU					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550					Cost Base ($x1,000):			Jun 2011	
Item No.	Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $/1000	Total Plant Cost $/kW
5A		Gas Cleanup & Piping									
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$9,894	$0	$6,236	$0	$16,130	$1,516	$0	$1,765	$19,411	$35
5A.4	Other Particulate Removal Materials	$677	$0	$720	$0	$1,397	$132	$0	$153	$1,682	$3
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$10,572**	**$0**	**$6,956**	**$0**	**$17,528**	**$1,648**	**$0**	**$1,918**	**$21,093**	**$38**
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification Unit/System	$82,078	$0	$62,345	$0	$144,423	$13,451	$28,885	$37,352	$224,111	$407
5B.2	CO_2 Compression & Drying	w/5B.1	$0	w/5B.1	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$82,078**	**$0**	**$62,345**	**$0**	**$144,423**	**$13,451**	**$28,885**	**$37,352**	**$224,111**	**$407**
7		HRSG, Ducting, & Stack									
7.1	Flue Gas Recycle Heat Exchanger	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$10,478	$0	$6,614	$0	$17,092	$1,444	$0	$2,780	$21,316	$39
7.4	Stack	$2,078	$0	$1,208	$0	$3,286	$308	$0	$359	$3,954	$7
7.9	Duct & Stack Foundations	$0	$1,075	$1,277	$0	$2,352	$220	$0	$514	$3,086	$6
	Subtotal	**$12,556**	**$1,075**	**$9,098**	**$0**	**$22,730**	**$1,972**	**$0**	**$3,654**	**$28,356**	**$52**
8		Steam Turbine Generator									
8.1	Steam TG & Accessories	$86,100	$0	$10,598	$0	$96,698	$7,473	$0	$9,260	$113,431	$206
8.2	Turbine Plant Auxiliaries	$477	$0	$1,014	$0	$1,491	$142	$0	$163	$1,797	$3
8.3	Condenser & Auxiliaries	$8,959	$0	$3,280	$0	$12,239	$1,142	$0	$1,338	$14,719	$27
8.4	Steam Piping	$20,818	$0	$9,992	$0	$30,809	$2,361	$0	$4,976	$38,146	$69
8.9	TG Foundations	$0	$1,420	$2,345	$0	$3,765	$355	$0	$824	$4,943	$9
	Subtotal	**$116,354**	**$1,420**	**$27,228**	**$0**	**$145,002**	**$11,474**	**$0**	**$16,561**	**$173,036**	**$315**
9		Cooling Water System									
9.1	Cooling Towers	$13,407	$0	$4,146	$0	$17,553	$1,635	$0	$1,919	$21,108	$38
9.2	Circulating Water Pumps	$3,235	$0	$257	$0	$3,492	$298	$0	$379	$4,169	$8
9.3	Circ.Water System Auxiliaries	$852	$0	$113	$0	$965	$89	$0	$105	$1,160	$2
9.4	Circ.Water Piping	$0	$7,183	$6,505	$0	$13,688	$1,212	$0	$2,235	$17,134	$31
9.5	Make-up Water System	$717	$0	$921	$0	$1,638	$151	$0	$268	$2,057	$4
9.6	Component Cooling Water Sys	$695	$0	$533	$0	$1,229	$112	$0	$201	$1,542	$3
9.9	Circ.Water System Foundations & Structures	$0	$3,836	$6,370	$0	$10,206	$962	$0	$2,234	$13,402	$24
	Subtotal	**$18,906**	**$11,019**	**$18,846**	**$0**	**$48,772**	**$4,459**	**$0**	**$7,341**	**$60,572**	**$110**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	$1,709	$0	$5,229	$0	$6,938	$666	$0	$760	$8,364	$15
10.7	Ash Transport & Feed Equipment	$11,352	$0	$11,254	$0	$22,606	$2,082	$0	$2,469	$27,157	$49
10.9	Ash/Spent Sorbent Foundation	$0	$386	$475	$0	$861	$81	$0	$188	$1,130	$2
	Subtotal	**$13,061**	**$386**	**$16,958**	**$0**	**$30,405**	**$2,829**	**$0**	**$3,418**	**$36,652**	**$67**

Exhibit 5-1 Reference SC Rankine Case total plant cost details (continued)

Total Plant Cost Summary											
	Case:	B22F – Supercritical Oxy-CFB w/ CPU					**Estimate Type:**			Conceptual	
	Plant Size (MW,net):	550					**Cost Base ($x1,000):**			Jun 2011	
Item No.	**Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Bare Erected Cost**	**Eng'g CM H.O.& Fee**	**Contingencies Process**	**Contingencies Project**	**Total Plant Cost $/1000**	**Total Plant Cost $/kW**
11		**Accessory Electric Plant**									
11.1	Generator Equipment	$2,200	$0	$352	$0	$2,552	$229	$0	$209	$2,989	$5
11.2	Station Service Equipment	$6,954	$0	$2,331	$0	$9,286	$863	$0	$761	$10,910	$20
11.3	Switchgear & Motor Control	$7,982	$0	$1,387	$0	$9,368	$866	$0	$1,023	$11,258	$20
11.4	Conduit & Cable Tray	$0	$5,473	$17,684	$0	$23,158	$2,161	$0	$3,798	$29,117	$53
11.5	Wire & Cable	$0	$10,422	$18,630	$0	$29,052	$2,333	$0	$4,708	$36,093	$66
11.6	Protective Equipment	$366	$0	$1,272	$0	$1,638	$157	$0	$180	$1,975	$4
11.7	Standby Equipment	$1,657	$0	$39	$0	$1,696	$155	$0	$185	$2,036	$4
11.8	Main Power Transformers	$16,268	$0	$234	$0	$16,502	$1,251	$0	$1,775	$19,528	$36
11.9	Electrical Foundations	$0	$417	$1,061	$0	$1,479	$140	$0	$324	$1,942	$4
	Subtotal	**$35,428**	**$16,313**	**$42,989**	**$0**	**$94,730**	**$8,156**	**$0**	**$12,962**	**$115,848**	**$211**
12		**Instrumentation & Control**									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$639	$0	$390	$0	$1,029	$96	$51	$177	$1,354	$2
12.7	Distributed Control System Equipment	$6,449	$0	$1,150	$0	$7,599	$702	$380	$868	$9,549	$17
12.8	Instrument Wiring & Tubing	$3,889	$0	$7,076	$0	$10,964	$888	$548	$1,860	$14,261	$26
12.9	Other I & C Equipment	$1,822	$0	$4,219	$0	$6,042	$577	$302	$692	$7,613	$14
	Subtotal	**$12,798**	**$0**	**$12,836**	**$0**	**$25,634**	**$2,264**	**$1,282**	**$3,597**	**$32,776**	**$60**
13		**Improvements to Site**									
13.1	Site Preparation	$0	$62	$1,323	$0	$1,385	$135	$0	$304	$1,825	$3
13.2	Site Improvements	$0	$2,065	$2,728	$0	$4,793	$476	$0	$1,054	$6,323	$11
13.3	Site Facilities	$3,700	$0	$3,882	$0	$7,582	$755	$0	$1,667	$10,004	$18
	Subtotal	**$3,700**	**$2,127**	**$7,933**	**$0**	**$13,761**	**$1,365**	**$0**	**$3,025**	**$18,152**	**$33**
14		**Buildings & Structures**									
14.1	Boiler Building	$0	$10,578	$9,296	$0	$19,874	$1,749	$0	$3,243	$24,866	$45
14.2	Turbine Building	$0	$15,285	$14,236	$0	$29,521	$2,605	$0	$4,819	$36,945	$67
14.3	Administration Building	$0	$767	$810	$0	$1,577	$140	$0	$258	$1,975	$4
14.4	Circulation Water Pumphouse	$0	$190	$151	$0	$342	$30	$0	$56	$427	$1
14.5	Water Treatment Buildings	$0	$945	$861	$0	$1,805	$159	$0	$295	$2,259	$4
14.6	Machine Shop	$0	$513	$344	$0	$857	$74	$0	$140	$1,072	$2
14.7	Warehouse	$0	$348	$348	$0	$696	$62	$0	$114	$871	$2
14.8	Other Buildings & Structures	$0	$284	$242	$0	$526	$46	$0	$86	$658	$1
14.9	Waste Treating Building & Str.	$0	$540	$1,637	$0	$2,176	$202	$0	$357	$2,735	$5
	Subtotal	**$0**	**$29,449**	**$27,925**	**$0**	**$57,375**	**$5,067**	**$0**	**$9,366**	**$71,808**	**$131**
	Total	**$577,825**	**$69,109**	**$418,082**	**$0**	**$1,449,995**	**$133,341**	**$30,166**	**$201,574**	**$1,815,076**	**$3,300**

Exhibit 5-2 Reference SC Rankine Case owner's costs

Owner's Costs		
Description	**$/1000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$11,929	$22
1-Month Maintenance Materials	$1,721	$3
1-Month Non-fuel Consumables	$2,027	$4
1-Month Waste Disposal	$1,746	$3
25% of 1-Month Fuel Cost at 100% CF	$2,994	$5
2% of TPC	$36,302	$66
Total	**$56,718**	**$103**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$27,388	$50
0.5% of TPC (spare parts)	$9,075	$16
Total	**$36,463**	**$66**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$272,261	$495
Financing Costs	$49,007	$89
Total Overnight Costs (TOC)	**$2,230,425**	**$4,055**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,542,685**	**$4,623**

Exhibit 5-3 Reference SC Rankine Case initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	B22F	– Supercritical Oxy-CFB w/ CPU			**Cost Base:**	Jun 2011
Plant Size (MW,net):	550		**Heat Rate-net (Btu/kWh):**	10,144	**Capacity Factor (%):**	85
Operating & Maintenance Labor						
Operating Labor				**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		39.70	**$/hour**		**1 unit/mod.**	**Total Plant**
Operating Labor Burden:		30.00	**% of base**	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	**% of labor**	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**($/kW-net)**
Annual Operating Labor:					$7,384,208	$13.425
Maintenance Labor:					$11,701,435	$21.274
Administrative & Support Labor:					$4,771,410.74	$8.675
Property Taxes and Insurance:					$36,301,510	$65.997
Total:					**$60,158,564**	**$109.370**
Variable Operating Costs						
					($)	**($/kWh-net)**
Maintenance Material:					$17,554,746	$0.00429
Consumables						
	Consumption		**Cost ($)**			
	Initial Fill	**Per Day**	**Per Unit**	**Initial Fill**		
Water (/1000 gallons):	0	6,061	$1.67	$0	$3,147,873	$0.00077
Makeup and Waste Water Treatment Chemicals (lbs):	0	29,340	$0.27	$0	$2,438,035	$0.00060
Limestone (ton)	0	1,380	$33.48	$0	$14,332,575	$0.00350
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,498	$1.63	$0	$755,178	$0.00018
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$20,673,661**	**$0.00505**
Waste Disposal						
Fly Ash (ton)	0	53	$25.11	$0	$412,398	$0.00010
Bottom Ash (ton)	0	2,234	$25.11	$0	$17,400,570	$0.00425
Subtotal:				**$0**	**$17,812,968**	**$0.00435**
By-Products						
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$56,041,375**	**$0.01368**
Fuel Cost						
Illinois Number 6 (ton):	0	5,739	$68.60	$0	$122,151,771	$0.02982
Total:				**$0**	**$122,151,771**	**$0.02982**

Exhibit 5-7 shows the COE results for the Reference SC Rankine Case using high-risk financing.

5.2 Reference AUSC Rankine Case Cost Estimate Results

Exhibit 5-4 shows a detailed breakdown of the capital costs. The majority of the equipment cost results reported for the Reference AUSC case follow the cost estimating methodology described previously in Section 2. However, the cost PC boiler & Accessories, Steam TG & Accessories, and Steam Piping that relate directly to the AUSC steam conditions, use appropriate alternate cost references. The CFB cost was based on the Reference SC case CFB cost but scaled to AUSC conditions with a factor of 1.148 based on data from STEAM PRO and PEACE. The steam turbine generator and steam piping costs were scaled from a reference provided by the AUSC Consortium. [8] Further details on the cost algorithms for these components can be found in the oxy-CFB study report. [11]

Exhibit 5-5 shows the owner's costs, TOC, and TASC; Exhibit 5-6 shows the initial and annual O&M costs.

Exhibit 5-4 Reference AUSC Rankine Case total plant cost details

Total Plant Cost Summary												
	Case:	B24F – AUSC Oxy-CFB w/ CPU					Estimate Type:			Conceptual		
	Plant Size (MW,net):	550					Cost Base ($x1,000):			Jun 2011		
Item No.	Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies		Total Plant Cost	
				Direct	Indirect			Process	Project	$/1000	$/kW
1		Coal & Sorbent Handling									
1.1	Coal Receive & Unload	$4,251	$0	$1,915	$0	$6,166	$534	$0	$1,005	$7,705	$14
1.2	Coal Stackout & Reclaim	$5,494	$0	$1,228	$0	$6,721	$569	$0	$1,094	$8,384	$15
1.3	Coal Conveyors	$5,108	$0	$1,215	$0	$6,322	$537	$0	$1,029	$7,888	$14
1.4	Other Coal Handling	$1,336	$0	$281	$0	$1,617	$137	$0	$263	$2,017	$4
1.5	Sorbent Receive & Unload	$300	$0	$89	$0	$389	$33	$0	$63	$485	$1
1.6	Sorbent Stackout & Reclaim	$4,842	$0	$875	$0	$5,717	$482	$0	$930	$7,128	$13
1.7	Sorbent Conveyors	$1,728	$375	$418	$0	$2,521	$211	$0	$410	$3,141	$6
1.8	Other Sorbent Handling	$1,043	$246	$540	$0	$1,829	$157	$0	$298	$2,283	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$5,304	$6,993	$0	$12,297	$1,153	$0	$2,017	$15,467	$28
	Subtotal	**$24,101**	**$5,924**	**$13,553**	**$0**	**$43,578**	**$3,813**	**$0**	**$7,109**	**$54,500**	**$99**
2		Coal & Sorbent Prep & Feed									
2.1	Coal Crushing & Drying	$2,441	$0	$469	$0	$2,910	$246	$0	$473	$3,629	$7
2.2	Coal Conveyor to Storage	$6,249	$0	$1,345	$0	$7,595	$643	$0	$1,236	$9,473	$17
2.5	Sorbent Prep Equipment	$8,301	$359	$1,701	$0	$10,361	$873	$0	$1,685	$12,919	$23
2.6	Sorbent Storage & Feed	$1,000	$0	$378	$0	$1,378	$119	$0	$224	$1,721	$3
2.9	Coal & Sorbent Feed Foundation	$0	$624	$547	$0	$1,171	$109	$0	$192	$1,472	$3
	Subtotal	**$17,992**	**$983**	**$4,440**	**$0**	**$23,415**	**$1,989**	**$0**	**$3,811**	**$29,215**	**$53**
3		Feedwater & Miscellaneous BOP Systems									
3.1	Feedwater System	$20,805	$0	$6,708	$0	$27,513	$2,351	$0	$4,480	$34,344	$62
3.2	Water Makeup & Pretreating	$6,793	$0	$2,149	$0	$8,942	$817	$0	$1,952	$11,710	$21
3.3	Other Feedwater Subsystems	$6,545	$0	$2,687	$0	$9,232	$793	$0	$1,504	$11,529	$21
3.4	Service Water Systems	$1,360	$0	$712	$0	$2,072	$186	$0	$452	$2,710	$5
3.5	Other Boiler Plant Systems	$8,034	$0	$7,596	$0	$15,630	$1,422	$0	$2,558	$19,610	$36
3.6	FO Supply Sys & Nat Gas	$331	$0	$387	$0	$718	$64	$0	$117	$900	$2
3.7	Waste Treatment Equipment	$1,140	$0	$660	$0	$1,801	$173	$0	$395	$2,369	$4
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,246	$0	$1,004	$0	$4,250	$404	$0	$931	$5,585	$10
	Subtotal	**$48,255**	**$0**	**$21,903**	**$0**	**$70,158**	**$6,211**	**$0**	**$12,388**	**$88,757**	**$161**
4		Boiler & Accessories									
4.1	CFB Boiler & Accessories	w/ BEC	$0	w/ BEC	$0	$442,093	$42,549	$0	$48,464	$533,106	$969
4.5	ASU/Oxidant Compression	$160,472	$0	$131,295	$0	$291,766	$28,281	$0	$32,005	$352,052	$640
4.6	Secondary Air System	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0
4.8	Major Component Rigging	$0	w/4.1	w/4.1	$0	$0	$0	$0	$0	$0	$0
4.9	Boiler Foundations	$0	w/14.1	w/14.1	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$160,472**	**$0**	**$131,295**	**$0**	**$733,860**	**$70,830**	**$0**	**$80,469**	**$885,158**	**$1,609**

Exhibit 5-4 Reference AUSC Rankine Case total plant cost details (continued)

Total Plant Cost Summary											
	Case:	B24F – AUSC Oxy-CFB w/ CPU					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550					Cost Base ($x1,000):			Jun 2011	
Item No.	Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $/1000	Total Plant Cost $/kW
5A		Gas Cleanup & Piping									
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$9,207	$0	$5,803	$0	$15,010	$1,411	$0	$1,642	$18,063	$33
5A.4	Other Particulate Removal Materials	$631	$0	$670	$0	$1,301	$123	$0	$142	$1,567	$3
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$9,838**	**$0**	**$6,474**	**$0**	**$16,312**	**$1,534**	**$0**	**$1,785**	**$19,630**	**$36**
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification Unit/System	$76,241	$0	$57,911	$0	$134,152	$12,494	$26,830	$34,695	$208,172	$379
5B.2	CO_2 Compression & Drying	w/5B.1	$0	w/5B.1	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$76,241**	**$0**	**$57,911**	**$0**	**$134,152**	**$12,494**	**$26,830**	**$34,695**	**$208,172**	**$379**
7		HRSG, Ducting, & Stack									
7.1	Flue Gas Recycle Heat Exchanger	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$10,117	$0	$6,386	$0	$16,504	$1,394	$0	$2,685	$20,582	$37
7.4	Stack	$1,988	$0	$1,155	$0	$3,143	$295	$0	$344	$3,782	$7
7.9	Duct & Stack Foundations	$0	$1,061	$1,260	$0	$2,321	$217	$0	$508	$3,046	$6
	Subtotal	**$12,105**	**$1,061**	**$8,802**	**$0**	**$21,968**	**$1,906**	**$0**	**$3,536**	**$27,411**	**$50**
8		Steam Turbine Generator									
8.1	Steam TG & Accessories	$100,483	$0	$10,439	$0	$110,923	$8,572	$0	$10,622	$130,117	$237
8.2	Turbine Plant Auxiliaries	$470	$0	$999	$0	$1,469	$140	$0	$161	$1,770	$3
8.3	Condenser & Auxiliaries	$8,020	$0	$2,936	$0	$10,956	$1,023	$0	$1,198	$13,177	$24
8.4	Steam Piping	$29,153	$0	$12,492	$0	$41,645	$3,192	$0	$6,726	$51,562	$94
8.9	TG Foundations	$0	$1,399	$2,311	$0	$3,710	$350	$0	$812	$4,871	$9
	Subtotal	**$138,126**	**$1,399**	**$29,177**	**$0**	**$168,703**	**$13,277**	**$0**	**$19,518**	**$201,497**	**$366**
9		Cooling Water System									
9.1	Cooling Towers	$12,089	$0	$3,739	$0	$15,828	$1,475	$0	$1,730	$19,033	$35
9.2	Circulating Water Pumps	$2,875	$0	$229	$0	$3,104	$265	$0	$337	$3,705	$7
9.3	Circ.Water System Auxiliaries	$780	$0	$103	$0	$883	$82	$0	$96	$1,061	$2
9.4	Circ.Water Piping	$0	$6,571	$5,950	$0	$12,521	$1,108	$0	$2,044	$15,673	$28
9.5	Make-up Water System	$659	$0	$846	$0	$1,505	$139	$0	$247	$1,891	$3
9.6	Component Cooling Water Sys	$636	$0	$488	$0	$1,124	$102	$0	$184	$1,410	$3
9.9	Circ.Water System Foundations & Structures	$0	$3,533	$5,867	$0	$9,400	$886	$0	$2,057	$12,343	$22
	Subtotal	**$17,039**	**$10,104**	**$17,223**	**$0**	**$44,365**	**$4,056**	**$0**	**$6,696**	**$55,117**	**$100**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	$1,624	$0	$4,969	$0	$6,592	$633	$0	$723	$7,948	$14
10.7	Ash Transport & Feed Equipment	$10,786	$0	$10,693	$0	$21,480	$1,979	$0	$2,346	$25,804	$47
10.9	Ash/Spent Sorbent Foundation	$0	$367	$451	$0	$818	$77	$0	$179	$1,073	$2
	Subtotal	**$12,410**	**$367**	**$16,113**	**$0**	**$28,890**	**$2,688**	**$0**	**$3,247**	**$34,825**	**$63**

Exhibit 5-4 Reference AUSC Rankine Case total plant cost details (continued)

Total Plant Cost Summary											
	Case:	B24F – AUSC Oxy-CFB w/ CPU					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550					Cost Base ($x1,000):			Jun 2011	
Item No.	Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies		Total Plant Cost	
				Direct	Indirect			Process	Project	$/1000	$/kW
11		Accessory Electric Plant									
11.1	Generator Equipment	$2,174	$0	$348	$0	$2,522	$226	$0	$206	$2,953	$5
11.2	Station Service Equipment	$6,679	$0	$2,239	$0	$8,918	$829	$0	$731	$10,478	$19
11.3	Switchgear & Motor Control	$7,666	$0	$1,332	$0	$8,997	$832	$0	$983	$10,812	$20
11.4	Conduit & Cable Tray	$0	$5,257	$16,984	$0	$22,240	$2,076	$0	$3,647	$27,964	$51
11.5	Wire & Cable	$0	$10,009	$17,892	$0	$27,901	$2,241	$0	$4,521	$34,664	$63
11.6	Protective Equipment	$352	$0	$1,221	$0	$1,573	$151	$0	$172	$1,896	$3
11.7	Standby Equipment	$1,641	$0	$38	$0	$1,680	$154	$0	$183	$2,017	$4
11.8	Main Power Transformers	$16,179	$0	$232	$0	$16,411	$1,244	$0	$1,766	$19,421	$35
11.9	Electrical Foundations	$0	$411	$1,046	$0	$1,457	$138	$0	$319	$1,914	$3
	Subtotal	**$34,691**	**$15,677**	**$41,332**	**$0**	**$91,700**	**$7,890**	**$0**	**$12,529**	**$112,119**	**$204**
12		Instrumentation & Control									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$631	$0	$386	$0	$1,017	$95	$51	$174	$1,337	$2
12.7	Distributed Control System Equipment	$6,370	$0	$1,136	$0	$7,507	$693	$375	$858	$9,433	$17
12.8	Instrument Wiring & Tubing	$3,841	$0	$6,990	$0	$10,831	$877	$542	$1,838	$14,088	$26
12.9	Other I & C Equipment	$1,800	$0	$4,168	$0	$5,968	$570	$298	$684	$7,521	$14
	Subtotal	**$12,643**	**$0**	**$12,680**	**$0**	**$25,323**	**$2,236**	**$1,266**	**$3,553**	**$32,378**	**$59**
13		Improvements to Site									
13.1	Site Preparation	$0	$63	$1,328	$0	$1,390	$136	$0	$305	$1,831	$3
13.2	Site Improvements	$0	$2,072	$2,737	$0	$4,809	$477	$0	$1,057	$6,344	$12
13.3	Site Facilities	$3,713	$0	$3,895	$0	$7,608	$757	$0	$1,673	$10,038	$18
	Subtotal	**$3,713**	**$2,134**	**$7,960**	**$0**	**$13,808**	**$1,370**	**$0**	**$3,036**	**$18,213**	**$33**
14		Buildings & Structures									
14.1	Boiler Building	$0	$10,587	$9,304	$0	$19,891	$1,750	$0	$3,246	$24,887	$45
14.2	Turbine Building	$0	$15,306	$14,255	$0	$29,561	$2,608	$0	$4,825	$36,995	$67
14.3	Administration Building	$0	$768	$812	$0	$1,580	$140	$0	$258	$1,978	$4
14.4	Circulation Water Pumphouse	$0	$175	$139	$0	$315	$28	$0	$51	$394	$1
14.5	Water Treatment Buildings	$0	$861	$784	$0	$1,645	$145	$0	$269	$2,059	$4
14.6	Machine Shop	$0	$514	$345	$0	$859	$75	$0	$140	$1,073	$2
14.7	Warehouse	$0	$348	$349	$0	$697	$62	$0	$114	$873	$2
14.8	Other Buildings & Structures	$0	$284	$242	$0	$527	$46	$0	$86	$659	$1
14.9	Waste Treating Building & Str.	$0	$534	$1,621	$0	$2,155	$200	$0	$353	$2,709	$5
	Subtotal	**$0**	**$29,378**	**$27,851**	**$0**	**$57,230**	**$5,054**	**$0**	**$9,343**	**$71,626**	**$130**
	Total	**$567,625**	**$67,029**	**$396,714**	**$0**	**$1,473,460**	**$135,348**	**$28,097**	**$201,713**	**$1,838,618**	**$3,343**

Exhibit 5-5 Reference AUSC Rankine Case owner's costs

Owner's Costs		
Description	**$1,000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$12,047	$22
1-Month Maintenance Materials	$1,743	$3
1-Month Non-fuel Consumables	$1,824	$3
1-Month Waste Disposal	$1,594	$3
25% of 1-Month Fuel Cost at 100% CF	$2,730	$5
2% of TPC	$36,772	$67
Total	**$56,710**	**$103**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$24,953	$45
0.5% of TPC (spare parts)	$9,193	$17
Total	**$34,146**	**$62**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$275,793	$501
Financing Costs	$49,643	$90
Total Overnight Costs (TOC)	**$2,255,810**	**$4,102**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,571,623**	**$4,676**

Exhibit 5-6 Reference AUSC Rankine Case initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	B24F – AUSC Oxy-CFB w/ CPU				**Cost Base:**	Jun 2011
Plant Size (MW,net):	550		**Heat Rate-net (Btu/kWh):**	9,252	**Capacity Factor (%):**	85
Operating & Maintenance Labor						
Operating Labor				**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		39.70	**$/hour**		**1 unit/mod.**	**Total Plant**
Operating Labor Burden:		30.00	**% of base**	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	**% of labor**	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**($/kW-net)**
Annual Operating Labor:					$7,384,208	$13.426
Maintenance Labor:					$11,890,804	$21.620
Administrative & Support Labor:					$4,818,753.04	$8.762
Property Taxes and Insurance:					$36,772,358	$66.861
Total:					**$60,866,123**	**$110.670**
Variable Operating Costs						
					($)	**($/kWh-net)**
Maintenance Material:					$17,782,439	$0.00434
Consumables						
	Consumption		**Cost ($)**			
	Initial Fill	**Per Day**	**Per Unit**	**Initial Fill**		
Water (/1000 gallons):	0	5,266	$1.67	$0	$2,734,866	$0.00067
Makeup and Waste Water Treatment Chemicals (lbs):	0	25,490	$0.27	$0	$2,118,160	$0.00052
Limestone (ton)	0	1,257	$33.48	$0	$13,059,755	$0.00319
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,366	$1.63	$0	$688,652	$0.00017
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$18,601,433**	**$0.00454**
Waste Disposal						
Fly Ash (ton)	0	48	$25.11	$0	$376,504	$0.00009
Bottom Ash (ton)	0	2,039	$25.11	$0	$15,882,383	$0.00388
Subtotal:				**$0**	**$16,258,887**	**$0.00397**
By-Products						
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$52,642,760**	**$0.01285**
Fuel Cost						
Illinois Number 6 (ton):	0	5,234	$68.60	$0	$111,392,153	$0.02720
Total:				**$0**	**$111,392,153**	**$0.02720**

Exhibit 5-7 shows the COE results for the Reference SC and AUSC Rankine Cases using high-risk financing.

Exhibit 5-7 Reference SC and AUSC Rankine Case COE breakdown

Case	Reference SC Rankine	Reference AUSC Rankine
Cost		
TPC (2011$/kW)	3,300	3,343
TOC (2011$/kW)	4,055	4,102
COE (2011$/MWh) (excluding T&S)	125.72	123.22
Capital	67.53	68.31
Fixed O&M	14.69	14.86
Variable O&M	13.68	12.85
Fuel	29.82	27.20
T&S	8.58	7.82
COE (2011$/MWh) (including T&S)	134.30	131.05

5.3 Baseline sCO_2

5.3.1 Case Baseline620 Cost Estimate Results

Exhibit 5-8 shows a detailed breakdown of the capital costs; Exhibit 5-9 shows the owner's costs, TOC, and TASC; Exhibit 5-10 shows the initial and annual O&M costs. Exhibit 5-11 shows the COE results for Case Baseline620 using high-risk financing.

Exhibit 5-8 Case Baseline620 total plant cost details

Total Plant Cost Summary											
	Case:	sCO2 – Case Baseline620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
	1	Coal & Sorbent Handling									
1.1	Coal Receive & Unload	$4,417	$0	$1,990	$0	$6,407	$555	$0	$1,044	$8,007	$15
1.2	Coal Stackout & Reclaim	$5,709	$0	$1,276	$0	$6,984	$592	$0	$1,136	$8,712	$16
1.3	Coal Conveyors	$5,307	$0	$1,262	$0	$6,570	$558	$0	$1,069	$8,196	$15
1.4	Other Coal Handling	$1,389	$0	$292	$0	$1,681	$142	$0	$273	$2,096	$4
1.5	Sorbent Receive & Unload	$312	$0	$93	$0	$405	$35	$0	$66	$506	$1
1.6	Sorbent Stackout & Reclaim	$5,042	$0	$911	$0	$5,953	$502	$0	$968	$7,423	$13
1.7	Sorbent Conveyors	$1,799	$391	$435	$0	$2,625	$220	$0	$427	$3,271	$6
1.8	Other Sorbent Handling	$1,087	$256	$562	$0	$1,904	$163	$0	$310	$2,378	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$5,512	$7,268	$0	$12,780	$1,198	$0	$2,097	$16,075	$29
	Subtotal	**$25,062**	**$6,158**	**$14,089**	**$0**	**$45,309**	**$3,964**	**$0**	**$7,391**	**$56,664**	**$103**
	2	Coal & Sorbent Prep & Feed									
2.1	Coal Crushing & Drying	$2,543	$0	$489	$0	$3,031	$256	$0	$493	$3,780	$7
2.2	Coal Conveyor to Storage	$6,510	$0	$1,402	$0	$7,912	$670	$0	$1,287	$9,868	$18
2.5	Sorbent Prep Equipment	$8,650	$374	$1,772	$0	$10,797	$910	$0	$1,756	$13,462	$24
2.6	Sorbent Storage & Feed	$1,042	$0	$394	$0	$1,436	$124	$0	$234	$1,794	$3
2.9	Coal & Sorbent Feed Foundation	$0	$650	$570	$0	$1,220	$113	$0	$200	$1,533	$3
	Subtotal	**$18,745**	**$1,024**	**$4,626**	**$0**	**$24,395**	**$2,072**	**$0**	**$3,970**	**$30,437**	**$55**
	3	Feedwater & Miscellaneous BOP Systems									
3.1	Feedwater System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.2	Water Makeup & Pretreating	$7,898	$0	$2,498	$0	$10,396	$950	$0	$2,269	$13,615	$25
3.3	Other Feedwater Subsystems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.4	Service Water Systems	$1,582	$0	$828	$0	$2,409	$216	$0	$525	$3,151	$6
3.5	Other Boiler Plant Systems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.6	FO Supply Sys & Nat Gas	$336	$0	$393	$0	$729	$65	$0	$119	$914	$2
3.7	Waste Treatment Equipment	$3,531	$0	$2,044	$0	$5,575	$537	$0	$1,222	$7,334	$13
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,296	$0	$1,020	$0	$4,316	$410	$0	$945	$5,672	$10
	Subtotal	**$16,643**	**$0**	**$6,782**	**$0**	**$23,425**	**$2,179**	**$0**	**$5,081**	**$30,685**	**$56**
	4	Boiler & Accessories									
4.1	CFB & Accessories	w/ BEC	$0	w/ BEC	$0	$292,561	$28,157	$0	$32,072	$352,790	$642
4.5	ASU/Oxidant Compression	$174,552	$0	$142,815	$0	$317,368	$30,762	$0	$34,813	$382,943	$696
	Flue Gas Cooler	$12,492	$0	$0	$0	$12,492	$1,162	$0	$1,999	$15,653	$28
	Flue Gas N2 Heater	$1,831	$0	$0	$0	$1,831	$170	$0	$293	$2,295	$4
	Subtotal	**$188,876**	**$0**	**$142,815**	**$0**	**$624,252**	**$60,252**	**$0**	**$69,177**	**$753,680**	**$1,370**
	5A	Gas Cleanup & Piping									
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$11,395	$0	$7,182	$0	$18,577	$1,746	$0	$2,032	$22,354	$41
5A.4	Other Particulate Removal Materials	$779	$0	$828	$0	$1,606	$152	$0	$176	$1,934	$4
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$12,173**	**$0**	**$8,009**	**$0**	**$20,183**	**$1,898**	**$0**	**$2,208**	**$24,288**	**$44**

Exhibit 5-8 Case Baseline620 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case Baseline620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification & Compression Unit/System	$80,108	$0	$60,848	$0	$140,956	$13,128	$28,191	$36,455	$218,730	$398
	Subtotal	**$80,108**	**$0**	**$60,848**	**$0**	**$140,956**	**$13,128**	**$28,191**	**$36,455**	**$218,730**	**$398**
7		HRSG, Ducting, & Stack									
7.3	Ductwork	$10,358	$0	$6,538	$0	$16,896	$1,427	$0	$2,749	$21,072	$38
7.4	Stack	$3,652	$0	$2,123	$0	$5,775	$542	$0	$632	$6,949	$13
7.9	Duct & Stack Foundations	$0	$1,070	$1,271	$0	$2,342	$219	$0	$512	$3,073	$6
	Subtotal	**$14,010**	**$1,070**	**$9,932**	**$0**	**$25,013**	**$2,188**	**$0**	**$3,892**	**$31,094**	**$57**
8B		sCO_2 Power Cycle									
	Main CO_2 Compressor	$43,515	$0	$26,109	$0	$69,623	$6,475	$0	$11,140	$87,238	$159
	Bypass CO_2 Compressor	$41,704	$0	$25,023	$0	$66,727	$6,206	$0	$10,676	$83,609	$152
	High Temperature CO_2 Recuperator	$20,065	$0	$0	$0	$20,065	$1,866	$0	$3,210	$25,142	$46
	Low Temperature CO_2 Recuperator	$46,194	$0	$0	$0	$46,194	$4,296	$0	$7,391	$57,881	$105
	CO_2 Cooler	$4,668	$0	$1,432	$0	$6,100	$567	$0	$976	$7,643	$14
	CO_2 Turbine Section	$100,863	$0	$0	$0	$100,863	$9,380	$0	$16,138	$126,381	$230
	CO_2 System Piping	$11,288	$0	$3,386	$0	$14,674	$1,365	$0	$2,348	$18,387	$33
	CO_2 System Foundations	$0	$2,192	$3,619	$0	$5,810	$540	$0	$930	$7,280	$13
	Subtotal	**$268,297**	**$2,192**	**$59,568**	**$0**	**$330,057**	**$30,695**	**$0**	**$52,809**	**$413,561**	**$752**
9		Cooling Water System									
9.1	Cooling Towers	$13,636	$0	$4,217	$0	$17,853	$1,663	$0	$1,952	$21,468	$39
9.2	Circulating Water Pumps	$3,519	$0	$280	$0	$3,799	$324	$0	$412	$4,536	$8
9.3	Circ.Water System Auxiliaries	$909	$0	$120	$0	$1,029	$95	$0	$112	$1,236	$2
9.4	Circ.Water Piping	$0	$7,655	$6,933	$0	$14,588	$1,291	$0	$2,382	$18,261	$33
9.5	Make-up Water System	$748	$0	$961	$0	$1,710	$158	$0	$280	$2,148	$4
9.6	Component Cooling Water Sys	$741	$0	$569	$0	$1,310	$119	$0	$214	$1,643	$3
9.9	Circ.Water System Foundations & Structures	$0	$4,069	$6,756	$0	$10,825	$1,020	$0	$2,369	$14,213	$26
	Subtotal	**$19,553**	**$11,724**	**$19,836**	**$0**	**$51,113**	**$4,671**	**$0**	**$7,722**	**$63,506**	**$115**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	$1,680	$0	$5,141	$0	$6,821	$655	$0	$748	$8,223	$15
10.7	Ash Transport & Feed Equipment	$11,161	$0	$11,064	$0	$22,225	$2,047	$0	$2,427	$26,700	$49
10.9	Ash/Spent Sorbent Foundation	$0	$379	$467	$0	$846	$79	$0	$185	$1,111	$2
	Subtotal	**$12,841**	**$379**	**$16,673**	**$0**	**$29,893**	**$2,781**	**$0**	**$3,360**	**$36,034**	**$66**

Exhibit 5-8 Case Baseline620 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case Baseline620					**Estimate Type:**			Conceptual	
	Plant Size (MW,net):	550 MWe					**Cost Base:**			Jun 2011	
Item No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor**		**Bare Erected Cost**	**Eng'g CM H.O.& Fee**	**Contingencies**		**Total Plant Cost**	
				Direct	**Indirect**			**Process**	**Project**	**$1,000**	**$/kW**
		$1,000									
11		**Accessory Electric Plant**									
11.1	Generator Equipment	$2,184	$0	$349	$0	$2,533	$227	$0	$207	$2,967	$5
11.2	Station Service Equipment	$6,785	$0	$2,275	$0	$9,060	$842	$0	$743	$10,645	$19
11.3	Switchgear & Motor Control	$7,788	$0	$1,353	$0	$9,141	$845	$0	$999	$10,985	$20
11.4	Conduit & Cable Tray	$0	$5,341	$17,255	$0	$22,595	$2,109	$0	$3,706	$28,410	$52
11.5	Wire & Cable	$0	$10,169	$18,178	$0	$28,347	$2,277	$0	$4,593	$35,217	$64
11.6	Protective Equipment	$358	$0	$1,241	$0	$1,598	$153	$0	$175	$1,927	$4
11.7	Standby Equipment	$1,647	$0	$38	$0	$1,686	$154	$0	$184	$2,024	$4
11.8	Main Power Transformers	$16,089	$0	$231	$0	$16,320	$1,237	$0	$1,756	$19,313	$35
11.9	Electrical Foundations	$0	$413	$1,052	$0	$1,465	$139	$0	$321	$1,924	$3
	Subtotal	**$34,851**	**$15,923**	**$41,971**	**$0**	**$92,745**	**$7,983**	**$0**	**$12,683**	**$113,411**	**$206**
12		**Instrumentation & Control**									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$634	$0	$388	$0	$1,022	$96	$51	$175	$1,344	$2
12.7	Distributed Control System Equipment	$6,401	$0	$1,141	$0	$7,543	$697	$377	$862	$9,478	$17
12.8	Instrument Wiring & Tubing	$3,860	$0	$7,023	$0	$10,883	$882	$544	$1,846	$14,155	$26
12.9	Other I & C Equipment	$1,809	$0	$4,188	$0	$5,997	$573	$300	$687	$7,557	$14
	Subtotal	**$12,704**	**$0**	**$12,741**	**$0**	**$25,444**	**$2,247**	**$1,272**	**$3,570**	**$32,534**	**$59**
13		**Improvements to Site**									
13.1	Site Preparation	$0	$60	$1,265	$0	$1,325	$129	$0	$291	$1,745	$3
13.2	Site Improvements	$0	$1,975	$2,609	$0	$4,584	$455	$0	$1,008	$6,046	$11
13.3	Site Facilities	$3,539	$0	$3,712	$0	$7,251	$722	$0	$1,595	$9,567	$17
	Subtotal	**$3,539**	**$2,034**	**$7,587**	**$0**	**$13,159**	**$1,306**	**$0**	**$2,893**	**$17,358**	**$32**
14		**Buildings & Structures**									
14.1	Boiler Building	$0	$10,461	$9,193	$0	$19,653	$1,729	$0	$3,207	$24,590	$45
14.2	Turbine Building	$0	$15,014	$13,984	$0	$28,998	$2,559	$0	$4,733	$36,290	$66
14.3	Administration Building	$0	$750	$792	$0	$1,542	$137	$0	$252	$1,931	$4
14.4	Circulation Water Pumphouse	$0	$230	$183	$0	$413	$36	$0	$67	$516	$1
14.5	Water Treatment Buildings	$0	$990	$902	$0	$1,893	$167	$0	$309	$2,368	$4
14.6	Machine Shop	$0	$502	$337	$0	$838	$73	$0	$137	$1,048	$2
14.7	Warehouse	$0	$340	$341	$0	$681	$60	$0	$111	$852	$2
14.8	Other Buildings & Structures	$0	$278	$236	$0	$514	$45	$0	$84	$643	$1
14.9	Waste Treating Building & Str.	$0	$542	$1,645	$0	$2,187	$203	$0	$359	$2,749	$5
	Subtotal	**$0**	**$29,107**	**$27,613**	**$0**	**$56,720**	**$5,009**	**$0**	**$9,259**	**$70,988**	**$129**
	Total	**$707,401**	**$69,612**	**$433,090**	**$0**	**$1,502,664**	**$140,372**	**$29,463**	**$220,470**	**$1,892,970**	**$3,442**

Exhibit 5-9 Case Baseline620 owner's costs

Owner's Costs		
Description	**$1,000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$11,929	$22
1-Month Maintenance Materials	$1,721	$3
1-Month Non-fuel Consumables	$2,027	$4
1-Month Waste Disposal	$1,746	$3
25% of 1-Month Fuel Cost at 100% CF	$2,994	$5
2% of TPC	$37,859	$69
Total	**$58,276**	**$106**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$27,388	$50
0.5% of TPC (spare parts)	$9,465	$17
Total	**$36,853**	**$67**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$283,945	$516
Financing Costs	$51,110	$93
Total Overnight Costs (TOC)	**$2,324,054**	**$4,226**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,649,422**	**$4,818**

Exhibit 5-10 Case Baseline620 initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	sCO2 – Case Baseline620				**Cost Base:**	Jun 2011
Plant Size (MW,net):	**550**		**Heat Rate-net (Btu/kWh):**	9,848	**Capacity Factor (%):**	85
Operating & Maintenance Labor						
Operating Labor				**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		39.70	**$/hour**		**1 unit/mod.**	**Total Plant**
Operating Labor Burden:		30.00	**% of base**	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	**% of labor**	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**($/kW-net)**
Annual Operating Labor:					$7,384,208	$13.427
Maintenance Labor:					$12,126,476	$22.050
Administrative & Support Labor:					$4,877,671	$8.869
Property Taxes and Insurance:					$37,859,400	$68.842
Total:					**$62,247,755**	**$113.189**
Variable Operating Costs						
					($)	**($/kWh-net)**
Maintenance Material:					$18,308,113	$0.00447
Consumables						
	Consumption		**Cost ($)**			
	Initial Fill	**Per Day**	**Per Unit**	**Initial Fill**		
Water (/1000 gallons):	0	6,511	$1.67	$0	$3,381,454	$0.00083
Makeup and Waste Water Treatment Chemicals (lbs):	0	31,517	$0.27	$0	$2,618,944	$0.00064
Limestone (ton)	0	1,339	$33.48	$0	$13,904,635	$0.00340
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,453	$1.63	$0	$732,630	$0.00018
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$20,637,664**	**$0.00504**
Waste Disposal						
Fly Ash (ton)	0	51	$25.11	$0	$400,085	$0.00010
Bottom Ash (ton)	0	2,167	$25.11	$0	$16,881,026	$0.00412
Subtotal:				**$0**	**$17,281,110**	**$0.00422**
By-Products						
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$56,226,888**	**$0.01373**
Fuel Cost						
Illinois Number 6 (ton):	0	5,568	$68.60	$0	$118,504,579	$0.02894
Total:				**$0**	**$118,504,579**	**$0.02894**

Exhibit 5-11 Case Baseline620 COE breakdown

Case	Baseline620
Cost	
TPC (2011$/kW)	3,442
TOC (2011$/kW)	4,226
COE (2011$/MWh) (excluding T&S)	128.25
Capital	70.38
Fixed O&M	15.20
Variable O&M	13.73
Fuel	28.94
T&S	8.32
COE (2011$/MWh) (including T&S)	136.57

5.3.2 Case Baseline760 Cost Estimate Results

Exhibit 5-12 shows a detailed breakdown of the capital costs; Exhibit 5-13 shows the owner's costs, TOC, and TASC; Exhibit 5-14 shows the initial and annual O&M costs.

Exhibit 5-12 Case Baseline760 total plant cost details

Total Plant Cost Summary											
	Case:	sCO2 – Case Baseline760					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
1		Coal & Sorbent Handling									
1.1	Coal Receive & Unload	$4,074	$0	$1,835	$0	$5,909	$512	$0	$963	$7,384	$13
1.2	Coal Stackout & Reclaim	$5,265	$0	$1,176	$0	$6,441	$546	$0	$1,048	$8,035	$15
1.3	Coal Conveyors	$4,895	$0	$1,164	$0	$6,059	$514	$0	$986	$7,559	$14
1.4	Other Coal Handling	$1,281	$0	$269	$0	$1,550	$131	$0	$252	$1,933	$4
1.5	Sorbent Receive & Unload	$287	$0	$85	$0	$373	$32	$0	$61	$465	$1
1.6	Sorbent Stackout & Reclaim	$4,638	$0	$838	$0	$5,476	$461	$0	$891	$6,828	$12
1.7	Sorbent Conveyors	$1,655	$359	$400	$0	$2,414	$202	$0	$392	$3,009	$5
1.8	Other Sorbent Handling	$1,000	$235	$517	$0	$1,752	$150	$0	$285	$2,187	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$5,083	$6,703	$0	$11,786	$1,105	$0	$1,934	$14,825	$27
	Subtotal	**$23,093**	**$5,678**	**$12,988**	**$0**	**$41,759**	**$3,654**	**$0**	**$6,812**	**$52,225**	**$95**
2		Coal & Sorbent Prep & Feed									
2.1	Coal Crushing & Drying	$2,333	$0	$448	$0	$2,781	$235	$0	$452	$3,468	$6
2.2	Coal Conveyor to Storage	$5,973	$0	$1,286	$0	$7,258	$614	$0	$1,181	$9,053	$16
2.5	Sorbent Prep Equipment	$7,946	$344	$1,628	$0	$9,918	$835	$0	$1,613	$12,367	$22
2.6	Sorbent Storage & Feed	$957	$0	$362	$0	$1,319	$114	$0	$215	$1,648	$3
2.9	Coal & Sorbent Feed Foundation	$0	$597	$524	$0	$1,120	$104	$0	$184	$1,408	$3
	Subtotal	**$17,209**	**$941**	**$4,247**	**$0**	**$22,397**	**$1,902**	**$0**	**$3,645**	**$27,944**	**$51**
3		Feedwater & Miscellaneous BOP Systems									
3.1	Feedwater System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.2	Water Makeup & Pretreating	$6,800	$0	$2,151	$0	$8,950	$818	$0	$1,954	$11,722	$21
3.3	Other Feedwater Subsystems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.4	Service Water Systems	$1,362	$0	$713	$0	$2,074	$186	$0	$452	$2,713	$5
3.5	Other Boiler Plant Systems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.6	FO Supply Sys & Nat Gas	$326	$0	$380	$0	$706	$63	$0	$115	$885	$2
3.7	Waste Treatment Equipment	$3,040	$0	$1,760	$0	$4,800	$462	$0	$1,052	$6,314	$11
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,191	$0	$987	$0	$4,177	$397	$0	$915	$5,489	$10
	Subtotal	**$14,717**	**$0**	**$5,990**	**$0**	**$20,708**	**$1,926**	**$0**	**$4,488**	**$27,123**	**$49**
4		Boiler & Accessories									
4.1	CFB & Accessories	w/ BEC	$0	w/ BEC	$0	$321,944	$30,985	$0	$35,293	$388,223	$706
4.5	ASU/Oxidant Compression	$159,305	$0	$130,340	$0	$289,645	$28,075	$0	$31,772	$349,492	$636
	Flue Gas Cooler	$11,401	$0	$0	$0	$11,401	$1,060	$0	$1,824	$14,286	$26
	Flue Gas N2 Heater	$1,607	$0	$0	$0	$1,607	$149	$0	$257	$2,014	$4
	Subtotal	**$172,313**	**$0**	**$130,340**	**$0**	**$624,597**	**$60,270**	**$0**	**$69,146**	**$754,014**	**$1,371**
5A		Gas Cleanup & Piping									
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$10,291	$0	$6,486	$0	$16,778	$1,577	$0	$1,835	$20,190	$37
5A.4	Other Particulate Removal Materials	$704	$0	$748	$0	$1,453	$138	$0	$159	$1,749	$3
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$10,995**	**$0**	**$7,235**	**$0**	**$18,230**	**$1,714**	**$0**	**$1,994**	**$21,939**	**$40**

Exhibit 5-12 Case Baseline760 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case Baseline760					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification & Compression Unit/System	$72,162	$0	$54,813	$0	$126,975	$11,826	$25,395	$32,839	$197,035	$358
	Subtotal	**$72,162**	**$0**	**$54,813**	**$0**	**$126,975**	**$11,826**	**$25,395**	**$32,839**	**$197,035**	**$358**
7		HRSG, Ducting, & Stack									
7.3	Ductwork	$9,857	$0	$6,222	$0	$16,078	$1,358	$0	$2,615	$20,052	$36
7.4	Stack	$3,430	$0	$1,994	$0	$5,424	$509	$0	$593	$6,526	$12
7.9	Duct & Stack Foundations	$0	$1,051	$1,248	$0	$2,299	$215	$0	$503	$3,017	$5
	Subtotal	**$13,287**	**$1,051**	**$9,464**	**$0**	**$23,802**	**$2,082**	**$0**	**$3,712**	**$29,596**	**$54**
8B		sCO_2 Power Cycle									
	Main CO_2 Compressor	$34,331	$0	$20,599	$0	$54,930	$5,109	$0	$8,789	$68,828	$125
	Bypass CO_2 Compressor	$31,765	$0	$19,059	$0	$50,824	$4,727	$0	$8,132	$63,682	$116
	High Temperature CO_2 Recuperator	$21,537	$0	$0	$0	$21,537	$2,003	$0	$3,446	$26,985	$49
	Low Temperature CO_2 Recuperator	$36,074	$0	$0	$0	$36,074	$3,355	$0	$5,772	$45,201	$82
	CO_2 Cooler	$3,667	$0	$1,125	$0	$4,791	$446	$0	$767	$6,004	$11
	CO_2 Turbine Section	$101,432	$0	$0	$0	$101,432	$9,433	$0	$16,229	$127,094	$231
	CO_2 System Piping	$27,483	$0	$8,245	$0	$35,728	$3,323	$0	$5,717	$44,767	$81
	CO_2 System Foundations	$0	$2,014	$3,325	$0	$5,340	$497	$0	$854	$6,690	$12
	Subtotal	**$256,289**	**$2,014**	**$52,353**	**$0**	**$310,656**	**$28,891**	**$0**	**$49,705**	**$389,252**	**$708**
9		Cooling Water System									
9.1	Cooling Towers	$11,765	$0	$3,639	$0	$15,403	$1,435	$0	$1,684	$18,522	$34
9.2	Circulating Water Pumps	$2,936	$0	$233	$0	$3,169	$270	$0	$344	$3,784	$7
9.3	Circ.Water System Auxiliaries	$792	$0	$105	$0	$897	$83	$0	$98	$1,078	$2
9.4	Circ.Water Piping	$0	$6,675	$6,045	$0	$12,720	$1,126	$0	$2,077	$15,923	$29
9.5	Make-up Water System	$659	$0	$847	$0	$1,506	$139	$0	$247	$1,892	$3
9.6	Component Cooling Water Sys	$646	$0	$496	$0	$1,142	$104	$0	$187	$1,433	$3
9.9	Circ.Water System Foundations & Structures	$0	$3,585	$5,953	$0	$9,538	$899	$0	$2,087	$12,524	$23
	Subtotal	**$16,798**	**$10,260**	**$17,318**	**$0**	**$44,376**	**$4,056**	**$0**	**$6,724**	**$55,156**	**$100**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	$1,563	$0	$4,781	$0	$6,344	$609	$0	$695	$7,648	$14
10.7	Ash Transport & Feed Equipment	$10,380	$0	$10,290	$0	$20,670	$1,904	$0	$2,257	$24,831	$45
10.9	Ash/Spent Sorbent Foundation	$0	$353	$434	$0	$787	$74	$0	$172	$1,033	$2
	Subtotal	**$11,942**	**$353**	**$15,506**	**$0**	**$27,801**	**$2,587**	**$0**	**$3,125**	**$33,512**	**$61**

Exhibit 5-12 Case Baseline760 total plant cost details (continued)

Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
Total Plant Cost Summary											
	Case:	sCO2 – Case Baseline760					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
		$1,000									
11		Accessory Electric Plant									
11.1	Generator Equipment	$2,150	$0	$344	$0	$2,493	$223	$0	$204	$2,920	$5
11.2	Station Service Equipment	$6,411	$0	$2,149	$0	$8,560	$795	$0	$702	$10,057	$18
11.3	Switchgear & Motor Control	$7,358	$0	$1,278	$0	$8,636	$799	$0	$943	$10,378	$19
11.4	Conduit & Cable Tray	$0	$5,046	$16,302	$0	$21,347	$1,993	$0	$3,501	$26,841	$49
11.5	Wire & Cable	$0	$9,607	$17,174	$0	$26,781	$2,151	$0	$4,340	$33,272	$61
11.6	Protective Equipment	$338	$0	$1,172	$0	$1,510	$145	$0	$165	$1,820	$3
11.7	Standby Equipment	$1,626	$0	$38	$0	$1,664	$152	$0	$182	$1,998	$4
11.8	Main Power Transformers	$16,089	$0	$231	$0	$16,320	$1,237	$0	$1,756	$19,313	$35
11.9	Electrical Foundations	$0	$405	$1,032	$0	$1,437	$136	$0	$315	$1,887	$3
	Subtotal	**$33,971**	**$15,058**	**$39,719**	**$0**	**$88,749**	**$7,631**	**$0**	**$12,107**	**$108,487**	**$197**
12		Instrumentation & Control									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$623	$0	$381	$0	$1,004	$94	$50	$172	$1,321	$2
12.7	Distributed Control System Equipment	$6,292	$0	$1,122	$0	$7,414	$685	$371	$847	$9,316	$17
12.8	Instrument Wiring & Tubing	$3,794	$0	$6,904	$0	$10,698	$867	$535	$1,815	$13,914	$25
12.9	Other I & C Equipment	$1,778	$0	$4,117	$0	$5,895	$563	$295	$675	$7,428	$14
	Subtotal	**$12,487**	**$0**	**$12,524**	**$0**	**$25,011**	**$2,209**	**$1,251**	**$3,509**	**$31,979**	**$58**
13		Improvements to Site									
13.1	Site Preparation	$0	$59	$1,256	$0	$1,316	$128	$0	$289	$1,733	$3
13.2	Site Improvements	$0	$1,961	$2,591	$0	$4,551	$452	$0	$1,001	$6,004	$11
13.3	Site Facilities	$3,514	$0	$3,686	$0	$7,200	$717	$0	$1,583	$9,500	$17
	Subtotal	**$3,514**	**$2,020**	**$7,533**	**$0**	**$13,067**	**$1,297**	**$0**	**$2,873**	**$17,236**	**$31**
14		Buildings & Structures									
14.1	Boiler Building	$0	$10,442	$9,177	$0	$19,619	$1,726	$0	$3,202	$24,546	$45
14.2	Turbine Building	$0	$14,972	$13,944	$0	$28,916	$2,551	$0	$4,720	$36,188	$66
14.3	Administration Building	$0	$747	$790	$0	$1,537	$136	$0	$251	$1,924	$4
14.4	Circulation Water Pumphouse	$0	$203	$161	$0	$364	$32	$0	$59	$455	$1
14.5	Water Treatment Buildings	$0	$862	$785	$0	$1,647	$145	$0	$269	$2,061	$4
14.6	Machine Shop	$0	$500	$336	$0	$835	$73	$0	$136	$1,044	$2
14.7	Warehouse	$0	$339	$340	$0	$678	$60	$0	$111	$849	$2
14.8	Other Buildings & Structures	$0	$277	$235	$0	$512	$45	$0	$84	$641	$1
14.9	Waste Treating Building & Str.	$0	$535	$1,621	$0	$2,155	$200	$0	$353	$2,709	$5
	Subtotal	**$0**	**$28,875**	**$27,388**	**$0**	**$56,263**	**$4,969**	**$0**	**$9,185**	**$70,417**	**$128**
	Total	**$658,778**	**$66,251**	**$397,417**	**$0**	**$1,444,391**	**$135,013**	**$26,646**	**$209,864**	**$1,815,914**	**$3,303**

Exhibit 5-13 Case Baseline760 owner's costs

Owner's Costs		
Description	**$1,000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$11,929	$22
1-Month Maintenance Materials	$1,721	$3
1-Month Non-fuel Consumables	$2,027	$4
1-Month Waste Disposal	$1,746	$3
25% of 1-Month Fuel Cost at 100% CF	$2,994	$5
2% of TPC	$36,318	$66
Total	**$56,735**	**$103**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$27,388	$50
0.5% of TPC (spare parts)	$9,080	$17
Total	**$36,467**	**$66**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$272,387	$495
Financing Costs	$49,030	$89
Total Overnight Costs (TOC)	**$2,231,433**	**$4,058**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,543,833**	**$4,627**

Exhibit 5-14 Case Baseline760 initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	sCO2 – Case Baseline760				**Cost Base:**	Jun 2011
Plant Size (MW,net):	**550**		**Heat Rate-net (Btu/kWh):**	8,645	**Capacity Factor (%):**	85
Operating & Maintenance Labor						
Operating Labor				**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		39.70	**$/hour**		**1 unit/mod.**	**Total Plant**
Operating Labor Burden:		30.00	**% of base**	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	**% of labor**	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**($/kW-net)**
Annual Operating Labor:					$7,384,208	$13.430
Maintenance Labor:					$11,656,212	$21.200
Administrative & Support Labor:					$4,760,105	$8.657
Property Taxes and Insurance:					$36,318,276	$66.054
Total:					**$60,118,801**	**$109.341**
Variable Operating Costs						
					($)	**($/kWh-net)**
Maintenance Material:					$17,562,854	$0.00429
Consumables						
	Consumption		**Cost ($)**			
	Initial Fill	**Per Day**	**Per Unit**	**Initial Fill**		
Water (/1000 gallons):	0	5,273	$1.67	$0	$2,738,647	$0.00067
Makeup and Waste Water Treatment Chemicals (lbs):	0	25,525	$0.27	$0	$2,121,088	$0.00052
Limestone (ton)	0	1,175	$33.48	$0	$12,202,516	$0.00298
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,275	$1.63	$0	$642,946	$0.00016
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$17,705,197**	**$0.00432**
Waste Disposal						
Fly Ash (ton)	0	45	$25.11	$0	$351,109	$0.00009
Bottom Ash (ton)	0	1,902	$25.11	$0	$14,814,555	$0.00362
Subtotal:				**$0**	**$15,165,664**	**$0.00370**
By-Products						
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$50,433,715**	**$0.01232**
Fuel Cost						
Illinois Number 6 (ton):	0	4,886	$68.60	$0	$103,997,984	$0.02540
Total:				**$0**	**$103,997,984**	**$0.02540**

Exhibit 5-15 shows the COE results for Case Baseline760 using high-risk financing. The COE result for Case Baseline620 is shown for comparison purposes, and uses high-risk financing assumptions.

Exhibit 5-15 Case Baseline760 COE breakdown

Case	Baseline620	Baseline760
Cost		
TPC (2011$/kW)	3,442	3,303
TOC (2011$/kW)	4,226	4,058
COE (2011$/MWh) (excluding T&S)	128.25	119.99
Capital	70.38	67.59
Fixed O&M	15.20	14.68
Variable O&M	13.73	12.32
Fuel	28.94	25.40
T&S	8.32	7.31
COE (2011$/MWh) (including T&S)	136.57	127.30

5.3.3 Comparison of Cost Estimate Results Between Reference Rankine Cases and Baseline sCO_2 Cases

Exhibit 5-16 shows the TPC (1,000 2011$) for the reference Rankine cases and the Baseline cases at two different TITs. The TPC for Case Baseline620 is 4 percent greater than the reference SC Rankine plant and Case Baseline760 is 1 percent lower than the reference AUSC Rankine plant. For most of the cost accounts, the ratios of the TPCs at the account level among the four cases are inversely proportional to the ratio of their efficiencies. The accounts that have the most impact on the differences in TPC are the Feedwater & Misc. BOP Systems account, the CFB account, and the respective Power Island account. At equivalent TIT, the sCO_2 TPC is significantly higher than the reference Rankine TPC but at the higher TIT, the reduction in TPC due to higher plant efficiency reduces the relative difference in TPC by half. While increasing process efficiency tends to proportionally reduce TPC, with a high TIT this TPC reduction is partially negated by the increase in material cost.

Exhibit 5-16 TPC (1,000 2011$) for Baseline cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Baseline620	Case Baseline760
Coal & Sorbent Handling	57,740	54,500	56,664	52,225
Coal & Sorbent Prep & Feed	31,040	29,215	30,437	27,944
Feedwater & Misc. BOP Systems	104,134	88,757	30,685	27,123
CFB, ASU, FG Cooling, CO_2 Recycle	464,234	533,106	370,737	404,522
O_2 Generation	375,525	352,052	382,943	349,492

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Baseline620	Case Baseline760
FG Treatment	21,093	19,630	24,288	21,939
FG Recycle	28,356	27,411	31,094	29,596
CO_2 Purification & Compression	224,111	208,172	218,730	197,035
Steam Turbine Generator	173,036	201,497	---	---
sCO_2 Cycle	---	---	413,561	389,252
Cooling Water Systems	60,572	55,117	63,506	55,156
Ash Removal	36,652	34,825	36,034	33,512
Accessory Electric Plant	115,848	112,119	113,411	108,487
Instrumentation & Controls	32,776	32,378	32,534	31,979
Site Preparation & Improvements	18,152	18,213	17,358	17,236
Buildings & Structures	71,808	71,626	70,988	70,417
Totals	**1,815,076**	**1,838,618**	**1,892,970**	**1,815,914**

Exhibit 5-17 shows the detailed TPC (1,000 2011$) for the sCO_2 power cycle for the Baseline cases at two different TITs. These results show more clearly the offsetting impacts of a higher TIT reducing TPC through increased efficiency (e.g., compressor and cooler costs) and a higher TIT increasing TPC through higher materials costs (e.g., CO_2 piping). Overall, sCO_2 cycle TPC is dominated by turbomachinery costs, which constitute 67-72 percent of the cycle cost.

Exhibit 5-17 TPC (1,000 2011$) for sCO_2 power cycle for Baseline cases

Parameter	Reference Rankine	Case Baseline620	Case Baseline760
Main CO_2 Compressor	---	87,238	68,828
Bypass CO_2 Compressor	---	83,609	63,682
High-Temperature CO_2 Recuperator	---	25,142	26,985
Low-Temperature CO_2 Recuperator	---	57,881	45,201
CO_2 Cooler	---	7,643	6,004
CO_2 Turbine Section	---	126,381	127,094
CO_2 System Piping	---	18,387	44,767
CO_2 System Foundations	---	7,280	6,690
Subtotal	**---**	**413,561**	**389,252**

Exhibit 5-18 shows the detailed TPC (1,000 2011$) for the CFB and accessories section for the reference Rankine cases and the Baseline cases at two different TITs. The CFB cost estimate is lower for the sCO_2 cycle cases because there is a substantial reduction in the total thermal duty of the CFB and a significant reduction in the oxidant preheater duty. In examining the TPC for the units that provide thermal input to the power cycle, the TPC for Case Baseline760 is 24 percent lower than the Reference AUSC Rankine Case while the TPC for Case Baseline620 is approximately 21 percent lower than the Reference SC Rankine Case.

Exhibit 5-18 TPC (1,000 2011$) for sCO_2 CFB section for Baseline cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Baseline620	Case Baseline760
CFB & Accessories	464,234	533,106	352,790	388,223
ASU/Oxidant Compression	375,525	352,052	382,943	349,492
Flue Gas Cooler	w/CFB	w/CFB	15,653	14,286
Water Knockout	w/CFB	w/CFB	2,295	2,014
Subtotal	**839,758**	**885,158**	**753,680**	**754,014**

Exhibit 5-19 shows the O&M cost, owner's cost, and COE for the reference Rankine case and the Baseline cases at two different TITs. Many of the cost entities follow the same trend as the TPC (e.g., fixed O&M, owner's costs) because they are driven primarily by the TPC. The cost entities that are primarily driven by efficiency (e.g., fuel cost) are lower for the sCO_2 cycle cases and lowest for the highest TIT. The net effect on the COE is that at a TIT of 620 °C, the COE for the baseline sCO_2 plant is significantly higher than the reference Rankine plant. Increasing the TIT to 760 °C lowers the COE to below the level of the reference AUSC Rankine plant.

Exhibit 5-19 O&M costs, owner's costs, and COE for Baseline cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Baseline620	Case Baseline760
O&M Costs ($1,000/yr)				
Total Fixed O&M	60,159	60,866	62,248	60,119
Total Variable O&M	56,041	52,643	56,227	50,434
Total Fuel	122,152	111,392	118,505	103,998
Total Annual O&M Costs	238,352	224,901	236,979	214,551
Owner's Cost ($1,000)				
Total Owner's Costs	415,350	417,192	431,084	415,519
Total Overnight Cost (TOC, $1,000)				
Total Overnight Cost	2,230,425	2,255,810	2,324,054	2,231,433

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Baseline620	Case Baseline760
COE ($/MWh)				
First-Year COE without T&S	**125.72**	**123.22**	**128.25**	**119.99**
First-Year COE with T&S	**134.30**	**131.05**	**136.57**	**127.30**

5.4 Recompression Cycle with Reheat

5.4.1 Case Reheat620 Cost Estimate Results

Exhibit 5-20 shows a detailed breakdown of the capital costs; Exhibit 5-21 shows the owner's costs, TOC, and TASC; Exhibit 5-22 shows the initial and annual O&M costs. Exhibit 5-23 shows the COE results for Case Reheat620 using high-risk financing.

Exhibit 5-20 Case Reheat620 total plant cost details

Total Plant Cost Summary											
	Case:	sCO2 – Case Reheat620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies		Total Plant Cost	
				Direct	Indirect			Process	Project	$1,000	$/kW
		$1,000									
1		Coal & Sorbent Handling									
1.1	Coal Receive & Unload	$4,299	$0	$1,937	$0	$6,236	$541	$0	$1,017	$7,793	$14
1.2	Coal Stackout & Reclaim	$5,556	$0	$1,242	$0	$6,798	$576	$0	$1,106	$8,480	$15
1.3	Coal Conveyors	$5,166	$0	$1,229	$0	$6,394	$543	$0	$1,041	$7,978	$15
1.4	Other Coal Handling	$1,352	$0	$284	$0	$1,636	$138	$0	$266	$2,040	$4
1.5	Sorbent Receive & Unload	$304	$0	$90	$0	$394	$34	$0	$64	$492	$1
1.6	Sorbent Stackout & Reclaim	$4,903	$0	$886	$0	$5,789	$488	$0	$942	$7,219	$13
1.7	Sorbent Conveyors	$1,750	$380	$423	$0	$2,553	$213	$0	$415	$3,181	$6
1.8	Other Sorbent Handling	$1,057	$249	$547	$0	$1,852	$159	$0	$302	$2,312	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$5,365	$7,074	$0	$12,439	$1,166	$0	$2,041	$15,646	$28
	Subtotal	**$24,386**	**$5,994**	**$13,711**	**$0**	**$44,091**	**$3,858**	**$0**	**$7,192**	**$55,141**	**$100**
2		Coal & Sorbent Prep & Feed									
2.1	Coal Crushing & Drying	$2,470	$0	$475	$0	$2,945	$249	$0	$479	$3,673	$7
2.2	Coal Conveyor to Storage	$6,325	$0	$1,362	$0	$7,687	$651	$0	$1,251	$9,588	$17
2.5	Sorbent Prep Equipment	$8,408	$364	$1,722	$0	$10,495	$884	$0	$1,707	$13,086	$24
2.6	Sorbent Storage & Feed	$1,013	$0	$383	$0	$1,396	$120	$0	$227	$1,743	$3
2.9	Coal & Sorbent Feed Foundation	$0	$631	$554	$0	$1,185	$110	$0	$194	$1,490	$3
	Subtotal	**$18,217**	**$995**	**$4,496**	**$0**	**$23,709**	**$2,014**	**$0**	**$3,858**	**$29,581**	**$54**
3		Feedwater & Miscellaneous BOP Systems									
3.1	Feedwater System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.2	Water Makeup & Pretreating	$7,524	$0	$2,380	$0	$9,903	$905	$0	$2,162	$12,970	$24
3.3	Other Feedwater Subsystems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.4	Service Water Systems	$1,507	$0	$789	$0	$2,295	$206	$0	$500	$3,002	$5
3.5	Other Boiler Plant Systems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.6	FO Supply Sys & Nat Gas	$333	$0	$389	$0	$722	$65	$0	$118	$904	$2
3.7	Waste Treatment Equipment	$3,364	$0	$1,947	$0	$5,311	$511	$0	$1,164	$6,986	$13
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,261	$0	$1,009	$0	$4,269	$406	$0	$935	$5,610	$10
	Subtotal	**$15,987**	**$0**	**$6,513**	**$0**	**$22,500**	**$2,093**	**$0**	**$4,879**	**$29,472**	**$54**
4		Boiler & Accessories									
4.1	CFB & Accessories	w/ BEC	$0	w/ BEC	$0	$284,416	$27,373	$0	$31,179	$342,968	$624
4.5	ASU/Oxidant Compression	$169,304	$0	$138,522	$0	$307,826	$29,837	$0	$33,766	$371,429	$676
	Flue Gas Cooler	$12,208	$0	$0	$0	$12,208	$1,135	$0	$1,953	$15,296	$28
	Flue Gas N2 Heater	$1,722	$0	$0	$0	$1,722	$160	$0	$276	$2,158	$4
	Subtotal	**$183,234**	**$0**	**$138,522**	**$0**	**$606,172**	**$58,506**	**$0**	**$67,174**	**$731,852**	**$1,331**
5A		Gas Cleanup & Piping									
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$11,046	$0	$6,962	$0	$18,007	$1,692	$0	$1,970	$21,670	$39
5A.4	Other Particulate Removal Materials	$755	$0	$803	$0	$1,558	$147	$0	$171	$1,876	$3
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$11,801**	**$0**	**$7,764**	**$0**	**$19,565**	**$1,840**	**$0**	**$2,140**	**$23,545**	**$43**

Exhibit 5-20 Case Reheat620 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case Reheat620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification & Compression Unit/System	$77,361	$0	$58,762	$0	$136,123	$12,678	$27,225	$35,205	$211,231	$384
	Subtotal	**$77,361**	**$0**	**$58,762**	**$0**	**$136,123**	**$12,678**	**$27,225**	**$35,205**	**$211,231**	**$384**
7		HRSG, Ducting, & Stack									
7.3	Ductwork	$10,188	$0	$6,431	$0	$16,619	$1,404	$0	$2,703	$20,726	$38
7.4	Stack	$3,577	$0	$2,079	$0	$5,655	$531	$0	$619	$6,805	$12
7.9	Duct & Stack Foundations	$0	$1,064	$1,263	$0	$2,327	$218	$0	$509	$3,054	$6
	Subtotal	**$13,765**	**$1,064**	**$9,773**	**$0**	**$24,601**	**$2,152**	**$0**	**$3,831**	**$30,585**	**$56**
8B		sCO_2 Power Cycle									
	Main CO_2 Compressor	$41,116	$0	$24,669	$0	$65,785	$6,118	$0	$10,526	$82,429	$150
	Bypass CO_2 Compressor	$36,550	$0	$21,930	$0	$58,481	$5,439	$0	$9,357	$73,276	$133
	High Temperature CO_2 Recuperator	$36,260	$0	$0	$0	$36,260	$3,372	$0	$5,802	$45,434	$83
	Low Temperature CO_2 Recuperator	$42,781	$0	$0	$0	$42,781	$3,979	$0	$6,845	$53,605	$97
	CO_2 Cooler	$4,292	$0	$1,316	$0	$5,608	$522	$0	$897	$7,027	$13
	CO_2 Turbine Section	$107,960	$0	$0	$0	$107,960	$10,040	$0	$17,274	$135,274	$246
	CO_2 System Piping	$20,736	$0	$6,221	$0	$26,957	$2,507	$0	$4,313	$33,778	$61
	CO_2 System Foundations	$0	$2,136	$3,528	$0	$5,664	$527	$0	$906	$7,097	$13
	Subtotal	**$289,697**	**$2,136**	**$57,665**	**$0**	**$349,498**	**$32,503**	**$0**	**$55,920**	**$437,921**	**$797**
9		Cooling Water System									
9.1	Cooling Towers	$12,999	$0	$4,020	$0	$17,019	$1,586	$0	$1,860	$20,465	$37
9.2	Circulating Water Pumps	$3,319	$0	$264	$0	$3,583	$306	$0	$389	$4,277	$8
9.3	Circ.Water System Auxiliaries	$869	$0	$115	$0	$984	$91	$0	$108	$1,183	$2
9.4	Circ.Water Piping	$0	$7,323	$6,631	$0	$13,954	$1,235	$0	$2,278	$17,468	$32
9.5	Make-up Water System	$718	$0	$923	$0	$1,641	$151	$0	$269	$2,061	$4
9.6	Component Cooling Water Sys	$709	$0	$544	$0	$1,253	$114	$0	$205	$1,572	$3
9.9	Circ.Water System Foundations & Structures	$0	$3,905	$6,485	$0	$10,390	$979	$0	$2,274	$13,642	$25
	Subtotal	**$18,614**	**$11,228**	**$18,982**	**$0**	**$48,824**	**$4,462**	**$0**	**$7,383**	**$60,668**	**$110**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	$1,640	$0	$5,020	$0	$6,660	$639	$0	$730	$8,029	$15
10.7	Ash Transport & Feed Equipment	$10,897	$0	$10,803	$0	$21,701	$1,999	$0	$2,370	$26,070	$47
10.9	Ash/Spent Sorbent Foundation	$0	$370	$456	$0	$826	$77	$0	$181	$1,084	$2
	Subtotal	**$12,538**	**$370**	**$16,279**	**$0**	**$29,187**	**$2,716**	**$0**	**$3,281**	**$35,184**	**$64**

Exhibit 5-20 Case Reheat620 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case Reheat620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
11		Accessory Electric Plant									
11.1	Generator Equipment	$2,172	$0	$347	$0	$2,519	$226	$0	$206	$2,950	$5
11.2	Station Service Equipment	$6,658	$0	$2,232	$0	$8,890	$826	$0	$729	$10,445	$19
11.3	Switchgear & Motor Control	$7,642	$0	$1,327	$0	$8,969	$829	$0	$980	$10,779	$20
11.4	Conduit & Cable Tray	$0	$5,240	$16,931	$0	$22,171	$2,069	$0	$3,636	$27,877	$51
11.5	Wire & Cable	$0	$9,978	$17,836	$0	$27,814	$2,234	$0	$4,507	$34,555	$63
11.6	Protective Equipment	$351	$0	$1,217	$0	$1,568	$151	$0	$172	$1,891	$3
11.7	Standby Equipment	$1,640	$0	$38	$0	$1,678	$154	$0	$183	$2,015	$4
11.8	Main Power Transformers	$16,089	$0	$231	$0	$16,320	$1,237	$0	$1,756	$19,313	$35
11.9	Electrical Foundations	$0	$411	$1,045	$0	$1,455	$138	$0	$319	$1,911	$3
	Subtotal	**$34,551**	**$15,629**	**$41,205**	**$0**	**$91,385**	**$7,863**	**$0**	**$12,487**	**$111,736**	**$203**
12		Instrumentation & Control									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$630	$0	$385	$0	$1,016	$95	$51	$174	$1,336	$2
12.7	Distributed Control System Equipment	$6,364	$0	$1,135	$0	$7,499	$693	$375	$857	$9,424	$17
12.8	Instrument Wiring & Tubing	$3,838	$0	$6,983	$0	$10,821	$877	$541	$1,836	$14,075	$26
12.9	Other I & C Equipment	$1,798	$0	$4,164	$0	$5,963	$570	$298	$683	$7,513	$14
	Subtotal	**$12,631**	**$0**	**$12,668**	**$0**	**$25,299**	**$2,234**	**$1,265**	**$3,550**	**$32,348**	**$59**
13		Improvements to Site									
13.1	Site Preparation	$0	$63	$1,331	$0	$1,394	$136	$0	$306	$1,836	$3
13.2	Site Improvements	$0	$2,077	$2,745	$0	$4,822	$479	$0	$1,060	$6,361	$12
13.3	Site Facilities	$3,723	$0	$3,905	$0	$7,628	$759	$0	$1,677	$10,065	$18
	Subtotal	**$3,723**	**$2,140**	**$7,981**	**$0**	**$13,844**	**$1,374**	**$0**	**$3,044**	**$18,261**	**$33**
14		Buildings & Structures									
14.1	Boiler Building	$0	$10,594	$9,310	$0	$19,904	$1,751	$0	$3,248	$24,904	$45
14.2	Turbine Building	$0	$15,322	$14,270	$0	$29,592	$2,611	$0	$4,830	$37,034	$67
14.3	Administration Building	$0	$769	$813	$0	$1,582	$140	$0	$258	$1,981	$4
14.4	Circulation Water Pumphouse	$0	$221	$175	$0	$396	$35	$0	$65	$496	$1
14.5	Water Treatment Buildings	$0	$947	$863	$0	$1,809	$159	$0	$295	$2,264	$4
14.6	Machine Shop	$0	$514	$345	$0	$860	$75	$0	$140	$1,075	$2
14.7	Warehouse	$0	$349	$349	$0	$698	$62	$0	$114	$874	$2
14.8	Other Buildings & Structures	$0	$285	$242	$0	$527	$46	$0	$86	$660	$1
14.9	Waste Treating Building & Str.	$0	$540	$1,637	$0	$2,177	$202	$0	$357	$2,736	$5
	Subtotal	**$0**	**$29,541**	**$28,005**	**$0**	**$57,546**	**$5,082**	**$0**	**$9,394**	**$72,022**	**$131**
	Total	**$716,504**	**$69,098**	**$422,326**	**$0**	**$1,492,344**	**$139,374**	**$28,490**	**$219,338**	**$1,879,546**	**$3,419**

Exhibit 5-21 Case Reheat620 owner's costs

Owner's Costs		
Description	**$1,000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$11,929	$22
1-Month Maintenance Materials	$1,721	$3
1-Month Non-fuel Consumables	$2,027	$4
1-Month Waste Disposal	$1,746	$3
25% of 1-Month Fuel Cost at 100% CF	$2,994	$5
2% of TPC	$37,591	$68
Total	**$58,008**	**$106**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$27,388	$50
0.5% of TPC (spare parts)	$9,398	$17
Total	**$36,785**	**$67**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$281,932	$513
Financing Costs	$50,748	$92
Total Overnight Costs (TOC)	**$2,307,918**	**$4,198**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,631,027**	**$4,785**

Exhibit 5-22 Case Reheat620 initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	sCO2 – Case Reheat620				**Cost Base:**	Jun 2011
Plant Size (MW,net):	**550**		**Heat Rate-net (Btu/kWh):**	9,430	**Capacity Factor (%):**	85
Operating & Maintenance Labor						
Operating Labor				**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		39.70	**$/hour**		**1 unit/mod.**	**Total Plant**
Operating Labor Burden:		30.00	**% of base**	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	**% of labor**	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**($/kW-net)**
Annual Operating Labor:					$7,384,208	$13.431
Maintenance Labor:					$12,043,194	$21.904
Administrative & Support Labor:					$4,856,850	$8.834
Property Taxes and Insurance:					$37,590,910	$68.371
Total:					**$61,875,162**	**$112.540**
Variable Operating Costs						
					($)	**($/kWh-net)**
Maintenance Material:					$18,178,277	$0.00444
Consumables						
	Consumption		**Cost ($)**			
	Initial Fill	**Per Day**	**Per Unit**	**Initial Fill**		
Water (/1000 gallons):	0	6,081	$1.67	$0	$3,158,097	$0.00077
Makeup and Waste Water Treatment Chemicals (lbs):	0	29,435	$0.27	$0	$2,445,954	$0.00060
Limestone (ton)	0	1,282	$33.48	$0	$13,311,291	$0.00325
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,391	$1.63	$0	$701,367	$0.00017
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$19,616,709**	**$0.00479**
Waste Disposal						
Fly Ash (ton)	0	49	$25.11	$0	$383,012	$0.00009
Bottom Ash (ton)	0	2,074	$25.11	$0	$16,160,672	$0.00395
Subtotal:				**$0**	**$16,543,684**	**$0.00404**
By-Products						
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$54,338,670**	**$0.01327**
Fuel Cost						
Illinois Number 6 (ton):	0	5,330	$68.60	$0	$113,447,703	$0.02771
Total:				**$0**	**$113,447,703**	**$0.02771**

Exhibit 5-23 Case Reheat620 COE breakdown

Case	Reheat620
Cost	
TPC (2011$/kW)	3,419
TOC (2011$/kW)	4,198
COE (2011$/MWh) (excluding T&S)	126.00
Capital	69.91
Fixed O&M	15.11
Variable O&M	13.27
Fuel	27.71
T&S	7.97
COE (2011$/MWh) (including T&S)	133.98

5.4.2 Case Reheat760 Cost Estimate Results

Exhibit 5-24 shows a detailed breakdown of the capital costs; Exhibit 5-25 shows the owner's costs, TOC, and TASC; Exhibit 5-26 shows the initial and annual O&M costs. Exhibit 5-27 shows the COE results for Case Reheat760 using high-risk financing.

Exhibit 5-24 Case Reheat760 total plant cost details

Total Plant Cost Summary											
	Case:	sCO2 – Case Reheat760					**Estimate Type:**			Conceptual	
	Plant Size (MW,net):	**550 MWe**					**Cost Base:**			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
1		Coal & Sorbent Handling									
1.1	Coal Receive & Unload	$3,991	$0	$1,798	$0	$5,789	$502	$0	$944	$7,235	$13
1.2	Coal Stackout & Reclaim	$5,158	$0	$1,153	$0	$6,311	$535	$0	$1,027	$7,872	$14
1.3	Coal Conveyors	$4,796	$0	$1,141	$0	$5,936	$504	$0	$966	$7,406	$13
1.4	Other Coal Handling	$1,255	$0	$264	$0	$1,519	$128	$0	$247	$1,894	$3
1.5	Sorbent Receive & Unload	$281	$0	$84	$0	$365	$31	$0	$59	$455	$1
1.6	Sorbent Stackout & Reclaim	$4,541	$0	$821	$0	$5,362	$452	$0	$872	$6,685	$12
1.7	Sorbent Conveyors	$1,620	$352	$392	$0	$2,364	$198	$0	$384	$2,946	$5
1.8	Other Sorbent Handling	$979	$230	$506	$0	$1,715	$147	$0	$279	$2,142	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$4,981	$6,567	$0	$11,548	$1,083	$0	$1,895	$14,525	$26
	Subtotal	**$22,621**	**$5,563**	**$12,725**	**$0**	**$40,908**	**$3,579**	**$0**	**$6,673**	**$51,160**	**$93**
2		Coal & Sorbent Prep & Feed									
2.1	Coal Crushing & Drying	$2,282	$0	$439	$0	$2,721	$230	$0	$443	$3,393	$6
2.2	Coal Conveyor to Storage	$5,844	$0	$1,258	$0	$7,102	$601	$0	$1,155	$8,859	$16
2.5	Sorbent Prep Equipment	$7,778	$337	$1,593	$0	$9,708	$818	$0	$1,579	$12,105	$22
2.6	Sorbent Storage & Feed	$937	$0	$354	$0	$1,291	$111	$0	$210	$1,613	$3
2.9	Coal & Sorbent Feed Foundation	$0	$584	$512	$0	$1,097	$102	$0	$180	$1,378	$3
	Subtotal	**$16,841**	**$921**	**$4,157**	**$0**	**$21,919**	**$1,862**	**$0**	**$3,567**	**$27,348**	**$50**
3		Feedwater & Miscellaneous BOP Systems									
3.1	Feedwater System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.2	Water Makeup & Pretreating	$6,539	$0	$2,068	$0	$8,607	$787	$0	$1,879	$11,272	$20
3.3	Other Feedwater Subsystems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.4	Service Water Systems	$1,309	$0	$685	$0	$1,995	$179	$0	$435	$2,609	$5
3.5	Other Boiler Plant Systems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.6	FO Supply Sys & Nat Gas	$323	$0	$377	$0	$700	$63	$0	$114	$877	$2
3.7	Waste Treatment Equipment	$2,923	$0	$1,692	$0	$4,615	$444	$0	$1,012	$6,072	$11
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,164	$0	$979	$0	$4,143	$394	$0	$907	$5,444	$10
	Subtotal	**$14,259**	**$0**	**$5,802**	**$0**	**$20,060**	**$1,866**	**$0**	**$4,347**	**$26,274**	**$48**
4		Boiler & Accessories									
4.1	CFB & Accessories	w/ BEC	$0	w/ BEC	$0	$309,669	$29,804	$0	$33,947	$373,420	$679
4.5	ASU/Oxidant Compression	$155,672	$0	$127,368	$0	$283,040	$27,435	$0	$31,047	$341,522	$621
	Flue Gas Cooler	$11,225	$0	$0	$0	$11,225	$1,044	$0	$1,796	$14,064	$26
	Flue Gas N2 Heater	$1,528	$0	$0	$0	$1,528	$142	$0	$244	$1,914	$3
	Subtotal	**$168,424**	**$0**	**$127,368**	**$0**	**$605,461**	**$58,425**	**$0**	**$67,035**	**$730,921**	**$1,329**
5A		Gas Cleanup & Piping									
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$10,059	$0	$6,340	$0	$16,399	$1,541	$0	$1,794	$19,735	$36
5A.4	Other Particulate Removal Materials	$688	$0	$732	$0	$1,420	$134	$0	$155	$1,710	$3
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$10,748**	**$0**	**$7,072**	**$0**	**$17,820**	**$1,676**	**$0**	**$1,950**	**$21,445**	**$39**

Exhibit 5-24 Case Reheat760 total plant cost details (continued)

Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
Total Plant Cost Summary											
	Case:	sCO2 – Case Reheat760					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
		$1,000									
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification & Compression Unit/System	$70,284	$0	$53,387	$0	$123,671	$11,518	$24,734	$31,985	$191,908	$349
	Subtotal	**$70,284**	**$0**	**$53,387**	**$0**	**$123,671**	**$11,518**	**$24,734**	**$31,985**	**$191,908**	**$349**
7		HRSG, Ducting, & Stack									
7.3	Ductwork	$9,734	$0	$6,144	$0	$15,878	$1,341	$0	$2,583	$19,803	$36
7.4	Stack	$3,377	$0	$1,962	$0	$5,339	$501	$0	$584	$6,424	$12
7.9	Duct & Stack Foundations	$0	$1,046	$1,242	$0	$2,289	$214	$0	$501	$3,003	$5
	Subtotal	**$13,111**	**$1,046**	**$9,349**	**$0**	**$23,506**	**$2,057**	**$0**	**$3,667**	**$29,230**	**$53**
8B		sCO_2 Power Cycle									
	Main CO_2 Compressor	$32,766	$0	$19,660	$0	$52,426	$4,876	$0	$8,388	$65,689	$119
	Bypass CO_2 Compressor	$30,734	$0	$18,441	$0	$49,175	$4,573	$0	$7,868	$61,616	$112
	High Temperature CO_2 Recuperator	$39,233	$0	$0	$0	$39,233	$3,649	$0	$6,277	$49,158	$89
	Low Temperature CO_2 Recuperator	$33,851	$0	$0	$0	$33,851	$3,148	$0	$5,416	$42,416	$77
	CO_2 Cooler	$3,416	$0	$1,048	$0	$4,464	$415	$0	$714	$5,593	$10
	CO_2 Turbine Section	$109,298	$0	$0	$0	$109,298	$10,165	$0	$17,488	$136,950	$249
	CO_2 System Piping	$59,689	$0	$17,907	$0	$77,595	$7,216	$0	$12,415	$97,227	$177
	CO_2 System Foundations	$0	$1,978	$3,265	$0	$5,243	$488	$0	$839	$6,570	$12
	Subtotal	**$308,987**	**$1,978**	**$60,320**	**$0**	**$371,285**	**$34,530**	**$0**	**$59,406**	**$465,220**	**$846**
9		Cooling Water System									
9.1	Cooling Towers	$11,319	$0	$3,501	$0	$14,820	$1,381	$0	$1,620	$17,821	$32
9.2	Circulating Water Pumps	$2,800	$0	$223	$0	$3,023	$258	$0	$328	$3,608	$7
9.3	Circ.Water System Auxiliaries	$764	$0	$101	$0	$865	$80	$0	$95	$1,040	$2
9.4	Circ.Water Piping	$0	$6,440	$5,832	$0	$12,272	$1,086	$0	$2,004	$15,362	$28
9.5	Make-up Water System	$638	$0	$820	$0	$1,457	$135	$0	$239	$1,831	$3
9.6	Component Cooling Water Sys	$623	$0	$478	$0	$1,102	$100	$0	$180	$1,382	$3
9.9	Circ.Water System Foundations & Structures	$0	$3,468	$5,760	$0	$9,228	$869	$0	$2,019	$12,117	$22
	Subtotal	**$16,145**	**$9,908**	**$16,714**	**$0**	**$42,767**	**$3,909**	**$0**	**$6,485**	**$53,161**	**$97**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	$1,534	$0	$4,694	$0	$6,228	$598	$0	$683	$7,508	$14
10.7	Ash Transport & Feed Equipment	$10,190	$0	$10,102	$0	$20,292	$1,869	$0	$2,216	$24,377	$44
10.9	Ash/Spent Sorbent Foundation	$0	$346	$426	$0	$773	$72	$0	$169	$1,014	$2
	Subtotal	**$11,724**	**$346**	**$15,222**	**$0**	**$27,293**	**$2,539**	**$0**	**$3,068**	**$32,900**	**$60**

Exhibit 5-24 Case Reheat760 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case Reheat760					**Estimate Type:**			Conceptual	
	Plant Size (MW,net):	550 MWe					**Cost Base:**			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
11		Accessory Electric Plant									
11.1	Generator Equipment	$2,142	$0	$342	$0	$2,485	$223	$0	$203	$2,910	$5
11.2	Station Service Equipment	$6,319	$0	$2,118	$0	$8,438	$784	$0	$692	$9,913	$18
11.3	Switchgear & Motor Control	$7,253	$0	$1,260	$0	$8,513	$787	$0	$930	$10,230	$19
11.4	Conduit & Cable Tray	$0	$4,974	$16,069	$0	$21,043	$1,964	$0	$3,451	$26,458	$48
11.5	Wire & Cable	$0	$9,470	$16,928	$0	$26,399	$2,120	$0	$4,278	$32,797	$60
11.6	Protective Equipment	$333	$0	$1,155	$0	$1,488	$143	$0	$163	$1,794	$3
11.7	Standby Equipment	$1,622	$0	$38	$0	$1,659	$152	$0	$181	$1,993	$4
11.8	Main Power Transformers	$16,089	$0	$231	$0	$16,320	$1,237	$0	$1,756	$19,313	$35
11.9	Electrical Foundations	$0	$404	$1,027	$0	$1,431	$135	$0	$313	$1,879	$3
	Subtotal	**$33,758**	**$14,848**	**$39,170**	**$0**	**$87,775**	**$7,545**	**$0**	**$11,967**	**$107,287**	**$195**
12		Instrumentation & Control									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$621	$0	$379	$0	$1,000	$94	$50	$172	$1,315	$2
12.7	Distributed Control System Equipment	$6,265	$0	$1,117	$0	$7,382	$682	$369	$843	$9,276	$17
12.8	Instrument Wiring & Tubing	$3,778	$0	$6,874	$0	$10,651	$863	$533	$1,807	$13,854	$25
12.9	Other I & C Equipment	$1,770	$0	$4,099	$0	$5,869	$561	$293	$672	$7,396	$13
	Subtotal	**$12,433**	**$0**	**$12,469**	**$0**	**$24,903**	**$2,199**	**$1,245**	**$3,494**	**$31,841**	**$58**
13		Improvements to Site									
13.1	Site Preparation	$0	$63	$1,329	$0	$1,391	$136	$0	$305	$1,832	$3
13.2	Site Improvements	$0	$2,073	$2,739	$0	$4,813	$478	$0	$1,058	$6,349	$12
13.3	Site Facilities	$3,716	$0	$3,898	$0	$7,613	$758	$0	$1,674	$10,045	$18
	Subtotal	**$3,716**	**$2,136**	**$7,966**	**$0**	**$13,817**	**$1,371**	**$0**	**$3,038**	**$18,226**	**$33**
14		Buildings & Structures									
14.1	Boiler Building	$0	$10,589	$9,306	$0	$19,895	$1,750	$0	$3,247	$24,892	$45
14.2	Turbine Building	$0	$15,310	$14,259	$0	$29,569	$2,609	$0	$4,827	$37,005	$67
14.3	Administration Building	$0	$769	$812	$0	$1,581	$140	$0	$258	$1,979	$4
14.4	Circulation Water Pumphouse	$0	$196	$156	$0	$352	$31	$0	$57	$440	$1
14.5	Water Treatment Buildings	$0	$831	$757	$0	$1,588	$140	$0	$259	$1,987	$4
14.6	Machine Shop	$0	$514	$345	$0	$859	$75	$0	$140	$1,074	$2
14.7	Warehouse	$0	$348	$349	$0	$697	$62	$0	$114	$873	$2
14.8	Other Buildings & Structures	$0	$285	$242	$0	$527	$46	$0	$86	$659	$1
14.9	Waste Treating Building & Str.	$0	$532	$1,614	$0	$2,147	$200	$0	$352	$2,698	$5
	Subtotal	**$0**	**$29,374**	**$27,841**	**$0**	**$57,215**	**$5,053**	**$0**	**$9,340**	**$71,607**	**$130**
	Total	**$703,050**	**$66,120**	**$399,561**	**$0**	**$1,478,399**	**$138,128**	**$25,979**	**$216,021**	**$1,858,528**	**$3,379**

Exhibit 5-25 Case Reheat760 owner's costs

Owner's Costs		
Description	**$1,000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$11,929	$22
1-Month Maintenance Materials	$1,721	$3
1-Month Non-fuel Consumables	$2,027	$4
1-Month Waste Disposal	$1,746	$3
25% of 1-Month Fuel Cost at 100% CF	$2,994	$5
2% of TPC	$37,171	$68
Total	**$57,587**	**$105**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$27,388	$50
0.5% of TPC (spare parts)	$9,293	$17
Total	**$36,680**	**$67**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$278,779	$507
Financing Costs	$50,180	$91
Total Overnight Costs (TOC)	**$2,282,655**	**$4,150**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,602,227**	**$4,731**

Exhibit 5-26 Case Reheat760 initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	sCO2 – Case Reheat760				Cost Base:	Jun 2011
Plant Size (MW,net):		550	Heat Rate-net (Btu/kWh):	8,360	Capacity Factor (%):	85
Operating & Maintenance Labor						
Operating Labor				Operating Labor Requirements per Shift		
Operating Labor Rate (base):		39.70	$/hour		1 unit/mod.	Total Plant
Operating Labor Burden:		30.00	% of base	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	% of labor	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	($/kW-net)
Annual Operating Labor:					$7,384,208	$13.424
Maintenance Labor:					$11,930,662	$21.689
Administrative & Support Labor:					$4,828,717	$8.778
Property Taxes and Insurance:					$37,170,559	$67.573
Total:					**$61,314,146**	**$111.464**
Variable Operating Costs						
					($)	($/kWh-net)
Maintenance Material:					$17,975,002	$0.00439
Consumables						
	Consumption		Cost ($)			
	Initial Fill	Per Day	Per Unit	Initial Fill		
Water (/1000 gallons):	0	4,990	$1.67	$0	$2,591,719	$0.00063
Makeup and Waste Water Treatment Chemicals (lbs):	0	24,156	$0.27	$0	$2,007,292	$0.00049
Limestone (ton)	0	1,137	$33.48	$0	$11,806,953	$0.00288
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,234	$1.63	$0	$622,104	$0.00015
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$17,028,069**	**$0.00416**
Waste Disposal						
Fly Ash (ton)	0	44	$25.11	$0	$339,727	$0.00008
Bottom Ash (ton)	0	1,840	$25.11	$0	$14,334,319	$0.00350
Subtotal:				**$0**	**$14,674,046**	**$0.00358**
By-Products						
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$49,677,117**	**$0.01213**
Fuel Cost						
Illinois Number 6 (ton):	0	4,728	$68.60	$0	$100,626,733	$0.02457
Total:				**$0**	**$100,626,733**	**$0.02457**

Exhibit 5-27 shows the COE results for Case Reheat760 using high-risk financing. The COE result for Case Reheat620 is shown for comparison purposes, and uses high-risk financing assumptions.

Exhibit 5-27 Case Reheat760 COE breakdown

Case	Reheat620	Reheat760
Cost		
TPC (2011$/kW)	3,419	3,379
TOC (2011$/kW)	4,198	4,150
COE (2011$/MWh) (excluding T&S)	126.00	120.77
Capital	69.91	69.11
Fixed O&M	15.11	14.97
Variable O&M	13.27	12.13
Fuel	27.71	24.57
T&S	7.97	7.07
COE (2011$/MWh) (including T&S)	133.98	127.84

5.4.3 Comparison of Cost Estimate Results Between Reference Rankine Cases and Reheat sCO_2 Cases

Exhibit 5-28 shows the TPC (1,000 2011$) for the reference Rankine case and the Reheat cases at two different TITs. The TPC for Case Reheat620 is 4 percent greater than the reference SC Rankine plant and Case Reheat760 is 1 percent greater than the reference AUSC Rankine plant. At the higher TIT, the effect of higher process efficiency in lowering TPC is offset by the increase in materials costs. Another notable observation is that with reheat, the TPC compared to the Baseline Cases decreases with a TIT of 620 °C but increases with a TIT of 760 °C.

Exhibit 5-28 TPC (1,000 2011$) for Reheat cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Reheat620	Case Reheat760
Coal & Sorbent Handling	57,740	54,500	55,141	51,160
Coal & Sorbent Prep & Feed	31,040	29,215	29,581	27,348
Feedwater & Misc. BOP Systems	104,134	88,757	29,472	26,274
CFB, ASU, FG Cooling, CO_2 Recycle	464,234	533,106	360,422	389,399
O_2 Generation	375,525	352,052	371,429	341,522
FG Treatment	21,093	19,630	23,545	21,445
FG Recycle	28,356	27,411	30,585	29,230
CO_2 Purification & Compression	224,111	208,172	211,231	191,908
Steam Turbine Generator	173,036	201,497	---	---

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Reheat620	Case Reheat760
sCO_2 Cycle	---	---	437,921	465,220
Cooling Water Systems	60,572	55,117	60,668	53,161
Ash Removal	36,652	34,825	35,184	32,900
Accessory Electric Plant	115,848	112,119	111,736	107,287
Instrumentation & Controls	32,776	32,378	32,348	31,841
Site Preparation & Improvements	18,152	18,213	18,261	18,226
Buildings & Structures	71,808	71,626	72,022	71,607
Totals	**1,815,076**	**1,838,618**	**1,879,546**	**1,858,528**

Exhibit 5-29 shows the detailed TPC (1,000 2011$) for the sCO_2 power cycle for the reference Rankine case and the Reheat cases at two different TITs. Both sCO_2 cases have higher TPC than the corresponding Baseline case but the increase with the high TIT is much greater (20 percent) than the increase with the low TIT (less than 6 percent). This is due to the high cost of materials needed at the high TIT case conditions.

Exhibit 5-29 TPC (1,000 2011$) for sCO_2 power cycle for Reheat cases

Parameter	Reference Rankine	Case Reheat620	Case Reheat760
Main CO_2 Compressor	---	82,429	65,689
Bypass CO_2 Compressor	---	73,276	61,616
High-Temperature CO_2 Recuperator	---	45,434	49,158
Low-Temperature CO_2 Recuperator	---	53,605	42,416
CO_2 Cooler	---	7,027	5,593
CO_2 Turbine Section	---	135,274	136,950
CO_2 System Piping	---	33,778	97,227
CO_2 System Foundations	---	7,097	6,570
Subtotal	**---**	**437,921**	**465,220**

Exhibit 5-30 shows the detailed TPC (1,000 2011$) for the CFB and accessories section for the reference Rankine case and the Reheat cases at two different TITs. The CFB TPC decreases 3-4 percent in the Reheat cases versus the Baseline cases and the ASU costs show reductions of 2-3 percent. Both effects reflect the increase in process efficiency for the Reheat cases. Compared to the reference Rankine cases, the total

TPC for this account is 13 percent lower for the 620 °C TIT and 17 percent lower for the 760 °C TIT.

Exhibit 5-30 TPC (1,000 2011$) for sCO_2 CFB section for Reheat cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Reheat620	Case Reheat760
CFB & Accessories	464,234	533,106	342,968	373,420
ASU/Oxidant Compression	375,525	352,052	371,429	341,522
Flue Gas Cooler	w/CFB	w/CFB	15,296	14,064
Water Knockout	w/CFB	w/CFB	2,158	1,914
Subtotal	**839,758**	**885,158**	**731,852**	**730,921**

Exhibit 5-31 shows the O&M cost, owner's cost, and COE for the reference Rankine case and the Reheat cases at two different TITs. The trends are qualitatively similar as for the Baseline cases. However, compared to the Baseline cases, there is a 2 percent reduction in COE with a TIT of 620 °C and a 0.7 percent increase in COE with a TIT of 760 °C.

Exhibit 5-31 O&M costs, owner's costs, and COE for Reheat cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case Reheat620	Case Reheat760
O&M Costs ($1,000/yr)				
Total Fixed O&M	60,159	60,866	61,875	61,314
Total Variable O&M	56,041	52,643	54,339	49,677
Total Fuel	122,152	111,392	113,448	100,627
Total Annual O&M Costs	238,352	224,901	229,662	211,618
Owner's Cost ($1,000)				
Total Owner's Costs	415,350	417,192	428,373	424,127
Total Overnight Cost (TOC, $1,000)				
Total Overnight Cost	2,230,425	2,255,810	2,307,918	2,282,565
COE ($/MWh)				
First-Year COE without T&S	**125.72**	**123.22**	**126.00**	**120.77**
First-Year COE with T&S	**134.30**	**131.05**	**133.98**	**127.84**

5.5 Recompression Cycle with Main Compressor Intercooling

5.5.1 Case IC620 Cost Estimate Results

Exhibit 5-32 shows a detailed breakdown of the capital costs; Exhibit 5-33 shows the owner's costs, TOC, and TASC; Exhibit 5-34 shows the initial and annual O&M costs. Exhibit 5-35 shows the COE results for Case IC620 using high-risk financing.

Exhibit 5-32 Case IC620 total plant cost details

Total Plant Cost Summary											
	Case:	sCO2 – Case IC620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
1	Coal & Sorbent Handling										
1.1	Coal Receive & Unload	$4,367	$0	$1,967	$0	$6,334	$549	$0	$1,032	$7,916	$14
1.2	Coal Stackout & Reclaim	$5,644	$0	$1,261	$0	$6,905	$585	$0	$1,123	$8,613	$16
1.3	Coal Conveyors	$5,247	$0	$1,248	$0	$6,495	$551	$0	$1,057	$8,103	$15
1.4	Other Coal Handling	$1,373	$0	$289	$0	$1,661	$141	$0	$270	$2,072	$4
1.5	Sorbent Receive & Unload	$308	$0	$92	$0	$400	$34	$0	$65	$500	$1
1.6	Sorbent Stackout & Reclaim	$4,983	$0	$901	$0	$5,883	$496	$0	$957	$7,336	$13
1.7	Sorbent Conveyors	$1,778	$386	$430	$0	$2,594	$217	$0	$422	$3,233	$6
1.8	Other Sorbent Handling	$1,074	$253	$555	$0	$1,882	$161	$0	$306	$2,350	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$5,449	$7,185	$0	$12,634	$1,185	$0	$2,073	$15,892	$29
	Subtotal	**$24,773**	**$6,088**	**$13,928**	**$0**	**$44,789**	**$3,919**	**$0**	**$7,306**	**$56,013**	**$102**
2	Coal & Sorbent Prep & Feed										
2.1	Coal Crushing & Drying	$2,512	$0	$483	$0	$2,995	$253	$0	$487	$3,734	$7
2.2	Coal Conveyor to Storage	$6,431	$0	$1,385	$0	$7,816	$661	$0	$1,272	$9,749	$18
2.5	Sorbent Prep Equipment	$8,547	$370	$1,751	$0	$10,668	$899	$0	$1,735	$13,301	$24
2.6	Sorbent Storage & Feed	$1,030	$0	$389	$0	$1,419	$122	$0	$231	$1,772	$3
2.9	Coal & Sorbent Feed Foundation	$0	$642	$563	$0	$1,205	$112	$0	$198	$1,515	$3
	Subtotal	**$18,519**	**$1,012**	**$4,570**	**$0**	**$24,102**	**$2,047**	**$0**	**$3,922**	**$30,071**	**$55**
3	Feedwater & Miscellaneous BOP Systems										
3.1	Feedwater System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.2	Water Makeup & Pretreating	$7,735	$0	$2,447	$0	$10,181	$930	$0	$2,222	$13,334	$24
3.3	Other Feedwater Subsystems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.4	Service Water Systems	$1,549	$0	$811	$0	$2,360	$212	$0	$514	$3,086	$6
3.5	Other Boiler Plant Systems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.6	FO Supply Sys & Nat Gas	$335	$0	$391	$0	$726	$65	$0	$119	$910	$2
3.7	Waste Treatment Equipment	$3,458	$0	$2,002	$0	$5,460	$526	$0	$1,197	$7,182	$13
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,281	$0	$1,015	$0	$4,296	$408	$0	$941	$5,645	$10
	Subtotal	**$16,358**	**$0**	**$6,665**	**$0**	**$23,023**	**$2,141**	**$0**	**$4,993**	**$30,158**	**$55**
4	Boiler & Accessories										
4.1	CFB & Accessories	w/ BEC	$0	w/ BEC	$0	$297,103	$28,594	$0	$32,570	$358,268	$651
4.5	ASU/Oxidant Compression	$172,308	$0	$140,979	$0	$313,287	$30,367	$0	$34,365	$378,019	$687
	Flue Gas Cooler	$14,387	$0	$0	$0	$14,387	$1,338	$0	$2,302	$18,027	$33
	Flue Gas N2 Heater	$3,145	$0	$0	$0	$3,145	$292	$0	$503	$3,941	$7
	Subtotal	**$189,840**	**$0**	**$140,979**	**$0**	**$627,922**	**$60,592**	**$0**	**$69,740**	**$758,254**	**$1,378**
5A	Gas Cleanup & Piping										
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$10,502	$0	$6,619	$0	$17,121	$1,609	$0	$1,873	$20,603	$37
5A.4	Other Particulate Removal Materials	$718	$0	$763	$0	$1,482	$140	$0	$162	$1,784	$3
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$11,220**	**$0**	**$7,383**	**$0**	**$18,603**	**$1,749**	**$0**	**$2,035**	**$22,387**	**$41**

Exhibit 5-32 Case IC620 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case IC620				Estimate Type:			Conceptual		
	Plant Size (MW,net):	550 MWe				Cost Base:			Jun 2011		
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification & Compression Unit/System	$78,932	$0	$59,955	$0	$138,887	$12,935	$27,777	$35,920	$215,520	$392
	Subtotal	**$78,932**	**$0**	**$59,955**	**$0**	**$138,887**	**$12,935**	**$27,777**	**$35,920**	**$215,520**	**$392**
7		HRSG, Ducting, & Stack									
7.3	Ductwork	$10,286	$0	$6,493	$0	$16,778	$1,417	$0	$2,729	$20,925	$38
7.4	Stack	$3,620	$0	$2,104	$0	$5,724	$537	$0	$626	$6,887	$13
7.9	Duct & Stack Foundations	$0	$1,068	$1,268	$0	$2,336	$219	$0	$511	$3,065	$6
	Subtotal	**$13,906**	**$1,068**	**$9,864**	**$0**	**$24,837**	**$2,173**	**$0**	**$3,866**	**$30,877**	**$56**
8B		sCO_2 Power Cycle									
	Main CO_2 Compressor	$50,634	$0	$30,380	$0	$81,014	$7,534	$0	$12,962	$101,511	$185
	Bypass CO_2 Compressor	$18,835	$0	$11,301	$0	$30,136	$2,803	$0	$4,822	$37,760	$69
	High Temperature CO_2 Recuperator	$17,982	$0	$0	$0	$17,982	$1,672	$0	$2,877	$22,531	$41
	Low Temperature CO_2 Recuperator	$42,690	$0	$0	$0	$42,690	$3,970	$0	$6,830	$53,490	$97
	CO_2 Cooler	$6,616	$0	$2,029	$0	$8,646	$804	$0	$1,383	$10,833	$20
	CO_2 Turbine Section	$95,486	$0	$0	$0	$95,486	$8,880	$0	$15,278	$119,643	$218
	CO_2 System Piping	$10,357	$0	$3,107	$0	$13,464	$1,252	$0	$2,154	$16,871	$31
	CO_2 System Foundations	$0	$2,018	$3,332	$0	$5,350	$498	$0	$856	$6,703	$12
	Subtotal	**$242,600**	**$2,018**	**$50,149**	**$0**	**$294,767**	**$27,413**	**$0**	**$47,163**	**$369,343**	**$671**
9		Cooling Water System									
9.1	Cooling Towers	$13,359	$0	$4,132	$0	$17,490	$1,629	$0	$1,912	$21,032	$38
9.2	Circulating Water Pumps	$3,432	$0	$273	$0	$3,705	$316	$0	$402	$4,423	$8
9.3	Circ.Water System Auxiliaries	$891	$0	$118	$0	$1,009	$93	$0	$110	$1,213	$2
9.4	Circ.Water Piping	$0	$7,511	$6,802	$0	$14,313	$1,267	$0	$2,337	$17,916	$33
9.5	Make-up Water System	$735	$0	$945	$0	$1,680	$155	$0	$275	$2,110	$4
9.6	Component Cooling Water Sys	$727	$0	$558	$0	$1,285	$117	$0	$210	$1,612	$3
9.9	Circ.Water System Foundations & Structures	$0	$3,998	$6,638	$0	$10,636	$1,002	$0	$2,328	$13,965	$25
	Subtotal	**$19,144**	**$11,508**	**$19,465**	**$0**	**$50,117**	**$4,580**	**$0**	**$7,574**	**$62,272**	**$113**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	sory Electric Plant	$0	$5,089	$0	$5,089	$488	$0	$558	$6,135	$11
10.7	Ash Transport & Feed Equipment	ntation & Control	$0	$10,951	$0	$10,951	$1,009	$0	$1,196	$13,156	$24
10.9	Ash/Spent Sorbent Foundation	$0	$376	$462	$0	$838	$78	$0	$183	$1,099	$2
	Subtotal	**$0**	**$376**	**$16,502**	**$0**	**$16,878**	**$1,576**	**$0**	**$1,937**	**$20,390**	**$37**

Exhibit 5-32 Case IC620 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case IC620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
11		Accessory Electric Plant									
11.1	Generator Equipment	$2,179	$0	$348	$0	$2,527	$226	$0	$206	$2,960	$5
11.2	Station Service Equipment	$6,726	$0	$2,255	$0	$8,981	$835	$0	$736	$10,552	$19
11.3	Switchgear & Motor Control	$7,720	$0	$1,341	$0	$9,062	$838	$0	$990	$10,889	$20
11.4	Conduit & Cable Tray	$0	$5,294	$17,105	$0	$22,399	$2,091	$0	$3,673	$28,163	$51
11.5	Wire & Cable	$0	$10,081	$18,020	$0	$28,101	$2,257	$0	$4,554	$34,911	$63
11.6	Protective Equipment	$354	$0	$1,230	$0	$1,584	$152	$0	$174	$1,910	$3
11.7	Standby Equipment	$1,644	$0	$38	$0	$1,682	$154	$0	$184	$2,020	$4
11.8	Main Power Transformers	$16,089	$0	$231	$0	$16,320	$1,237	$0	$1,756	$19,313	$35
11.9	Electrical Foundations	$0	$412	$1,049	$0	$1,461	$138	$0	$320	$1,919	$3
	Subtotal	**$34,713**	**$15,787**	**$41,617**	**$0**	**$92,118**	**$7,928**	**$0**	**$12,593**	**$112,638**	**$205**
12		Instrumentation & Control									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$632	$0	$387	$0	$1,019	$95	$51	$175	$1,340	$2
12.7	Distributed Control System Equipment	$6,384	$0	$1,138	$0	$7,523	$695	$376	$859	$9,453	$17
12.8	Instrument Wiring & Tubing	$3,850	$0	$7,005	$0	$10,855	$879	$543	$1,841	$14,118	$26
12.9	Other I & C Equipment	$1,804	$0	$4,177	$0	$5,981	$571	$299	$685	$7,537	$14
	Subtotal	**$12,670**	**$0**	**$12,707**	**$0**	**$25,377**	**$2,241**	**$1,269**	**$3,561**	**$32,448**	**$59**
13		Improvements to Site									
13.1	Site Preparation	$0	$62	$1,324	$0	$1,386	$135	$0	$304	$1,825	$3
13.2	Site Improvements	$0	$2,066	$2,729	$0	$4,795	$476	$0	$1,054	$6,325	$11
13.3	Site Facilities	$3,702	$0	$3,883	$0	$7,585	$755	$0	$1,668	$10,008	$18
	Subtotal	**$3,702**	**$2,128**	**$7,936**	**$0**	**$13,766**	**$1,366**	**$0**	**$3,026**	**$18,158**	**$33**
14		Buildings & Structures									
14.1	Boiler Building	$0	$10,579	$9,297	$0	$19,876	$1,749	$0	$3,244	$24,869	$45
14.2	Turbine Building	$0	$15,287	$14,238	$0	$29,525	$2,605	$0	$4,820	$36,950	$67
14.3	Administration Building	$0	$767	$811	$0	$1,578	$140	$0	$258	$1,975	$4
14.4	Circulation Water Pumphouse	$0	$226	$180	$0	$406	$36	$0	$66	$507	$1
14.5	Water Treatment Buildings	$0	$971	$885	$0	$1,856	$164	$0	$303	$2,323	$4
14.6	Machine Shop	$0	$513	$344	$0	$857	$74	$0	$140	$1,072	$2
14.7	Warehouse	$0	$348	$348	$0	$696	$62	$0	$114	$871	$2
14.8	Other Buildings & Structures	$0	$284	$242	$0	$526	$46	$0	$86	$658	$1
14.9	Waste Treating Building & Str.	$0	$541	$1,641	$0	$2,183	$203	$0	$358	$2,744	$5
	Subtotal	**$0**	**$29,517**	**$27,986**	**$0**	**$57,503**	**$5,078**	**$0**	**$9,387**	**$71,969**	**$131**
	Total	**$666,376**	**$69,502**	**$419,708**	**$0**	**$1,452,689**	**$135,738**	**$29,046**	**$213,024**	**$1,830,497**	**$3,328**

Exhibit 5-33 Case IC620 owner's costs

Owner's Costs		
Description	**$1,000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$11,929	$21.68
1-Month Maintenance Materials	$1,721	$3
1-Month Non-fuel Consumables	$2,027	$4
1-Month Waste Disposal	$1,746	$3
25% of 1-Month Fuel Cost at 100% CF	$2,994	$5
2% of TPC	$36,610	$67
Total	**$57,027**	**$104**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$27,388	$50
0.5% of TPC (spare parts)	$9,152	$17
Total	**$36,540**	**$66**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$274,575	$499
Financing Costs	$49,423	$90
Total Overnight Costs (TOC)	**$2,248,962**	**$4,088**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,563,817**	**$4,661**

Exhibit 5-34 Case IC620 initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	sCO2 – Case IC620				**Cost Base:**	Jun 2011
Plant Size (MW,net):	**550**		**Heat Rate-net (Btu/kWh):**	9,665	**Capacity Factor (%):**	85
Operating & Maintenance Labor						
Operating Labor				**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		39.70	**$/hour**		**1 unit/mod.**	**Total Plant**
Operating Labor Burden:		30.00	**% of base**	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	**% of labor**	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**($/kW-net)**
Annual Operating Labor:					$7,384,208	$13.424
Maintenance Labor:					$11,723,180	$21.312
Administrative & Support Labor:					$4,776,847	$8.684
Property Taxes and Insurance:					$36,609,948	$66.553
Total:					**$60,494,183**	**$109.973**
Variable Operating Costs						
					($)	**($/kWh-net)**
Maintenance Material:					$17,703,901	$0.00432
Consumables						
	Consumption		**Cost ($)**			
	Initial Fill	**Per Day**	**Per Unit**	**Initial Fill**		
Water (/1000 gallons):	0	6,323	$1.67	$0	$3,283,695	$0.00080
Makeup and Waste Water Treatment Chemicals (lbs):	0	30,606	$0.27	$0	$2,543,229	$0.00062
Limestone (ton)	0	1,314	$33.48	$0	$13,649,916	$0.00333
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,426	$1.63	$0	$719,209	$0.00018
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$20,196,050**	**$0.00493**
Waste Disposal						
Fly Ash (ton)	0	50	$25.11	$0	$392,756	$0.00010
Bottom Ash (ton)	0	2,127	$25.11	$0	$16,571,783	$0.00405
Subtotal:				**$0**	**$16,964,538**	**$0.00414**
By-Products						
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$54,864,490**	**$0.01339**
Fuel Cost						
Illinois Number 6 (ton):	0	5,466	$68.60	$0	$116,333,698	$0.02840
Total:				**$0**	**$116,333,698**	**$0.02840**

Exhibit 5-35 Case IC620 COE breakdown

Case	IC620
Cost	
TPC (2011$/kW)	3,328
TOC (2011$/kW)	4,088
COE (2011$/MWh) (excluding T&S)	124.65
Capital	68.09
Fixed O&M	14.77
Variable O&M	13.39
Fuel	28.40
T&S	8.17
COE (2011$/MWh) (including T&S)	132.82

5.5.2 Case IC760 Cost Estimate Results

Exhibit 5-36 shows a detailed breakdown of the capital costs; Exhibit 5-37 shows the owner's costs, TOC, and TASC; Exhibit 5-38 shows the initial and annual O&M costs. Exhibit 5-39 shows the COE results for Case IC760 using high-risk financing.

Exhibit 5-36 Case IC760 total plant cost details

Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
	Total Plant Cost Summary										
	Case:	sCO2 – Case IC760				Estimate Type:			Conceptual		
	Plant Size (MW,net):	550 MWe				Cost Base:			Jun 2011		
		$1,000									
1	Coal & Sorbent Handling										
1.1	Coal Receive & Unload	$4,049	$0	$1,824	$0	$5,874	$509	$0	$957	$7,340	$13
1.2	Coal Stackout & Reclaim	$5,233	$0	$1,169	$0	$6,403	$542	$0	$1,042	$7,987	$15
1.3	Coal Conveyors	$4,866	$0	$1,157	$0	$6,023	$511	$0	$980	$7,514	$14
1.4	Other Coal Handling	$1,273	$0	$268	$0	$1,541	$130	$0	$251	$1,922	$3
1.5	Sorbent Receive & Unload	$285	$0	$85	$0	$370	$32	$0	$60	$462	$1
1.6	Sorbent Stackout & Reclaim	$4,609	$0	$833	$0	$5,442	$459	$0	$885	$6,786	$12
1.7	Sorbent Conveyors	$1,645	$357	$398	$0	$2,400	$201	$0	$390	$2,990	$5
1.8	Other Sorbent Handling	$993	$234	$514	$0	$1,741	$149	$0	$284	$2,174	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$5,053	$6,663	$0	$11,716	$1,099	$0	$1,922	$14,737	$27
	Subtotal	**$22,954**	**$5,644**	**$12,911**	**$0**	**$41,509**	**$3,632**	**$0**	**$6,771**	**$51,912**	**$94**
2	Coal & Sorbent Prep & Feed										
2.1	Coal Crushing & Drying	$2,318	$0	$445	$0	$2,763	$233	$0	$449	$3,446	$6
2.2	Coal Conveyor to Storage	$5,935	$0	$1,278	$0	$7,212	$610	$0	$1,173	$8,996	$16
2.5	Sorbent Prep Equipment	$7,897	$342	$1,618	$0	$9,856	$830	$0	$1,603	$12,289	$22
2.6	Sorbent Storage & Feed	$951	$0	$359	$0	$1,311	$113	$0	$214	$1,637	$3
2.9	Coal & Sorbent Feed Foundation	$0	$593	$520	$0	$1,113	$103	$0	$183	$1,399	$3
	Subtotal	**$17,101**	**$935**	**$4,221**	**$0**	**$22,256**	**$1,890**	**$0**	**$3,622**	**$27,768**	**$50**
3	Feedwater & Miscellaneous BOP Systems										
3.1	Feedwater System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.2	Water Makeup & Pretreating	$6,719	$0	$2,125	$0	$8,844	$808	$0	$1,930	$11,582	$21
3.3	Other Feedwater Subsystems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.4	Service Water Systems	$1,345	$0	$704	$0	$2,050	$184	$0	$447	$2,680	$5
3.5	Other Boiler Plant Systems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.6	FO Supply Sys & Nat Gas	$325	$0	$379	$0	$704	$63	$0	$115	$883	$2
3.7	Waste Treatment Equipment	$3,004	$0	$1,739	$0	$4,742	$456	$0	$1,040	$6,239	$11
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,183	$0	$985	$0	$4,167	$396	$0	$913	$5,476	$10
	Subtotal	**$14,575**	**$0**	**$5,932**	**$0**	**$20,507**	**$1,908**	**$0**	**$4,445**	**$26,860**	**$49**
4	Boiler & Accessories										
4.1	CFB & Accessories	w/ BEC	$0	w/ BEC	$0	$324,180	$31,200	$0	$35,538	$390,918	$711
4.5	ASU/Oxidant Compression	$158,235	$0	$129,465	$0	$287,700	$27,887	$0	$31,559	$347,145	$631
	Flue Gas Cooler	$13,211	$0	$0	$0	$13,211	$1,229	$0	$2,114	$16,554	$30
	Flue Gas N2 Heater	$2,785	$0	$0	$0	$2,785	$259	$0	$446	$3,489	$6
	Subtotal	**$174,231**	**$0**	**$129,465**	**$0**	**$627,876**	**$60,575**	**$0**	**$69,656**	**$758,107**	**$1,378**
5A	Gas Cleanup & Piping										
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$9,551	$0	$6,020	$0	$15,570	$1,463	$0	$1,703	$18,737	$34
5A.4	Other Particulate Removal Materials	$654	$0	$695	$0	$1,349	$128	$0	$148	$1,625	$3
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$10,205**	**$0**	**$6,715**	**$0**	**$16,920**	**$1,591**	**$0**	**$1,851**	**$20,362**	**$37**

Exhibit 5-36 Case IC760 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case IC760				Estimate Type:			Conceptual		
	Plant Size (MW,net):	550 MWe				Cost Base:			Jun 2011		
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification & Compression Unit/System	$71,608	$0	$54,393	$0	$126,001	$11,735	$25,200	$32,587	$195,523	$355
	Subtotal	**$71,608**	**$0**	**$54,393**	**$0**	**$126,001**	**$11,735**	**$25,200**	**$32,587**	**$195,523**	**$355**
7		HRSG, Ducting, & Stack									
7.3	Ductwork	$9,821	$0	$6,199	$0	$16,020	$1,353	$0	$2,606	$19,979	$36
7.4	Stack	$3,415	$0	$1,984	$0	$5,399	$507	$0	$591	$6,496	$12
7.9	Duct & Stack Foundations	$0	$1,050	$1,246	$0	$2,296	$215	$0	$502	$3,013	$5
	Subtotal	**$13,235**	**$1,050**	**$9,430**	**$0**	**$23,715**	**$2,075**	**$0**	**$3,699**	**$29,488**	**$54**
8B		sCO_2 Power Cycle									
	Main CO_2 Compressor	$38,804	$0	$23,283	$0	$62,087	$5,774	$0	$9,934	$77,795	$141
	Bypass CO_2 Compressor	$12,943	$0	$7,766	$0	$20,708	$1,926	$0	$3,313	$25,948	$47
	High Temperature CO_2 Recuperator	$19,006	$0	$0	$0	$19,006	$1,768	$0	$3,041	$23,814	$43
	Low Temperature CO_2 Recuperator	$33,879	$0	$0	$0	$33,879	$3,151	$0	$5,421	$42,451	$77
	CO_2 Cooler	$5,287	$0	$1,622	$0	$6,909	$643	$0	$1,105	$8,657	$16
	CO_2 Turbine Section	$97,517	$0	$0	$0	$97,517	$9,069	$0	$15,603	$122,189	$222
	CO_2 System Piping	$25,599	$0	$7,680	$0	$33,279	$3,095	$0	$5,325	$41,699	$76
	CO_2 System Foundations	$0	$1,882	$3,108	$0	$4,990	$464	$0	$798	$6,252	$11
	Subtotal	**$233,036**	**$1,882**	**$43,457**	**$0**	**$278,375**	**$25,889**	**$0**	**$44,540**	**$348,804**	**$634**
9		Cooling Water System									
9.1	Cooling Towers	$11,627	$0	$3,596	$0	$15,222	$1,418	$0	$1,664	$18,304	$33
9.2	Circulating Water Pumps	$2,893	$0	$230	$0	$3,124	$266	$0	$339	$3,729	$7
9.3	Circ.Water System Auxiliaries	$784	$0	$104	$0	$887	$82	$0	$97	$1,066	$2
9.4	Circ.Water Piping	$0	$6,602	$5,979	$0	$12,581	$1,114	$0	$2,054	$15,749	$29
9.5	Make-up Water System	$653	$0	$839	$0	$1,491	$138	$0	$244	$1,873	$3
9.6	Component Cooling Water Sys	$639	$0	$490	$0	$1,129	$103	$0	$185	$1,417	$3
9.9	Circ.Water System Foundations & Structures	$0	$3,549	$5,893	$0	$9,442	$890	$0	$2,066	$12,398	$23
	Subtotal	**$16,595**	**$10,151**	**$17,131**	**$0**	**$43,877**	**$4,011**	**$0**	**$6,650**	**$54,537**	**$99**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	$1,554	$0	$4,756	$0	$6,310	$605	$0	$692	$7,607	$14
10.7	Ash Transport & Feed Equipment	$10,324	$0	$10,235	$0	$20,560	$1,894	$0	$2,245	$24,699	$45
10.9	Ash/Spent Sorbent Foundation	$0	$351	$432	$0	$783	$73	$0	$171	$1,027	$2
	Subtotal	**$11,879**	**$351**	**$15,423**	**$0**	**$27,653**	**$2,573**	**$0**	**$3,108**	**$33,334**	**$61**

Exhibit 5-36 Case IC760 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case IC760					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
11		Accessory Electric Plant									
11.1	Generator Equipment	$2,147	$0	$343	$0	$2,491	$223	$0	$204	$2,917	$5
11.2	Station Service Equipment	$6,379	$0	$2,139	$0	$8,518	$792	$0	$698	$10,008	$18
11.3	Switchgear & Motor Control	$7,322	$0	$1,272	$0	$8,594	$795	$0	$939	$10,327	$19
11.4	Conduit & Cable Tray	$0	$5,021	$16,222	$0	$21,243	$1,983	$0	$3,484	$26,710	$49
11.5	Wire & Cable	$0	$9,561	$17,090	$0	$26,650	$2,140	$0	$4,319	$33,109	$60
11.6	Protective Equipment	$336	$0	$1,166	$0	$1,503	$144	$0	$165	$1,811	$3
11.7	Standby Equipment	$1,625	$0	$38	$0	$1,663	$152	$0	$182	$1,997	$4
11.8	Main Power Transformers	$16,089	$0	$231	$0	$16,320	$1,237	$0	$1,756	$19,313	$35
11.9	Electrical Foundations	$0	$405	$1,030	$0	$1,435	$136	$0	$314	$1,885	$3
	Subtotal	**$33,899**	**$14,986**	**$39,531**	**$0**	**$88,416**	**$7,602**	**$0**	**$12,059**	**$108,077**	**$196**
12		Instrumentation & Control									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$622	$0	$380	$0	$1,003	$94	$50	$172	$1,319	$2
12.7	Distributed Control System Equipment	$6,283	$0	$1,120	$0	$7,403	$684	$370	$846	$9,303	$17
12.8	Instrument Wiring & Tubing	$3,788	$0	$6,894	$0	$10,682	$865	$534	$1,812	$13,894	$25
12.9	Other I & C Equipment	$1,775	$0	$4,111	$0	$5,886	$562	$294	$674	$7,417	$13
	Subtotal	**$12,469**	**$0**	**$12,505**	**$0**	**$24,974**	**$2,205**	**$1,249**	**$3,504**	**$31,932**	**$58**
13		Improvements to Site									
13.1	Site Preparation	$0	$62	$1,316	$0	$1,378	$134	$0	$302	$1,815	$3
13.2	Site Improvements	$0	$2,054	$2,713	$0	$4,767	$473	$0	$1,048	$6,288	$11
13.3	Site Facilities	$3,680	$0	$3,861	$0	$7,541	$751	$0	$1,658	$9,950	$18
	Subtotal	**$3,680**	**$2,116**	**$7,891**	**$0**	**$13,687**	**$1,358**	**$0**	**$3,009**	**$18,054**	**$33**
14		Buildings & Structures									
14.1	Boiler Building	$0	$10,564	$9,284	$0	$19,847	$1,746	$0	$3,239	$24,833	$45
14.2	Turbine Building	$0	$15,252	$14,205	$0	$29,457	$2,599	$0	$4,808	$36,865	$67
14.3	Administration Building	$0	$765	$808	$0	$1,573	$140	$0	$257	$1,970	$4
14.4	Circulation Water Pumphouse	$0	$201	$159	$0	$360	$32	$0	$59	$450	$1
14.5	Water Treatment Buildings	$0	$852	$776	$0	$1,629	$144	$0	$266	$2,038	$4
14.6	Machine Shop	$0	$512	$343	$0	$855	$74	$0	$139	$1,069	$2
14.7	Warehouse	$0	$347	$347	$0	$694	$61	$0	$113	$869	$2
14.8	Other Buildings & Structures	$0	$283	$241	$0	$524	$46	$0	$86	$656	$1
14.9	Waste Treating Building & Str.	$0	$534	$1,619	$0	$2,153	$200	$0	$353	$2,706	$5
	Subtotal	**$0**	**$29,309**	**$27,784**	**$0**	**$57,092**	**$5,042**	**$0**	**$9,320**	**$71,455**	**$130**
	Total	**$635,467**	**$66,424**	**$386,787**	**$0**	**$1,412,858**	**$132,085**	**$26,449**	**$204,821**	**$1,776,212**	**$3,229**

Exhibit 5-37 Case IC760 owner's costs

Owner's Costs		
Description	**$1,000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$11,929	$21.68
1-Month Maintenance Materials	$1,721	$3
1-Month Non-fuel Consumables	$2,027	$4
1-Month Waste Disposal	$1,746	$3
25% of 1-Month Fuel Cost at 100% CF	$2,994	$5
2% of TPC	$35,524	$65
Total	**$55,941**	**$102**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$27,388	$50
0.5% of TPC (spare parts)	$8,881	$16
Total	**$36,269**	**$66**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$266,432	$484
Financing Costs	$47,958	$87
Total Overnight Costs (TOC)	**$2,183,712**	**$3,969**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,489,431**	**$4,525**

Exhibit 5-38 Case IC760 initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	sCO2 – Case IC760				**Cost Base:**	Jun 2011
Plant Size (MW,net):	**550**		**Heat Rate-net (Btu/kWh):**	8,557	**Capacity Factor (%):**	85
Operating & Maintenance Labor						
	Operating Labor			**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		39.70	**$/hour**		**1 unit/mod.**	**Total Plant**
Operating Labor Burden:		30.00	**% of base**	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	**% of labor**	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**($/kW-net)**
Annual Operating Labor:					$7,384,208	$13.423
Maintenance Labor:					$11,401,742	$20.726
Administrative & Support Labor:					$4,696,487	$8.537
Property Taxes and Insurance:					$35,524,246	$64.574
Total:					**$59,006,683**	**$107.260**
Variable Operating Costs						
					($)	**($/kWh-net)**
Maintenance Material:					$17,178,875	$0.00419
			Consumables			
	Consumption		**Cost ($)**			
	Initial Fill	**Per Day**	**Per Unit**	**Initial Fill**		
Water (/1000 gallons):	0	5,185	$1.67	$0	$2,692,773	$0.00066
Makeup and Waste Water Treatment Chemicals (lbs):	0	25,098	$0.27	$0	$2,085,559	$0.00051
Limestone (ton)	0	1,164	$33.48	$0	$12,085,645	$0.00295
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,263	$1.63	$0	$636,788	$0.00016
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$17,500,766**	**$0.00427**
			Waste Disposal			
Fly Ash (ton)	0	45	$25.11	$0	$347,746	$0.00008
Bottom Ash (ton)	0	1,883	$25.11	$0	$14,672,667	$0.00358
Subtotal:				**$0**	**$15,020,413**	**$0.00367**
			By-Products			
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$49,700,055**	**$0.01213**
Fuel Cost						
Illinois Number 6 (ton):	0	4,840	$68.60	$0	$103,001,933	$0.02515
Total:				**$0**	**$103,001,933**	**$0.02515**

Exhibit 5-39 shows the COE results for Case IC760 using high-risk financing. The COE result for Case IC620 is shown for comparison purposes, and uses high-risk financing assumptions.

Exhibit 5-39 Case IC760 COE breakdown

Case	IC620	IC760
Cost		
TPC (2011$/kW)	3,328	3,229
TOC (2011$/kW)	4,088	3,969
COE (2011$/MWh) (excluding T&S)	124.65	117.79
Capital	68.09	66.10
Fixed O&M	14.77	14.41
Variable O&M	13.39	12.13
Fuel	28.40	25.15
T&S	8.17	7.23
COE (2011$/MWh) (including T&S)	132.82	125.02

5.5.3 Comparison of Cost Estimate Results Between Reference Rankine Cases and Intercooled sCO_2 Cases

Exhibit 5-40 shows the TPC (1,000 2011$) for the reference Rankine case and the Intercooling cases at two different TITs. The TPC for Case IC620 is 1 percent greater than the reference SC Rankine plant and Case IC760 is 3 percent lower than the reference AUSC Rankine plant. In this case the effect of higher process efficiency dominates the impact on TPC. Unlike the reheat cases, there is a reduction in TPC for the sCO_2 cases compared to the Baseline cases at both TITs.

Exhibit 5-40 TPC (1,000 2011$) for Intercooling cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case IC620	Case IC760
Coal & Sorbent Handling	57,740	54,500	56,013	51,912
Coal & Sorbent Prep & Feed	31,040	29,215	30,071	27,768
Feedwater & Misc. BOP Systems	104,134	88,757	30,158	26,860
CFB, ASU, FG Cooling, CO_2 Recycle	464,234	533,106	380,235	410,961
O_2 Generation	375,525	352,052	378,019	347,145
FG Treatment	21,093	19,630	22,387	20,362
FG Recycle	28,356	27,411	30,877	29,488
CO_2 Purification & Compression	224,111	208,172	215,520	195,523
Steam Turbine Generator	173,036	201,497	---	---

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case IC620	Case IC760
sCO_2 Cycle	---	---	369,343	348,804
Cooling Water Systems	60,572	55,117	62,272	54,537
Ash Removal	36,652	34,825	20,390	33,334
Accessory Electric Plant	115,848	112,119	112,638	108,077
Instrumentation & Controls	32,776	32,378	32,448	31,932
Site Preparation & Improvements	18,152	18,213	18,158	18,054
Buildings & Structures	71,808	71,626	71,969	71,455
Totals	**1,815,076**	**1,838,618**	**1,830,497**	**1,776,212**

Exhibit 5-41 shows the detailed TPC (1,000 2011$) for the sCO_2 power cycle for the reference Rankine case and the Intercooling cases at two different TITs. Compared to the Baseline cases, the TPC of the sCO_2 cycle account decreases significantly for both TITs. Apart from the main CO_2 compressor and the CO_2 cooler (which includes the intercooler cost), all the sub-account TPCs are lower in the Intercooling case than in the corresponding Baseline case. This is due both to an increase in cycle efficiency, as well as an increase in cycle specific power for the intercooled cases. Increasing specific power requires less sCO_2 cycle mass flow for a comparable power output, thereby reducing sCO_2 cycle size and cost.

Exhibit 5-41 TPC (1,000 2011$) for sCO_2 power cycle for Intercooling cases

Parameter	Reference Rankine	Case IC620	Case IC760
Main CO_2 Compressor	---	101,511	77,795
Bypass CO_2 Compressor	---	37,760	25,948
High-Temperature CO_2 Recuperator	---	22,531	23,814
Low-Temperature CO_2 Recuperator	---	53,490	42,451
CO_2 Cooler	---	10,833	8,657
CO_2 Turbine Section	---	119,643	122,189
CO_2 System Piping	---	16,871	41,699
CO_2 System Foundations	---	6,703	6,252
Subtotal	**---**	**369,343**	**348,804**

Exhibit 5-42 shows the detailed TPC (1,000 2011$) for the CFB and accessories section for the reference Rankine case and the Intercooling cases at two different TITs. There is little difference in the CFB TPC for both sCO_2 cases compared to the Baseline cases.

While the ASU costs decrease compared to the Baseline cases due to the increase in process efficiency, the impact is less than in the Reheat cases because the increase in process efficiency is less.

Exhibit 5-42 TPC (1,000 2011$) for sCO_2 CFB section for Intercooling cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case IC620	Case IC760
CFB & Accessories	464,234	533,106	358,268	390,918
ASU/Oxidant Compression	375,525	352,052	378,019	347,145
Flue Gas Cooler	w/CFB	w/CFB	18,027	16,554
Water Knockout	w/CFB	w/CFB	3,941	3,489
Subtotal	**839,758**	**885,158**	**758,254**	**758,108**

Exhibit 5-43 shows the O&M cost, owner's cost, and COE for the reference Rankine case and the Intercooling cases at two different TITs. Most of the trends in the results are similar to those observed in the reheat cases; however, with the intercooling cases, a significant reduction in COE was attained at both TITs.

Exhibit 5-43 O&M costs, owner's costs, and COE for Intercooling cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case IC620	Case IC760
O&M Costs ($1,000/yr)				
Total Fixed O&M	60,159	60,866	60,494	59,007
Total Variable O&M	56,041	52,643	54,864	49,700
Total Fuel	122,152	111,392	116,334	103,002
Total Annual O&M Costs	238,352	224,901	231,692	211,709
Owner's Cost ($1,000)				
Total Owner's Costs	415,350	417,192	418,465	407,499
Total Overnight Cost (TOC, $1,000)				
Total Overnight Cost	2,230,425	2,255,810	2,248,962	2,183,712
COE ($/MWh)				
First-Year COE without T&S	**125.72**	**123.22**	**124.65**	**117.79**
First-Year COE with T&S	**134.30**	**131.05**	**132.82**	**125.02**

5.6 Recompression Cycle with Combination of Reheat and Intercooling

5.6.1 Case RhtIC620 Cost Estimate Results

Exhibit 5-44 shows a detailed breakdown of the capital costs; Exhibit 5-45 shows the owner's costs, TOC, and TASC; Exhibit 5-46 shows the initial and annual O&M costs. Exhibit 5-47 shows the COE results for Case RhtIC620 using high-risk financing.

Exhibit 5-44 Case RhtIC620 total plant cost details

Total Plant Cost Summary											
	Case:	sCO2 – Case RhtIC620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
1		Coal & Sorbent Handling									
1.1	Coal Receive & Unload	$4,256	$0	$1,917	$0	$6,173	$535	$0	$1,006	$7,715	$14
1.2	Coal Stackout & Reclaim	$5,500	$0	$1,229	$0	$6,729	$570	$0	$1,095	$8,394	$15
1.3	Coal Conveyors	$5,114	$0	$1,216	$0	$6,330	$537	$0	$1,030	$7,897	$14
1.4	Other Coal Handling	$1,338	$0	$281	$0	$1,619	$137	$0	$263	$2,020	$4
1.5	Sorbent Receive & Unload	$300	$0	$89	$0	$390	$33	$0	$63	$486	$1
1.6	Sorbent Stackout & Reclaim	$4,852	$0	$877	$0	$5,729	$483	$0	$932	$7,144	$13
1.7	Sorbent Conveyors	$1,731	$376	$419	$0	$2,526	$211	$0	$411	$3,148	$6
1.8	Other Sorbent Handling	$1,046	$246	$541	$0	$1,833	$157	$0	$298	$2,288	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$5,311	$7,003	$0	$12,314	$1,155	$0	$2,020	$15,488	$28
	Subtotal	**$24,138**	**$5,933**	**$13,572**	**$0**	**$43,643**	**$3,818**	**$0**	**$7,119**	**$54,581**	**$99**
2		Coal & Sorbent Prep & Feed									
2.1	Coal Crushing & Drying	$2,444	$0	$470	$0	$2,914	$246	$0	$474	$3,634	$7
2.2	Coal Conveyor to Storage	$6,258	$0	$1,347	$0	$7,605	$644	$0	$1,237	$9,486	$17
2.5	Sorbent Prep Equipment	$8,320	$360	$1,704	$0	$10,384	$875	$0	$1,689	$12,948	$24
2.6	Sorbent Storage & Feed	$1,002	$0	$379	$0	$1,381	$119	$0	$225	$1,725	$3
2.9	Coal & Sorbent Feed Foundation	$0	$625	$548	$0	$1,173	$109	$0	$192	$1,474	$3
	Subtotal	**$18,023**	**$985**	**$4,448**	**$0**	**$23,456**	**$1,992**	**$0**	**$3,817**	**$29,266**	**$53**
3		Feedwater & Miscellaneous BOP Systems									
3.1	Feedwater System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.2	Water Makeup & Pretreating	$7,386	$0	$2,336	$0	$9,723	$888	$0	$2,122	$12,733	$23
3.3	Other Feedwater Subsystems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.4	Service Water Systems	$1,479	$0	$774	$0	$2,253	$202	$0	$491	$2,947	$5
3.5	Other Boiler Plant Systems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.6	FO Supply Sys & Nat Gas	$331	$0	$387	$0	$719	$64	$0	$117	$900	$2
3.7	Waste Treatment Equipment	$3,302	$0	$1,912	$0	$5,214	$502	$0	$1,143	$6,859	$12
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,247	$0	$1,004	$0	$4,252	$404	$0	$931	$5,587	$10
	Subtotal	**$15,747**	**$0**	**$6,414**	**$0**	**$22,160**	**$2,061**	**$0**	**$4,805**	**$29,027**	**$53**
4		Boiler & Accessories									
4.1	CFB & Accessories	w/ BEC	$0	w/ BEC	$0	$284,558	$27,387	$0	$31,195	$343,140	$624
4.5	ASU/Oxidant Compression	$167,379	$0	$136,946	$0	$304,325	$29,498	$0	$33,382	$367,205	$668
	Flue Gas Cooler	$14,001	$0	$0	$0	$14,001	$1,302	$0	$2,240	$17,544	$32
	Flue Gas N2 Heater	$2,930	$0	$0	$0	$2,930	$272	$0	$469	$3,671	$7
	Subtotal	**$184,309**	**$0**	**$136,946**	**$0**	**$605,814**	**$58,460**	**$0**	**$67,286**	**$731,559**	**$1,330**
5A		Gas Cleanup & Piping									
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$10,193	$0	$6,424	$0	$16,617	$1,562	$0	$1,818	$19,997	$36
5A.4	Other Particulate Removal Materials	$698	$0	$741	$0	$1,439	$136	$0	$158	$1,733	$3
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$10,890**	**$0**	**$7,166**	**$0**	**$18,056**	**$1,698**	**$0**	**$1,975**	**$21,729**	**$40**

Exhibit 5-44 Case RhtIC620 total plant cost details (continued)

Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
Total Plant Cost Summary											
	Case:	sCO2 – Case RhtIC620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
		$1,000									
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification & Compression Unit/System	$76,356	$0	$57,999	$0	$134,356	$12,513	$26,871	$34,748	$208,488	$379
	Subtotal	**$76,356**	**$0**	**$57,999**	**$0**	**$134,356**	**$12,513**	**$26,871**	**$34,748**	**$208,488**	**$379**
7		HRSG, Ducting, & Stack									
7.3	Ductwork	$10,125	$0	$6,391	$0	$16,516	$1,395	$0	$2,687	$20,598	$37
7.4	Stack	$3,549	$0	$2,062	$0	$5,611	$527	$0	$614	$6,752	$12
7.9	Duct & Stack Foundations	$0	$1,062	$1,261	$0	$2,322	$217	$0	$508	$3,047	$6
	Subtotal	**$13,673**	**$1,062**	**$9,714**	**$0**	**$24,449**	**$2,139**	**$0**	**$3,808**	**$30,396**	**$55**
8B		sCO_2 Power Cycle									
	Main CO_2 Compressor	$43,667	$0	$26,200	$0	$69,866	$6,498	$0	$11,179	$87,543	$159
	Bypass CO_2 Compressor	$18,399	$0	$11,039	$0	$29,438	$2,738	$0	$4,710	$36,886	$67
	High Temperature CO_2 Recuperator	$33,506	$0	$0	$0	$33,506	$3,116	$0	$5,361	$41,983	$76
	Low Temperature CO_2 Recuperator	$39,688	$0	$0	$0	$39,688	$3,691	$0	$6,350	$49,729	$90
	CO_2 Cooler	$6,135	$0	$1,882	$0	$8,017	$746	$0	$1,283	$10,045	$18
	CO_2 Turbine Section	$102,750	$0	$0	$0	$102,750	$9,556	$0	$16,440	$128,745	$234
	CO_2 System Piping	$20,858	$0	$6,257	$0	$27,116	$2,522	$0	$4,339	$33,976	$62
	CO_2 System Foundations	$0	$1,977	$3,264	$0	$5,240	$487	$0	$838	$6,566	$12
	Subtotal	**$265,003**	**$1,977**	**$48,642**	**$0**	**$315,621**	**$29,353**	**$0**	**$50,499**	**$395,473**	**$719**
9		Cooling Water System									
9.1	Cooling Towers	$12,765	$0	$3,948	$0	$16,713	$1,557	$0	$1,827	$20,097	$37
9.2	Circulating Water Pumps	$3,245	$0	$258	$0	$3,504	$299	$0	$380	$4,183	$8
9.3	Circ.Water System Auxiliaries	$855	$0	$113	$0	$968	$90	$0	$106	$1,163	$2
9.4	Circ.Water Piping	$0	$7,200	$6,521	$0	$13,721	$1,215	$0	$2,240	$17,176	$31
9.5	Make-up Water System	$707	$0	$909	$0	$1,616	$149	$0	$265	$2,029	$4
9.6	Component Cooling Water Sys	$697	$0	$535	$0	$1,232	$112	$0	$202	$1,546	$3
9.9	Circ.Water System Foundations & Structures	$0	$3,845	$6,385	$0	$10,229	$964	$0	$2,239	$13,432	$24
	Subtotal	**$18,269**	**$11,045**	**$18,668**	**$0**	**$47,982**	**$4,385**	**$0**	**$7,258**	**$59,626**	**$108**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	$1,626	$0	$4,974	$0	$6,600	$633	$0	$723	$7,956	$14
10.7	Ash Transport & Feed Equipment	$10,798	$0	$10,705	$0	$21,503	$1,981	$0	$2,348	$25,832	$47
10.9	Ash/Spent Sorbent Foundation	$0	$367	$452	$0	$819	$77	$0	$179	$1,075	$2
	Subtotal	**$12,423**	**$367**	**$16,130**	**$0**	**$28,921**	**$2,691**	**$0**	**$3,251**	**$34,862**	**$63**

Exhibit 5-44 Case RhtIC620 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case RhtIC620					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies		Total Plant Cost	
				Direct	Indirect			Process	Project	$1,000	$/kW
		$1,000									
11		Accessory Electric Plant									
11.1	Generator Equipment	$2,168	$0	$347	$0	$2,514	$225	$0	$205	$2,945	$5
11.2	Station Service Equipment	$6,606	$0	$2,215	$0	$8,821	$820	$0	$723	$10,364	$19
11.3	Switchgear & Motor Control	$7,583	$0	$1,317	$0	$8,900	$823	$0	$972	$10,695	$19
11.4	Conduit & Cable Tray	$0	$5,200	$16,800	$0	$21,999	$2,053	$0	$3,608	$27,661	$50
11.5	Wire & Cable	$0	$9,901	$17,698	$0	$27,599	$2,216	$0	$4,472	$34,288	$62
11.6	Protective Equipment	$348	$0	$1,208	$0	$1,556	$149	$0	$171	$1,876	$3
11.7	Standby Equipment	$1,637	$0	$38	$0	$1,676	$153	$0	$183	$2,012	$4
11.8	Main Power Transformers	$16,089	$0	$231	$0	$16,320	$1,237	$0	$1,756	$19,313	$35
11.9	Electrical Foundations	$0	$410	$1,042	$0	$1,452	$137	$0	$318	$1,907	$3
	Subtotal	**$34,431**	**$15,510**	**$40,896**	**$0**	**$90,837**	**$7,815**	**$0**	**$12,408**	**$111,060**	**$202**
12		Instrumentation & Control									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$629	$0	$384	$0	$1,013	$95	$51	$174	$1,333	$2
12.7	Distributed Control System Equipment	$6,350	$0	$1,132	$0	$7,482	$691	$374	$855	$9,402	$17
12.8	Instrument Wiring & Tubing	$3,829	$0	$6,967	$0	$10,796	$875	$540	$1,831	$14,041	$26
12.9	Other I & C Equipment	$1,794	$0	$4,154	$0	$5,949	$568	$297	$681	$7,496	$14
	Subtotal	**$12,601**	**$0**	**$12,638**	**$0**	**$25,239**	**$2,229**	**$1,262**	**$3,541**	**$32,272**	**$59**
13		Improvements to Site									
13.1	Site Preparation	$0	$62	$1,324	$0	$1,386	$135	$0	$304	$1,825	$3
13.2	Site Improvements	$0	$2,065	$2,729	$0	$4,794	$476	$0	$1,054	$6,324	$11
13.3	Site Facilities	$3,701	$0	$3,883	$0	$7,584	$755	$0	$1,668	$10,007	$18
	Subtotal	**$3,701**	**$2,128**	**$7,935**	**$0**	**$13,764**	**$1,366**	**$0**	**$3,026**	**$18,156**	**$33**
14		Buildings & Structures									
14.1	Boiler Building	$0	$10,579	$9,297	$0	$19,875	$1,749	$0	$3,244	$24,868	$45
14.2	Turbine Building	$0	$15,287	$14,237	$0	$29,524	$2,605	$0	$4,819	$36,948	$67
14.3	Administration Building	$0	$767	$810	$0	$1,577	$140	$0	$258	$1,975	$4
14.4	Circulation Water Pumphouse	$0	$217	$173	$0	$390	$34	$0	$64	$488	$1
14.5	Water Treatment Buildings	$0	$931	$848	$0	$1,779	$157	$0	$290	$2,226	$4
14.6	Machine Shop	$0	$513	$344	$0	$857	$74	$0	$140	$1,072	$2
14.7	Warehouse	$0	$348	$348	$0	$696	$62	$0	$114	$871	$2
14.8	Other Buildings & Structures	$0	$284	$242	$0	$526	$46	$0	$86	$658	$1
14.9	Waste Treating Building & Str.	$0	$539	$1,634	$0	$2,173	$202	$0	$356	$2,731	$5
	Subtotal	**$0**	**$29,464**	**$27,934**	**$0**	**$57,398**	**$5,069**	**$0**	**$9,370**	**$71,837**	**$131**
	Total	**$689,566**	**$68,470**	**$409,102**	**$0**	**$1,451,696**	**$135,589**	**$28,133**	**$212,913**	**$1,828,331**	**$3,324**

Exhibit 5-45 Case RhtIC620 owner's costs

Owner's Costs		
Description	**$1,000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$11,929	$21.69
1-Month Maintenance Materials	$1,721	$3
1-Month Non-fuel Consumables	$2,027	$4
1-Month Waste Disposal	$1,746	$3
25% of 1-Month Fuel Cost at 100% CF	$2,994	$5
2% of TPC	$36,567	$66
Total	**$56,983**	**$104**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$27,388	$50
0.5% of TPC (spare parts)	$9,142	$17
Total	**$36,529**	**$66**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$274,250	$499
Financing Costs	$49,365	$90
Total Overnight Costs (TOC)	**$2,246,358**	**$4,084**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,560,848**	**$4,655**

Exhibit 5-46 Case RhtIC620 initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	sCO2 – Case RhtIC620				**Cost Base:**	Jun 2011
Plant Size (MW,net):	**550**		**Heat Rate-net (Btu/kWh):**	9,273	**Capacity Factor (%):**	85
Operating & Maintenance Labor						
Operating Labor				**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		39.70	**$/hour**		**1 unit/mod.**	**Total Plant**
Operating Labor Burden:		30.00	**% of base**	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	**% of labor**	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**($/kW-net)**
Annual Operating Labor:					$7,384,208	$13.424
Maintenance Labor:					$11,715,169	$21.297
Administrative & Support Labor:					$4,774,844	$8.680
Property Taxes and Insurance:					$36,566,617	$66.476
Total:					**$60,440,838**	**$109.878**
Variable Operating Costs						
					($)	**($/kWh-net)**
Maintenance Material:					$17,682,947	$0.00432
Consumables						
	Consumption		**Cost ($)**			
	Initial Fill	**Per Day**	**Per Unit**	**Initial Fill**		
Water (/1000 gallons):	0	5,925	$1.67	$0	$3,077,271	$0.00075
Makeup and Waste Water Treatment Chemicals (lbs):	0	28,682	$0.27	$0	$2,383,354	$0.00058
Limestone (ton)	0	1,261	$33.48	$0	$13,095,529	$0.00320
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,368	$1.63	$0	$689,999	$0.00017
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$19,246,153**	**$0.00470**
Waste Disposal						
Fly Ash (ton)	0	48	$25.11	$0	$376,804	$0.00009
Bottom Ash (ton)	0	2,041	$25.11	$0	$15,898,725	$0.00388
Subtotal:				**$0**	**$16,275,529**	**$0.00397**
By-Products						
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$53,204,629**	**$0.01299**
Fuel Cost						
Illinois Number 6 (ton):	0	5,244	$68.60	$0	$111,608,839	$0.02725
Total:				**$0**	**$111,608,839**	**$0.02725**

Exhibit 5-47 Case RhtIC620 COE breakdown

Case	RhtIC620
Cost	
TPC (2011$/kW)	3,324
TOC (2011$/kW)	4,084
COE (2011$/MWh) (excluding T&S)	123.00
Capital	68.01
Fixed O&M	14.76
Variable O&M	12.99
Fuel	27.25
T&S	7.84
COE (2011$/MWh) (including T&S)	130.84

5.6.2 Case RhtIC760 Cost Estimate Results

Exhibit 5-48 shows a detailed breakdown of the capital costs; Exhibit 5-49 shows the owner's costs, TOC, and TASC; Exhibit 5-50 shows the initial and annual O&M costs.

Exhibit 5-48 Case RhtIC760 total plant cost details

Total Plant Cost Summary											
	Case:	sCO2 – Case RhtIC760					**Estimate Type:**			Conceptual	
	Plant Size (MW,net):	**550 MWe**					**Cost Base:**			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
1		Coal & Sorbent Handling									
1.1	Coal Receive & Unload	$3,971	$0	$1,789	$0	$5,760	$499	$0	$939	$7,198	$13
1.2	Coal Stackout & Reclaim	$5,132	$0	$1,147	$0	$6,279	$532	$0	$1,022	$7,833	$14
1.3	Coal Conveyors	$4,772	$0	$1,135	$0	$5,906	$501	$0	$961	$7,369	$13
1.4	Other Coal Handling	$1,248	$0	$263	$0	$1,511	$128	$0	$246	$1,885	$3
1.5	Sorbent Receive & Unload	$280	$0	$83	$0	$363	$31	$0	$59	$453	$1
1.6	Sorbent Stackout & Reclaim	$4,517	$0	$816	$0	$5,334	$449	$0	$867	$6,651	$12
1.7	Sorbent Conveyors	$1,612	$350	$390	$0	$2,352	$197	$0	$382	$2,931	$5
1.8	Other Sorbent Handling	$974	$229	$504	$0	$1,706	$146	$0	$278	$2,130	$4
1.9	Coal & Sorbent Hnd.Foundations	$0	$4,956	$6,534	$0	$11,489	$1,077	$0	$1,885	$14,452	$26
	Subtotal	**$22,506**	**$5,535**	**$12,660**	**$0**	**$40,700**	**$3,561**	**$0**	**$6,639**	**$50,900**	**$93**
2		Coal & Sorbent Prep & Feed									
2.1	Coal Crushing & Drying	$2,270	$0	$436	$0	$2,707	$228	$0	$440	$3,375	$6
2.2	Coal Conveyor to Storage	$5,813	$0	$1,251	$0	$7,064	$598	$0	$1,149	$8,811	$16
2.5	Sorbent Prep Equipment	$7,737	$335	$1,585	$0	$9,657	$813	$0	$1,571	$12,041	$22
2.6	Sorbent Storage & Feed	$932	$0	$352	$0	$1,284	$111	$0	$209	$1,604	$3
2.9	Coal & Sorbent Feed Foundation	$0	$581	$510	$0	$1,091	$101	$0	$179	$1,371	$2
	Subtotal	**$16,752**	**$916**	**$4,135**	**$0**	**$21,802**	**$1,852**	**$0**	**$3,548**	**$27,202**	**$49**
3		Feedwater & Miscellaneous BOP Systems									
3.1	Feedwater System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.2	Water Makeup & Pretreating	$6,467	$0	$2,046	$0	$8,513	$778	$0	$1,858	$11,149	$20
3.3	Other Feedwater Subsystems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.4	Service Water Systems	$1,295	$0	$678	$0	$1,973	$177	$0	$430	$2,580	$5
3.5	Other Boiler Plant Systems	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3.6	FO Supply Sys & Nat Gas	$322	$0	$376	$0	$699	$63	$0	$114	$876	$2
3.7	Waste Treatment Equipment	$2,891	$0	$1,674	$0	$4,565	$439	$0	$1,001	$6,005	$11
3.8	Misc. Equip. (Cranes, Air Comp., Comm.)	$3,158	$0	$977	$0	$4,135	$393	$0	$906	$5,433	$10
	Subtotal	**$14,134**	**$0**	**$5,751**	**$0**	**$19,885**	**$1,850**	**$0**	**$4,309**	**$26,044**	**$47**
4		Boiler & Accessories									
4.1	CFB & Accessories	w/ BEC	$0	w/ BEC	$0	$312,356	$30,062	$0	$34,242	$376,660	$685
4.5	ASU/Oxidant Compression	$154,786	$0	$126,643	$0	$281,429	$27,279	$0	$30,871	$339,578	$618
	Flue Gas Cooler	$12,948	$0	$0	$0	$12,948	$1,204	$0	$2,072	$16,224	$30
	Flue Gas N2 Heater	$2,620	$0	$0	$0	$2,620	$244	$0	$419	$3,283	$6
	Subtotal	**$170,353**	**$0**	**$126,643**	**$0**	**$609,352**	**$58,789**	**$0**	**$67,603**	**$735,745**	**$1,338**
5A		Gas Cleanup & Piping									
5A.1	Absorber Vessels & Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.2	Other FGD	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5A.3	Bag House & Accessories	$9,342	$0	$5,888	$0	$15,230	$1,431	$0	$1,666	$18,328	$33
5A.4	Other Particulate Removal Materials	$640	$0	$680	$0	$1,320	$125	$0	$145	$1,590	$3
5A.5	Gypsum Dewatering System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Subtotal	**$9,982**	**$0**	**$6,568**	**$0**	**$16,550**	**$1,556**	**$0**	**$1,811**	**$19,917**	**$36**

Exhibit 5-48 Case RhtIC760 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case RhtIC760					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies		Total Plant Cost	
				Direct	Indirect			Process	Project	$1,000	$/kW
		$1,000									
5B		CO_2 Removal & Compression									
5B.1	CO_2 Purification & Compression Unit/System	$69,827	$0	$53,040	$0	$122,867	$11,443	$24,573	$31,777	$190,660	$347
	Subtotal	**$69,827**	**$0**	**$53,040**	**$0**	**$122,867**	**$11,443**	**$24,573**	**$31,777**	**$190,660**	**$347**
7		HRSG, Ducting, & Stack									
7.3	Ductwork	$9,704	$0	$6,125	$0	$15,829	$1,337	$0	$2,575	$19,741	$36
7.4	Stack	$3,363	$0	$1,955	$0	$5,318	$499	$0	$582	$6,399	$12
7.9	Duct & Stack Foundations	$0	$1,045	$1,241	$0	$2,286	$214	$0	$500	$3,000	$5
	Subtotal	**$13,067**	**$1,045**	**$9,321**	**$0**	**$23,433**	**$2,050**	**$0**	**$3,657**	**$29,140**	**$53**
8B		sCO_2 Power Cycle									
	Main CO_2 Compressor	$36,883	$0	$22,130	$0	$59,012	$5,488	$0	$9,442	$73,942	$134
	Bypass CO_2 Compressor	$12,716	$0	$7,630	$0	$20,345	$1,892	$0	$3,255	$25,493	$46
	High Temperature CO_2 Recuperator	$35,407	$0	$0	$0	$35,407	$3,293	$0	$5,665	$44,365	$81
	Low Temperature CO_2 Recuperator	$31,834	$0	$0	$0	$31,834	$2,961	$0	$5,093	$39,888	$73
	CO_2 Cooler	$4,957	$0	$1,520	$0	$6,477	$602	$0	$1,036	$8,115	$15
	CO_2 Turbine Section	$105,379	$0	$0	$0	$105,379	$9,800	$0	$16,861	$132,039	$240
	CO_2 System Piping	$55,333	$0	$16,600	$0	$71,933	$6,690	$0	$11,509	$90,132	$164
	CO_2 System Foundations	$0	$1,853	$3,060	$0	$4,913	$457	$0	$786	$6,156	$11
	Subtotal	**$282,507**	**$1,853**	**$50,939**	**$0**	**$335,300**	**$31,183**	**$0**	**$53,648**	**$420,131**	**$764**
9		Cooling Water System									
9.1	Cooling Towers	$11,198	$0	$3,463	$0	$14,661	$1,366	$0	$1,603	$17,630	$32
9.2	Circulating Water Pumps	$2,763	$0	$220	$0	$2,983	$254	$0	$324	$3,561	$6
9.3	Circ.Water System Auxiliaries	$757	$0	$100	$0	$857	$79	$0	$94	$1,030	$2
9.4	Circ.Water Piping	$0	$6,376	$5,774	$0	$12,150	$1,075	$0	$1,984	$15,209	$28
9.5	Make-up Water System	$632	$0	$812	$0	$1,444	$133	$0	$237	$1,814	$3
9.6	Component Cooling Water Sys	$617	$0	$474	$0	$1,091	$99	$0	$179	$1,369	$2
9.9	Circ.Water System Foundations & Structures	$0	$3,436	$5,707	$0	$9,143	$861	$0	$2,001	$12,005	$22
	Subtotal	**$15,967**	**$9,812**	**$16,549**	**$0**	**$42,328**	**$3,869**	**$0**	**$6,420**	**$52,617**	**$96**
10		Ash & Spent Sorbent Handling Systems									
10.6	Ash Storage Silos	$1,527	$0	$4,673	$0	$6,200	$595	$0	$679	$7,474	$14
10.7	Ash Transport & Feed Equipment	$10,144	$0	$10,056	$0	$20,200	$1,861	$0	$2,206	$24,267	$44
10.9	Ash/Spent Sorbent Foundation	$0	$345	$424	$0	$769	$72	$0	$168	$1,009	$2
	Subtotal	**$11,671**	**$345**	**$15,153**	**$0**	**$27,169**	**$2,528**	**$0**	**$3,054**	**$32,750**	**$60**

Exhibit 5-48 Case RhtIC760 total plant cost details (continued)

Total Plant Cost Summary											
	Case:	sCO2 – Case RhtIC760					Estimate Type:			Conceptual	
	Plant Size (MW,net):	550 MWe					Cost Base:			Jun 2011	
Item No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	Total Plant Cost $1,000	Total Plant Cost $/kW
		$1,000									
11		Accessory Electric Plant									
11.1	Generator Equipment	$2,139	$0	$342	$0	$2,481	$222	$0	$203	$2,906	$5
11.2	Station Service Equipment	$6,292	$0	$2,109	$0	$8,401	$781	$0	$689	$9,871	$18
11.3	Switchgear & Motor Control	$7,222	$0	$1,255	$0	$8,476	$784	$0	$926	$10,186	$19
11.4	Conduit & Cable Tray	$0	$4,952	$16,000	$0	$20,953	$1,956	$0	$3,436	$26,344	$48
11.5	Wire & Cable	$0	$9,430	$16,856	$0	$26,286	$2,111	$0	$4,260	$32,656	$59
11.6	Protective Equipment	$332	$0	$1,150	$0	$1,482	$142	$0	$162	$1,787	$3
11.7	Standby Equipment	$1,620	$0	$38	$0	$1,658	$152	$0	$181	$1,990	$4
11.8	Main Power Transformers	$16,089	$0	$231	$0	$16,320	$1,237	$0	$1,756	$19,313	$35
11.9	Electrical Foundations	$0	$403	$1,025	$0	$1,428	$135	$0	$313	$1,876	$3
	Subtotal	**$33,694**	**$14,785**	**$39,007**	**$0**	**$87,485**	**$7,520**	**$0**	**$11,925**	**$106,930**	**$194**
12		Instrumentation & Control									
12.1	PC Control Equipment	w/12.7	$0	w/12.7	$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
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$620	$0	$379	$0	$999	$94	$50	$171	$1,313	$2
12.7	Distributed Control System Equipment	$6,257	$0	$1,116	$0	$7,372	$681	$369	$842	$9,264	$17
12.8	Instrument Wiring & Tubing	$3,773	$0	$6,865	$0	$10,638	$862	$532	$1,805	$13,836	$25
12.9	Other I & C Equipment	$1,768	$0	$4,094	$0	$5,862	$560	$293	$671	$7,386	$13
	Subtotal	**$12,417**	**$0**	**$12,453**	**$0**	**$24,870**	**$2,196**	**$1,244**	**$3,490**	**$31,799**	**$58**
13		Improvements to Site									
13.1	Site Preparation	$0	$62	$1,322	$0	$1,384	$135	$0	$304	$1,823	$3
13.2	Site Improvements	$0	$2,063	$2,725	$0	$4,788	$475	$0	$1,053	$6,316	$11
13.3	Site Facilities	$3,697	$0	$3,878	$0	$7,575	$754	$0	$1,666	$9,994	$18
	Subtotal	**$3,697**	**$2,125**	**$7,925**	**$0**	**$13,747**	**$1,364**	**$0**	**$3,022**	**$18,133**	**$33**
14		Buildings & Structures									
14.1	Boiler Building	$0	$10,575	$9,294	$0	$19,869	$1,748	$0	$3,243	$24,860	$45
14.2	Turbine Building	$0	$15,279	$14,230	$0	$29,509	$2,604	$0	$4,817	$36,929	$67
14.3	Administration Building	$0	$767	$810	$0	$1,576	$140	$0	$257	$1,974	$4
14.4	Circulation Water Pumphouse	$0	$194	$154	$0	$349	$31	$0	$57	$436	$1
14.5	Water Treatment Buildings	$0	$822	$749	$0	$1,572	$139	$0	$257	$1,967	$4
14.6	Machine Shop	$0	$513	$344	$0	$857	$74	$0	$140	$1,071	$2
14.7	Warehouse	$0	$347	$348	$0	$696	$62	$0	$114	$871	$2
14.8	Other Buildings & Structures	$0	$284	$242	$0	$525	$46	$0	$86	$657	$1
14.9	Waste Treating Building & Str.	$0	$532	$1,613	$0	$2,145	$199	$0	$352	$2,696	$5
	Subtotal	**$0**	**$29,313**	**$27,784**	**$0**	**$57,098**	**$5,042**	**$0**	**$9,321**	**$71,461**	**$130**
	Total	**$676,574**	**$65,729**	**$387,928**	**$0**	**$1,442,587**	**$134,803**	**$25,817**	**$210,223**	**$1,813,430**	**$3,298**

Exhibit 5-49 Case RhtIC760 owner's costs

Owner's Costs		
Description	**$1,000**	**$/kW**
Pre-Production Costs		
6-Months All Labor	$11,929	$21.69
1-Month Maintenance Materials	$1,721	$3
1-Month Non-fuel Consumables	$2,027	$4
1-Month Waste Disposal	$1,746	$3
25% of 1-Month Fuel Cost at 100% CF	$2,994	$5
2% of TPC	$36,269	$66
Total	**$56,685**	**$103**
Inventory Capital		
60-day supply of fuel and consumables at 100% CF	$27,388	$50
0.5% of TPC (spare parts)	$9,067	$16
Total	**$36,455**	**$66**
Other Costs		
Initial Cost for Catalyst and Chemicals	$0	$0
Land	$900	$2
Other Owner's Costs	$272,014	$495
Financing Costs	$48,963	$89
Total Overnight Costs (TOC)	**$2,228,447**	**$4,053**
TASC Multiplier (IOU, high-risk, 35-year)	1.140	
Total As-Spent Cost (TASC)	**$2,540,430**	**$4,620**

Exhibit 5-50 Case RhtIC760 initial and annual operating and maintenance costs

Initial & Annual O&M Expenses						
Case:	sCO2 – Case RhtIC760				**Cost Base:**	Jun 2011
Plant Size (MW,net):	**550**		**Heat Rate-net (Btu/kWh):**	8,296	**Capacity Factor (%):**	85
Operating & Maintenance Labor						
Operating Labor				**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		39.70	**$/hour**		**1 unit/mod.**	**Total Plant**
Operating Labor Burden:		30.00	**% of base**	Skilled Operator:	2.0	2.0
Labor O-H Charge Rate:		25.00	**% of labor**	Operator:	11.3	11.3
				Foreman:	1.0	1.0
				Lab Tech's, etc.:	2.0	2.0
				Total:	**16.3**	**16.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**($/kW-net)**
Annual Operating Labor:					$7,384,208	$13.430
Maintenance Labor:					$11,641,654	$21.173
Administrative & Support Labor:					$4,756,466	$8.651
Property Taxes and Insurance:					$36,268,600	$65.962
Total:					**$60,050,927**	**$109.216**
Variable Operating Costs						
					($)	**($/kWh-net)**
Maintenance Material:					$17,538,831	$0.00428
Consumables						
	Consumption		**Cost ($)**			
	Initial Fill	**Per Day**	**Per Unit**	**Initial Fill**		
Water (/1000 gallons):	0	4,914	$1.67	$0	$2,552,096	$0.00062
Makeup and Waste Water Treatment Chemicals (lbs):	0	23,787	$0.27	$0	$1,976,605	$0.00048
Limestone (ton)	0	1,127	$33.48	$0	$11,711,059	$0.00286
Soda Ash (ton)	0	0	$275.00	$0	$0	$0.00000
Carbon (lb)	0	0	$1.63	$0	$0	$0.00000
MEA Solvent (ton)	0	0	$3,481.91	$0	$0	$0.00000
NaOH (ton)	0	0	$671.16	$0	$0	$0.00000
H_2SO_4 (ton)	0	0	$214.78	$0	$0	$0.00000
Corrosion Inhibitor	0	0	$214.78	$0	$0	$0.00000
Activated Carbon (lb)	0	1,224	$1.63	$0	$617,052	$0.00015
Ammonia (19% NH_3, ton)	0	0	$330.00	$0	$0	$0.00000
SCR Catalyst (m^3)	0	0	$8,938.80	$0	$0	$0.00000
Subtotal:				**$0**	**$16,856,811**	**$0.00412**
Waste Disposal						
Fly Ash (ton)	0	43	$25.11	$0	$336,968	$0.00008
Bottom Ash (ton)	0	1,825	$25.11	$0	$14,217,898	$0.00347
Subtotal:				**$0**	**$14,554,866**	**$0.00356**
By-Products						
Gypsum (ton)	0	0	$0.00	$0	$0	$0.00000
Subtotal:				**$0**	**$0**	**$0.00000**
Total Variable O&M:				**$0**	**$48,950,509**	**$0.01196**
Fuel Cost						
Illinois Number 6 (ton):	0	4,690	$68.60	$0	$99,809,460	$0.02438
Total:				**$0**	**$99,809,460**	**$0.02438**

Exhibit 5-51 shows the COE results for Case RhtIC760 using high-risk financing. The COE result for Case RhtIC620 is shown for comparison purposes, and uses high-risk financing assumptions.

Exhibit 5-51 Case RhtIC760 COE breakdown

Case	RhtIC620	RhtIC760
Cost		
TPC (2011$/kW)	3,324	3,298
TOC (2011$/kW)	4,084	4,053
COE (2011$/MWh) (excluding T&S)	123.00	118.50
Capital	68.01	67.49
Fixed O&M	14.76	14.67
Variable O&M	12.99	11.96
Fuel	27.25	24.38
T&S	7.84	7.01
COE (2011$/MWh) (including T&S)	130.84	125.51

5.6.3 Comparison of Cost Estimate Results Between Reference Rankine Cases and Reheat/Intercooling sCO_2 Cases

Exhibit 5-52 shows the TPC (1,000 2011$) for the reference Rankine case and the Reheat/Intercooling cases at two different TITs. Compared to the reference Rankine cases, the TPC for Case RhtIC620 is 1 percent higher and the TPC for Case RhtIC760 is 1 percent lower.

Exhibit 5-52 TPC (1,000 2011$) for Reheat/Intercooling cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case RhtIC620	Case RhtIC760
Coal & Sorbent Handling	57,740	54,500	54,581	50,900
Coal & Sorbent Prep & Feed	31,040	29,215	29,266	27,202
Feedwater & Misc. BOP Systems	104,134	88,757	29,027	26,044
CFB, ASU, FG Cooling, CO_2 Recycle	464,234	533,106	364,354	396,167
O_2 Generation	375,525	352,052	367,205	339,578
FG Treatment	21,093	19,630	21,729	19,917
FG Recycle	28,356	27,411	30,396	29,140
CO_2 Purification & Compression	224,111	208,172	208,488	190,660
Steam Turbine Generator	173,036	201,497	---	---
sCO_2 Cycle	---	---	395,473	420,131
Cooling Water Systems	60,572	55,117	59,626	52,617

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case RhtIC620	Case RhtIC760
Ash Removal	36,652	34,825	34,862	32,750
Accessory Electric Plant	115,848	112,119	111,060	106,930
Instrumentation & Controls	32,776	32,378	32,272	31,799
Site Preparation & Improvements	18,152	18,213	18,156	18,133
Buildings & Structures	71,808	71,626	71,837	71,461
Totals	**1,815,076**	**1,838,618**	**1,838,331**	**1,813,430**

Exhibit 5-53 shows the detailed TPC (1,000 2011$) for the sCO_2 power cycle for the reference Rankine case and the Reheat/Intercooling cases at two different TITs. Compared to the Baseline cases, for a TIT of 760 °C the TPC is 8 percent higher, whereas for a TIT of 620 °C the TPC is 4 percent lower. It appears that the high material costs encountered with the high TIT almost completely negates the effect that a higher process efficiency has on lowering the TPC. As with the reheat case, the cost penalty of the high TIT is most readily seen in the CO_2 piping costs.

Exhibit 5-53 TPC (1,000 2011$) for sCO_2 power cycle for Reheat/Intercooling cases

Parameter	Reference Rankine	Case RhtIC620	Case RhtIC760
Main CO_2 Compressor	---	87,543	73,942
Bypass CO_2 Compressor	---	36,886	25,493
High-Temperature CO_2 Recuperator	---	41,983	44,365
Low-Temperature CO_2 Recuperator	---	49,729	39,888
CO_2 Cooler	---	10,045	8,115
CO_2 Turbine Section	---	128,745	132,039
CO_2 System Piping	---	33,976	90,132
CO_2 System Foundations	---	6,566	6,156
Subtotal	**---**	**395,473**	**420,131**

Exhibit 5-54 shows the detailed TPC (1,000 2011$) for the CFB and accessories section for the reference Rankine case and the Reheat/Intercooling cases at two different TITs. Compared to the Baseline cases, the TPCs for both the CFB and the ASU are lower at both TITs and the magnitude of the decrease is similar to that obtained for the reheat only cases.

Exhibit 5-54 TPC (1,000 2011$) for CFB section for Reheat/Intercooling cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case RhtIC620	Case RhtIC760
CFB & Accessories	464,234	533,106	343,140	376,660
ASU/Oxidant Compression	375,525	352,052	367,205	339,578
Flue Gas Cooler	w/CFB	w/CFB	17,544	16,224
Water Knockout	w/CFB	w/CFB	3,671	3,283
Subtotal	**839,758**	**885,158**	**731,559**	**735,435**

Exhibit 5-55 shows the O&M cost, owner's cost, and COE for the reference Rankine case and the Reheat/Intercooling cases at two different TITs. Compared to the other configurations, the COE for the sCO_2 cycle with reheat and intercooling at 620 °C TIT is lower than with any corresponding configuration. For Case RhtIC760, the COE is slightly higher than case IC760 but the difference is within the uncertainty of the cost estimates. The COE for the reheat and intercooling cases is lower than for the corresponding reference Rankine cycles for both TITs. The decrease in COE for Case RhtIC620 is 2 percent and the decrease in COE for Case RhtIC760 is 4 percent.

Exhibit 5-55 O&M costs, owner's costs, and COE for Reheat/Intercooling cases

Parameter	Reference SC Rankine	Reference AUSC Rankine	Case RhtIC620	Case RhtIC760
O&M Costs ($1,000/yr)				
Total Fixed O&M	60,159	60,866	60,449	60,051
Total Variable O&M	56,041	52,643	53,205	48,951
Total Fuel	122,152	111,392	111,609	99,809
Total Annual O&M Costs	238,352	224,901	225,254	208,811
Owner's Cost ($1,000)				
Total Owner's Costs	415,350	417,192	418,027	415,017
Total Overnight Cost (TOC, $1,000)				
Total Overnight Cost	2,230,425	2,255,810	2,246,358	2,228,447
COE ($/MWh)				
First-Year COE without T&S	**125.72**	**123.22**	**123.00**	**118.50**
First-Year COE with T&S	**134.30**	**131.05**	**130.84**	**125.51**

Exhibit 5-56 shows a comparison of the power cycle TPC ($/kW basis) between Case RhtIC760 and the Reference AUSC Rankine case. The accounts and sub-accounts shown are directly attributable to the power cycle. The sCO_2 Power Cycle account TPC is 110% greater than Steam Turbine Generator account TPC. However, the total attributable sCO_2 power cycle TPC is only 2.1% greater than attributable Rankine power cycle TPC. If the ASU is included, the sCO_2 power cycle TPC is only 0.35% greater than Rankine power cycle TPC.

Exhibit 5-56 Power cycle TPC comparison between Case RhtIC760 and AUSC Rankine case

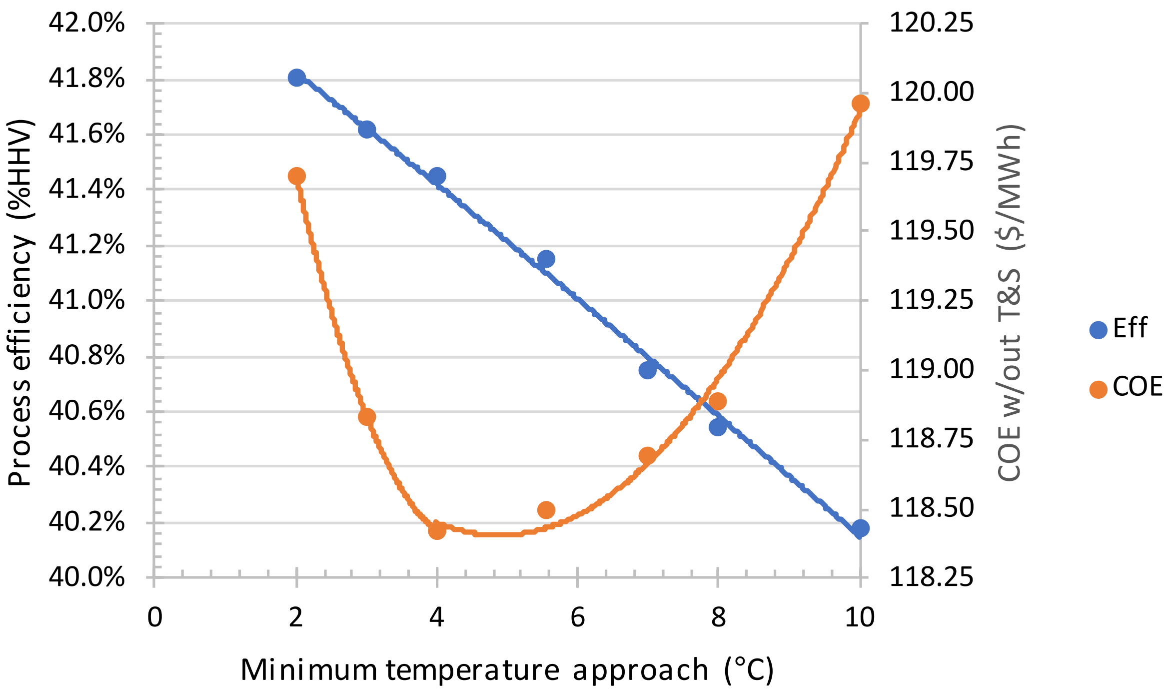
Account / Sub-account TPC ($/kW)	Reference AUSC Rankine	Case RhtIC760
Feedwater & Miscellaneous BOP Systems		
Feedwater System	62	0
Other Feedwater Subsystems	21	0
Other Boiler Plant Systems	36	0
Boiler & Accessories		
CFB & Accessories	969	685
Flue Gas Cooler	0	30
Flue Gas N_2 Heater	0	6
Steam Turbine Generator		
Total	366	0
sCO_2 Power Cycle		
Total	**0**	**764**
Total	**1,455**	**1,485**

6 Sensitivity Analyses

6.1 Sensitivity to Recuperator Minimum Temperature Approach

As the recuperator minimum temperature approach increases, the amount of heat exchanged in the sCO_2 power cycle recuperators decreases resulting in a reduction in the total amount of working fluid that can be heated by the CFB. This reduces sCO_2 power cycle output and efficiency. However, if the minimum temperature approach is too small, the recuperator heat transfer area, and hence cost, increases. In addition, as the minimum approach temperature decreases, the pressure drop in the recuperator increases which decreases power cycle and plant efficiency. To determine if the recuperator minimum approach temperature used in this study was in the economical region, a sensitivity analysis was performed on Case RhtIC760 on the system performance and economics as a function of the minimum temperature approach. All other variables were kept constant. The results of this sensitivity analysis are shown in Exhibit 6-1 which plots overall process efficiency and COE as a function of minimum temperature approach.

Exhibit 6-1 Process efficiency and COE versus minimum approach temperature for Case RhtIC760



Source: NETL

The results in Exhibit 6-1 follow the expected trend with the process efficiency increasing monotonically with decreasing minimum approach temperature and the COE showing a minimum as a certain minimum approach temperature (approximately 4-5 °C in this case). The minimum temperature approach of 5.6 °C used in this study falls close to the minimum in the COE and just above the point where the magnitude of the rate of change of COE with minimum temperature approach starts to increase markedly.

Exhibit 6-2 shows a more detailed side by side comparison of the performance results between the RHTIC760 case with a 10 °F minimum temperature approach versus a 10 °C minimum temperature approach. Exhibit 6-3 shows the power summary and Exhibit 6-4 shows the cycle performance summary for these two cases.

Exhibit 6-2 Performance for Case RhtIC760 - Tapp = 10 °F versus 10 °C

Parameter	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °C
CFB Coal Flow Rate (lb/hr)	390,800	400,400
Limestone Flow Rate (lb/hr)	94,017	96,326
Oxygen Flow Rate (lb/hr)	835,197	855,714
Coal Thermal Input (MMBtu/hr)	4,559	4,671
Net Plant Power Output (kW)	549,802	550,038
Net Plant Efficiency (HHV %)	**41.15**	**40.18**
HHV Heat Rate (Btu/kWh)	8,292	8,492
Raw Water Withdrawal (gpm)	5,152	5,386

Exhibit 6-3 Plant power summary for Case RhtIC760 - Tapp = 10 °F versus 10 °C

POWER SUMMARY		
Item (kW)	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °C
POWER CYCLE SUMMARY		
sCO_2 Turbine Gross Power	855,600	872,500
sCO_2 Main Compressor	-115,000	-110,700
sCO_2 Bypass Compressor	-44,900	-62,300
sCO_2 Generator Loss	-10,436	-10,493
TOTAL sCO_2 POWER GENERATED	**685,265**	**689,038**
AUXILIARY LOAD SUMMARY		
Coal Handling	-422	-432

POWER SUMMARY		
Item (kW)	**Case RhtIC760 Tapp = 10 °F**	**Case RhtIC760 Tapp = 10 °C**
Limestone Prep	-190	-190
Pulverizers	-80	-90
Slag Handling and Dewatering	-2,090	-2,140
Primary Air Fans	-210	-220
Forced Draft Fans	-270	-280
Induced Draft Fans	-1,650	-1,790
Air Separation Unit	-69,690	-71,400
Baghouse	-10	-10
CPU (Purification and Compression) Auxiliaries	-47,520	-48,690
Turbine Auxiliaries	-400	-400
Miscellaneous Balance of Plant	-2,000	-2,000
Circulating Water Pump	-5,370	-5,610
Cooling Tower Fans	-3,140	-3,270
Transformer Losses	-2,420	-2,440
TOTAL AUXILIARIES	**-135,462**	**-138,960**
NET POWER	**549,802**	**550,077**

Exhibit 6-4 sCO_2 cycle performance summary for Case RhtIC760 - Tapp = 10 °F versus 10 °C

Parameter	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °C
THERMAL INPUT		
Power Cycle Thermal Input - CFB (MMBtu/hr)	4,113	4,201
Power Cycle Thermal Input – Flue gas (MMBtu/hr)	159	121
Power Cycle Thermal Input - Total (MMBtu/hr)	4,272	4,322
Fractional Thermal Input to Power Cycle	0.937	0.925
RECUPERATOR DUTY		
Recuperator Duty – VTR (MMBtu/hr)	4,937	4,704
Recuperator Duty – HTR (MMBtu/hr)	2,511	2,686
Recuperator Duty – LTR (MMBtu/hr)	2,144	2,249
Recuperator Duty – Total (MMBtu/hr)	9,592	9,640

COOLING DUTY		
Power Cycle Cooling Duty – CO_2 cooler (MMBtu/hr)	1,428	1,486
Power Cycle Cooling Duty – CO_2 intercooler (MMBtu/hr)	470	453
Power Cycle Cooling Duty – Total (MMBtu/hr)	1,898	1,938
POWER OUTPUT		
Net Cycle Power Output (kW)	685,265	689,000
SPECIFIC POWER		
sCO_2 Flow Rate (lb/hr)	29,158,094	29,730,995
sCO_2 Cycle Specific Power (Wh/lb)	23.50	23.17
sCO_2 Cycle Specific Power (kJ/kg)	186.5	183.9
OVERALL CYCLE PERFORMANCE		
sCO_2 Power Cycle Efficiency (%)	54.74	54.40
sCO_2 Cycle Heat Rate (Btu/kWh)	6,233	6,273

Increasing the minimum temperature approach from 10 °F to 10 °C decreases the fraction of heat recovered from 93.7 percent to 92.5 percent, decreases the sCO_2 power cycle efficiency by 0.3 percentage points, and decreases the overall process efficiency by 1.0 percentage point. In order to keep the net plant output the same at 550 MW, there was a 2.5 percent increase in the coal flow rate with a 10 °C minimum temperature approach. This caused a parallel increase in the auxiliary power requirement and the limestone flow rate. The 1.0 percentage point drop in process efficiency with a 10 °C minimum temperature approach causes parallel increases in raw water withdrawal and raw water consumption. In addition to these impacts, increasing the minimum temperature approach to 10 °C increases the CO_2 bypass fraction from 0.16 to 0.21. This increases the CO_2 bypass compressor power by 38% due to the increased CO_2 flow rate and the increased temperature of this stream. While increasing the CO_2 bypass fraction would be expected to cause a compensating decrease in the main CO_2 compressor power requirement, this reduction is partially offset by the increased temperature of this stream.

The economic evaluation for this sensitivity analysis was performed using two different cost algorithms for the recuperators, as described in Section 4.7. Results are presented for economic analyses based on the recuperator designs from Vendor A and Vendor B. [17]

Exhibit 6-5 compares the TPC between the RHTIC760 case with a 10 °F minimum temperature approach versus a 10 °C minimum temperature approach. Exhibit 6-6 compares the TPC for the power cycle components, Exhibit 6-7 compares the BEC for the three recuperators, and Exhibit 6-8 compares the COE for these two cases.

Exhibit 6-5 TPC (1,000 2011$) for Case RhtIC760 - Tapp = 10 °F versus 10 °C

Parameter	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °F
	Vendor A		Vendor B	
Coal & Sorbent Handling	50,900	51,678	50,900	51,678
Coal & Sorbent Prep & Feed	27,202	27,638	27,202	27,638
Feedwater & Misc. BOP Systems	26,044	26,694	26,044	26,694
CFB, ASU, FG Cooling, CO_2 Recycle	396,167	400,211	396,167	400,211
O_2 Generation	339,578	345,396	339,578	345,396
FG Treatment	19,917	20,745	19,917	20,745
FG Recycle	29,140	29,408	29,140	29,408
CO_2 Purification & Compression	190,660	194,398	190,660	194,398
sCO_2 Cycle	914,996	778,693	420,131	415,779
Cooling Water Systems	52,617	54,149	52,617	54,149
Ash Removal	32,750	33,200	32,750	33,200
Accessory Electric Plant	106,930	107,842	106,930	107,842
Instrumentation & Controls	31,799	31,905	31,799	31,905
Site Preparation & Improvements	19,094	18,868	18,133	18,164
Buildings & Structures	72,650	72,469	71,461	71,578
Totals	**2,310,425**	**2,193,294**	**1,813,430**	**1,828,785**

Exhibit 6-6 TPC (1,000 2011$) for sCO_2 power cycle for Case RhtIC760 - Tapp = 10 °F versus 10 °C

Parameter	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °F
	Vendor A		Vendor B	
Main CO_2 Compressor	73,942	80,203	73,942	80,203
Bypass CO_2 Compressor	25,493	39,360	25,493	39,360
High-Temperature CO_2 Recuperator	516,792	383,236	44,365	33,401

Low-Temperature CO_2 Recuperator	39,888	23,250	39,888	23,250
CO_2 Cooler	8,115	7,816	8,115	7,816
CO_2 Turbine Section	132,039	133,693	132,039	133,693
CO_2 System Piping	90,132	91,773	90,132	91,773
CO_2 System Foundations	6,156	6,283	6,156	6,283
Subtotal	**914,996**	**778,693**	**420,131**	**415,779**

Exhibit 6-7 BEC (1,000 2011$) for sCO_2 recuperators for Case RhtIC760 - Tapp = 10 °F versus 10 °C

Recuperator	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °F	Case RhtIC760 Tapp = 10 °F
	Vendor A		Vendor B	
VTR	346,881	251,806	25,716	18,667
HTR	65,562	54,049	9,691	7,989
LTR	49,743	28,994	31,835	18,556
Total	**462,186**	**334,848**	**67,242**	**45,212**

Exhibit 6-8 COE breakdown for Case RhtIC760 - Tapp = 10 °F versus 10 °C

Case	RhtIC760 Tapp = 10 °F	RhtIC760 Tapp = 10 °C	RhtIC760 Tapp = 10 °F	RhtIC760 Tapp = 10 °C
	Vendor A		Vendor B	
Cost				
TPC (2011$/kW)	4,202	3,988	3,298	3,325
TOC (2011$/kW)	5,139	4,882	4,053	4,085
COE (2011$/MWh) (excluding T&S)	141.17	136.58	118.50	119.96
Capital	85.59	81.29	67.49	68.03
Fixed O&M	18.07	17.26	14.67	14.77
Variable O&M	13.13	13.06	11.96	12.20
Fuel	24.38	24.97	24.38	24.97
T&S	7.01	7.18	7.01	7.18

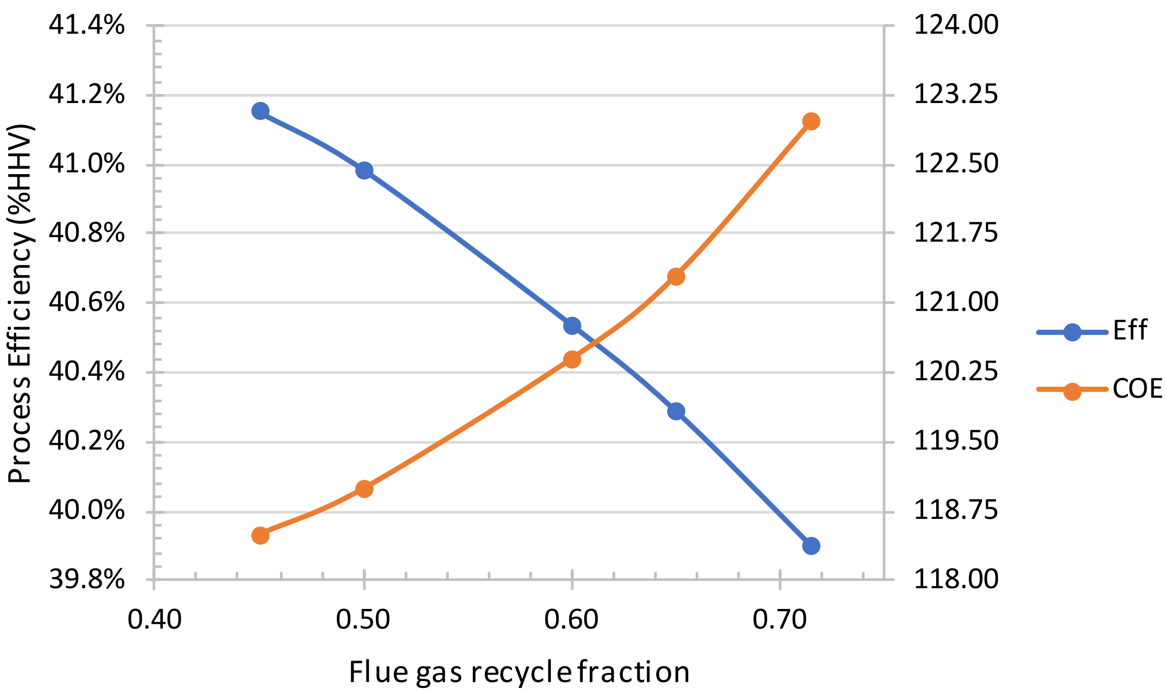
COE (2011$/MWh) (including T&S)	148.18	143.77	125.51	127.14

Increasing the minimum temperature approach from 10 °F to 10 °C decreases recuperator costs by increasing the driving force for heat transfer. The HTR and VTR capital costs were reduced by 25 percent while the LTR capital cost was reduced by 42 percent. However, increasing the minimum temperature approach from 10 °F to 10 °C also decreases the power cycle efficiency resulting in increased costs for some cycle components. The most significant increases were for the bypass CO_2 compressor (54 percent increase) and the main CO_2 compressor (8 percent increase). Clearly, the recuperator design determines the net impact. In this study, the Vendor A design favors a higher minimum temperature approach while the Vendor B design favors a lower minimum temperature approach.

6.2 Sensitivity to Flue Gas Recycle

The amount of flue gas recycle used in the sCO_2 cycle cases was 45 percent and this was the same value used in both reference Rankine cycle cases. The flue gas recycle controls the oxygen concentration in the CFB and maintains isothermal conditions in the CFB bed. If the flue gas recycle fraction is too low it will tend to cause hot spots in the CFB which may lead to a higher solids recirculation rate and/or a shortened CFB life. As the flue gas recycle fraction increases, the oxygen concentration decreases which may impair carbon conversion in the CFB. However, a higher flue gas recycle fraction will also increase the proportion of the CFB heat that is transferred to the high temperature section of the sCO_2 power cycle which would act to increase process efficiency. However, a large recycle fraction increases the required fan power which acts to decrease process efficiency. To explore these trade-offs further a sensitivity analysis was performed on Case RhtIC760 on the system performance and economics as a function of the flue gas recycle fraction. In the sensitivity analysis, the flue gas recycle fraction was varied between 45 percent and 71 percent. The results are shown in Exhibit 6-9.

Exhibit 6-9 Process efficiency and COE versus flue gas recycle fraction for Case RhtIC760



Source: NETL

The results showed that as the flue gas recycle fraction increases, the process efficiency decreases and the COE increases. Further, as the flue gas recycle fraction increases, the rate of change of the process efficiency and COE both increase in magnitude. No optimum in either variable is apparent in the region examined. It appears that an optimum in both variables may occur at very low flue gas recycle fractions but this was not explored. A flue gas recycle fraction of 45 percent was deemed the lowest value for safe CFB operation.

Exhibit 6-10 compares the TPC between the RhtIC760 case with a flue gas recycle fraction of 0.45 versus a flue gas recycle fraction of 0.715.

Exhibit 6-10 TPC (1,000 2011$) for Case RhtIC760 - Recycle = 0.45 versus 0.715

Parameter	Case RhtIC760 Recycle = 0.45	Case RhtIC760 Recycle = 0.715
Coal & Sorbent Handling	50,900	52,048
Coal & Sorbent Prep & Feed	27,202	27,908
Feedwater & Misc. BOP Systems	26,044	26,867

Parameter	Case RhtIC760 Recycle = 0.45	Case RhtIC760 Recycle = 0.715
CFB, ASU, FG Cooling, CO_2 Recycle	396,167	435,417
O_2 Generation	339,578	346,964
FG Treatment	19,917	31,287
FG Recycle	29,140	195,454
CO_2 Purification & Compression	190,660	29,478
sCO_2 Cycle	420,131	424,039
Cooling Water Systems	52,617	54,559
Ash Removal	32,750	33,543
Accessory Electric Plant	106,930	108,588
Instrumentation & Controls	31,799	31,991
Site Preparation & Improvements	18,133	18,290
Buildings & Structures	71,461	71,758
Totals	**1,813,430**	1,888,192

Increasing the flue gas recycle fraction from 0.45 to 0.715 increases the Boiler & Accessory account TPC by 10 percent, increases the Gas Cleanup & Piping account TPC by 57 percent, and increases the overall plant TPC by 4 percent. As the flue gas recycle fraction increases, the TPC increases in all accounts. For accounts other than Boiler and Gas Cleanup, the increase in TPC is due to the decrease in efficiency.

Exhibit 6-11 compares the TPC for the power cycle components for the two flue gas recycle fractions. Increasing the flue gas recycle fraction from 0.45 to 0.715 has little impact on the sCO_2 power cycle TPC. The most significant change is a 3 percent increase in the CO_2 System Piping account TPC. The CO_2 bypass fraction decreases due to the change in flue gas heat recovery.

Exhibit 6-11 TPC (1,000 2011$) for sCO_2 power cycle for Case RhtIC760 - Recycle = 0.45 versus 0.715

Parameter	Case RhtIC760 Recycle = 0.45	Case RhtIC760 Recycle = 0.715
Main CO_2 Compressor	73,942	75,304
Bypass CO_2 Compressor	25,493	23,798
High-Temperature CO_2 Recuperator	44,365	44,766

Low-Temperature CO_2 Recuperator	39,888	40,139
CO_2 Cooler	8,115	8,309
CO_2 Turbine Section	132,039	132,560
CO_2 System Piping	90,132	92,989
CO_2 System Foundations	6,156	6,174
Subtotal	**420,131**	**424,039**

Exhibit 6-12 compares the TPC for the CFB components. Increasing the flue gas recycle fraction from 0.45 to 0.715 increases the Boiler & Accessories account TPC by 6 percent. The increase in TPC is primarily due to the increase in flue gas flow rate. The increase in the ASU TPC is due to the decrease in process efficiency.

Exhibit 6-12 TPC (1,000 2011$) for CFB section for Case RhtIC760 - Recycle = 0.45 versus 0.715

Parameter	Case RhtIC760 Recycle = 0.45	Case RhtIC760 Recycle = 0.715
CFB & Accessories	376,660	412,136
ASU/Oxidant Compression	339,578	346,964
Flue Gas Cooler	16,224	19,076
Water Knockout	3,283	4,205
Subtotal	**735,435**	**782,382**

Exhibit 6-13 compares the COE for these two cases. Increasing the flue gas recycle fraction from 0.45 to 0.715 increases plant TPC, TOC, and COE by 4 percent. There was no significant change in the relative proportions of the COE component costs

Exhibit 6-13 COE breakdown for Case RhtIC760 - Recycle = 0.45 versus 0.715

Case	RhtIC760 Recycle = 0.45	RhtIC760 Recycle = 0.715
TPC (2011$/kW)	3,298	3,435
TOC (2011$/kW)	4,053	4,217
COE (2011$/MWh) (excluding T&S)	118.50	122.97

Capital	67.49	70.23
Fixed O&M	14.67	15.19
Variable O&M	11.96	12.40
Fuel	24.38	25.13
T&S	7.01	7.24
COE (2011$/MWh) (including T&S)	125.51	130.20

6.3 SENSITIVITY TO FLUE GAS HEAT RECOVERY

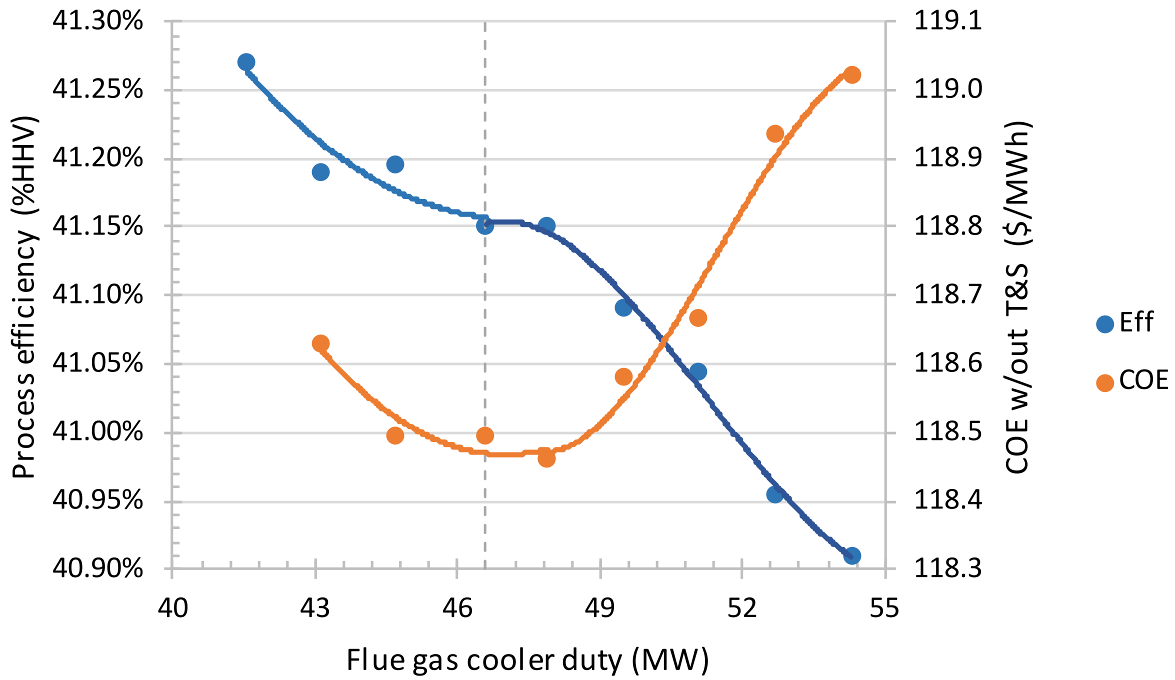
In the conceptual designs for the sCO_2 cycle cases in this study the CFB heats the maximum amount of sCO_2 working fluid possible subject to the minimum temperature approach specification. After heating the working fluid, the flue gas preheats the incoming oxidant streams (primary and secondary oxidant streams consisting of the oxygen mixed with the recycle flue gas). The flue gas then exits the CFB and passes through two heat exchangers in series. The first heat exchanger is the N_2 heater which heats nitrogen used to regenerate the adsorbent in the ASU air pre-purifier. The second heat exchanger is the flue gas cooler which is used to heat a portion of the cold high pressure sCO_2 exiting the main CO_2 compressor. The total amount of heat that can be recovered from the flue gas is limited by the main CO_2 compressor exit stream temperature and the minimum temperature approach specification. While the heat duty of the N_2 heater is fixed by the plant's oxygen demand, the duties of the other two heat exchangers are a degree of freedom in the process. In the conceptual design used in this study, changing the distribution of heat between the oxidant pre-heater and the flue gas cooler is done by changing the flue gas exit temperature from the oxidant pre-heater. As this temperature increases, the oxidant pre-heater duty decreases and the flue gas cooler duty increases a corresponding amount. However, there are constraints on this temperature. If the flue gas oxidant pre-heater exit temperature is too low, the N_2 heater will not be able to heat the N_2 to a sufficient temperature for the ASU regenerator. However, the flue gas cooler duty cannot exceed the thermal capacitance of the sCO_2 working fluid exiting the main CO_2 compressor so if the flue gas oxidant pre-heater exit temperature is too high, it may not be possible to attain the maximum amount of heat recoverable from the flue gas.

One further constraint on the flue gas cooler operation is that to attain optimal sCO_2 power cycle performance, the temperature of the sCO_2 working fluid exiting the flue gas cooler should be the same as the temperatures of the sCO_2 working fluid exiting the bypass CO_2 compressor. Before entering the HTR, the bypass sCO_2 stream, the sCO_2 exiting the LTR and the sCO_2 exiting the flue gas cooler are mixed. The temperature of the sCO_2 exiting the LTR is equal to the temperature of the sCO_2 exiting the bypass CO_2 compressor by design. If the sCO2 stream exiting the flue gas cooler is not also at this same temperature, exergy loss will occur during the mixing of the three streams which is deleterious to cycle efficiency.

Even within these constraints there is an interesting trade-off between larger oxidant pre-heater duty and larger flue gas cooler duty. As the duty of the flue gas cooler increases, the fraction of the total CFB thermal output that is absorbed by the power cycle increases which acts to increases process efficiency. However, as the flue gas duty increases, the size and cost of the exchanger increases. Since the minimum temperature approach specification is enforced at both the hot and cold end of the flue gas cooler, the cost of recovered heat, in terms of heat transfer area, in the flue gas cooler is greater than for the oxidant pre-heater although the actual capital cost may not follow this same trend.

To explore these effects further a sensitivity analysis was performed on Case RhtIC760 on the system performance and economics as a function of the flue gas cooler duty. As the flue gas cooler duty changed, the oxidant pre-heater duty changed correspondingly to attain the maximum possible flue gas heat recovery. All other variables were kept constant subject to the constraints noted previously. The results of the sensitivity analysis are shown in Exhibit 6-14.

Exhibit 6-14 Process efficiency and COE versus flue gas cooler duty for Case RhtIC760



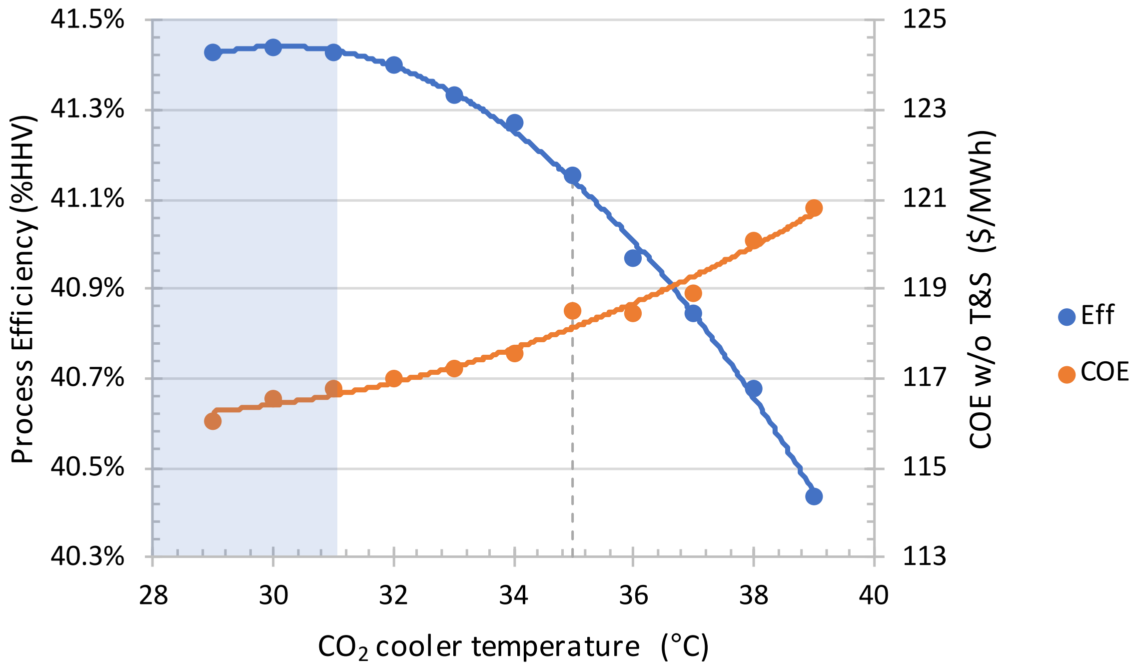
Source: NETL

In Exhibit 6-14. The dashed vertical line represents the state point used in this study. This point corresponds to a flue gas cooler duty of 46.6 MW, an oxidant pre-heater duty of 32.6 MW and a temperature of 200 °C for the flue gas exiting the oxidant preheater. As the flue gas cooler duty increases, the process efficiency decreases, although there is an apparent inflection point near the selected state point for Case RhtIC760. The results indicate that with the total heat recovered from the flue gas maximized, it is better from the standpoint of process efficiency to increase the oxidant pre-heater duty at the expense of the flue gas cooler duty. However, the COE plot in Exhibit 6-5 shows a minimum at a flue gas cooler duty near or just above the operating point. As the flue gas cooler duty decreases below the selected state point, the oxidant preheater duty increases and the driving force for heat transfer decreases. This dual effect compounds the increase in oxidant pre-heater capital cost. In contrast, the flue gas cooler duty driving force for heat transfer remains constant in this region so the change in capital cost is proportional to the change in duty only. Thus, the impact of increased oxidant pre-heater cost dominates the cost reduction from lower flue gas cooler cost and the COE increases. As the flue gas cooler duty increases beyond the selected state point, the opposite effects on the oxidant pre-heater and flue gas cooler capital costs occur but the precipitous drop in process efficiency overwhelms the capitals cost effects and the COE increases. The results indicate that the selected state point is probably optimal with respect to the flue gas heat recovery.

6.4 Sensitivity to CO_2 Cooler Temperature

The CO_2 cooler temperature has a large impact on both process efficiency and COE. The selected state point CO_2 cooler temperature of 35 °C was based on engineering heuristics and prior studies. A lower CO_2 cooler temperature will decrease the sCO_2 compression power requirement and increases the fraction of CFB heat absorbed by the power cycle. Both factors act to increase process efficiency. However, a lower CO_2 cooler temperature will also lower the sCO_2 working fluid temperature exiting the HTR. This decreases the amount of sCO_2 that can be heated by the CFB reducing plant output and efficiency. In addition, a lower CO_2 cooler temperature decreases the driving force for heat transfer in the cooler leading to increased capital cost for this unit. To further explore these trade-offs, a sensitivity analysis was performed on Case RhtIC760 on the system performance and economics as a function of the CO_2 cooler temperature. In this analysis, the CO_2 cooler temperature was varied from 29 °C to 39 °C with all other variables kept constant. The results are shown in Exhibit 6-15. The blue shaded region in this Exhibit denote sub-critical temperatures. The vertical dashed line corresponds to the selected state point.

Exhibit 6-15 Process efficiency and COE versus CO_2 cooler temperature for Case RhtIC760



Source: NETL

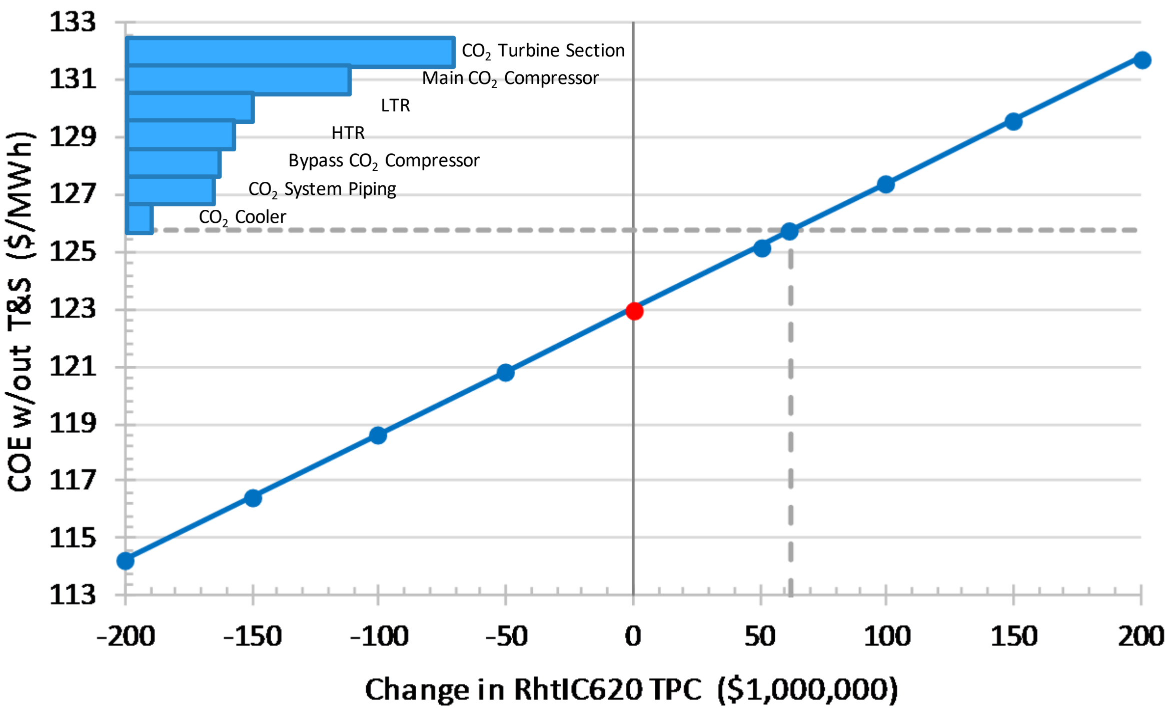
The results show that as the CO_2 cooler temperature decreases the process efficiency increases but at a decreasing rate until an apparent maximum in efficiency occurs at a CO_2 cooler temperature near 30 °C. At this point, the trade-off between lower compressor power and lower cycle output appear to balance. The COE plot in Exhibit 6-6 follows the opposite trend although it does not attain a minimum within the range of CO_2 cooler temperatures examined. At lower CO_2 cooler temperatures the impact of increased CO_2 cooler capital cost on the COE is more than offset by the impact of higher efficiency on COE, until the CO_2 cooler temperature gets very low.

It should be emphasized that this was a first-order sensitivity analysis. In a whole plant optimization, additional process parameters would probably change. For example, as the CO_2 cooler temperature changes, the CO_2 compressor inlet pressure (and by extension, the turbine exit pressure) should also change. At low enough CO_2 cooler temperatures, the entire process heat integration scheme would need to be re-assessed,

6.5 Sensitivity to Change in Total Plant Cost

Because of the relatively large uncertainty in the cost estimate for the sCO_2 cycle components, a sensitivity analysis of COE to capital cost was performed for the Reheat and Intercooling cases at both TITs. Exhibit 6-16 shows a plot of first-year COE (without T&S) versus the change in TPC compared to the estimated value for Case RhtIC620. The vertical solid line marks the zero change in TPC and the red dot on this line corresponds to the results from the techno-economic analysis (TEA). The dashed horizontal line is the COE for the reference SC Rankine cycle. The sensitivity line shows that the COE increases just over $1/MWh for every $25MM increase in TPC. The dashed vertical line indicates the change in TPC ($62MM) that would have to occur for Case RhtIC620 to have the same COE as the reference Rankine cycle. Hence as long as the total uncertainty in the TPC is less than $62MM, Case RhtIC620 will still have a lower COE than the reference Rankine cycle.

Exhibit 6-16 Sensitivity of COE to TPC for Case RhtIC620

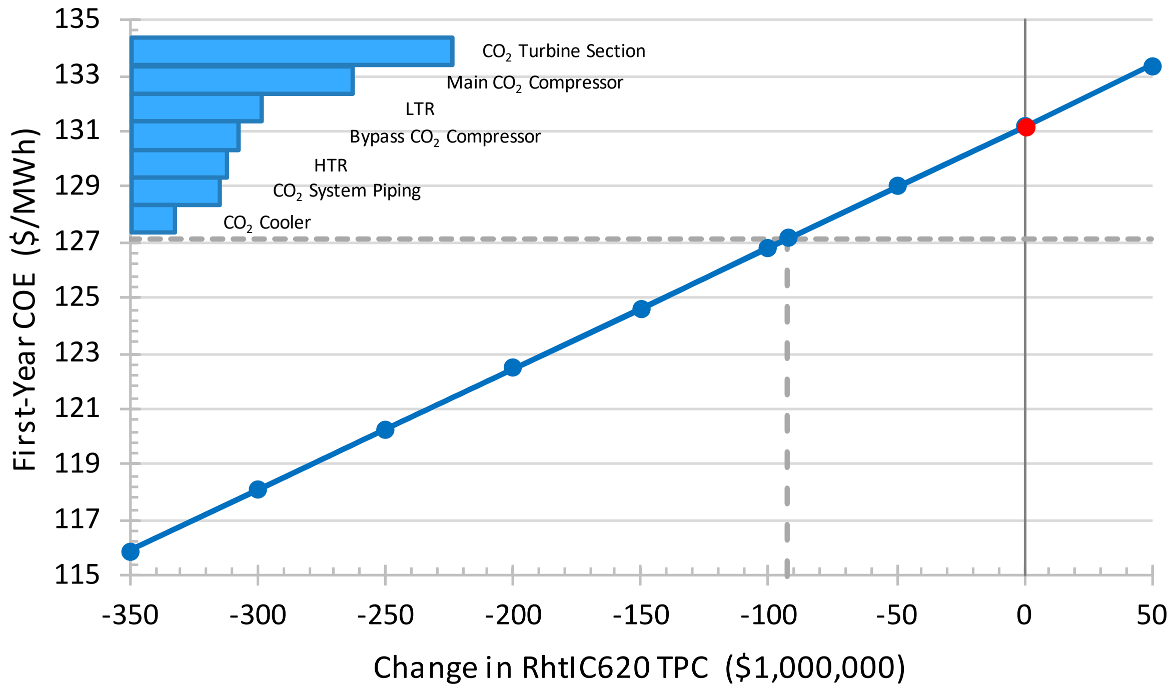


Source: NETL

Also shown on the plot as horizontal blue bars in the upper left portion of the plot are the TPC values for the major components in the sCO_2 power cycle, ranked from top to bottom from largest to smallest TPC. The horizontal length of the bars follows the scale for change in TPC on the horizontal axis. In relation to the total sCO_2 power cycle TPC, the CO_2 Turbine Section and Main CO_2 compressor contribute the largest portion. The TPC for the CO_2 Turbine Section would have to increase over 50 percent for the COE of Case RhtIC620 to exceed that of the reference Rankine cycle. It would take an increase of over 70 percent in the CO_2 main compressor TPC to have the same effect. The TPC for the entire sCO_2 power cycle would have to increase over 15 percent for the COE of Case RhtIC620 to exceed that of the reference Rankine cycle.

Exhibit 6-17 shows a plot of first-year COE (without T&S) versus the change in TPC compared to the estimated value for Case RhtIC760. Again, the red dot corresponds to the results from the TEA and the dashed horizontal line is the COE for the reference AUSC Rankine cycle. In this case, the plot shows that the COE for Case RhtIC760 can be reduced to that of the reference Rankine plant with a reduction in TPC of $108MM, corresponding to just over 25 percent of the sCO_2 power cycle TPC.

Exhibit 6-17 Sensitivity of COE to TPC for Case RhtIC760



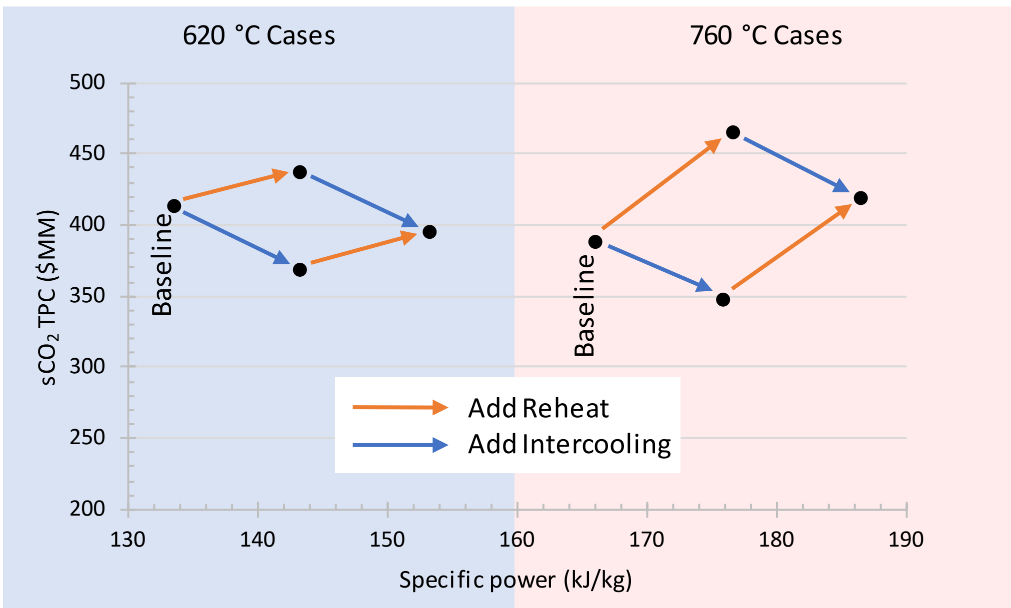
Source: NETL

As with Case RhtIC620, the CO_2 Turbine Section and Main CO_2 compressor contribute the most to the sCO_2 power cycle TPC. The TPC for the CO_2 Turbine Section would have to increase 84 percent or the TPC of the Main CO_2 compressor would have to increase over 150 percent for the COE of Case RhtIC760 to exceed that of the reference AUSC Rankine cycle.

7 Specific Power as a Surrogate for Cost

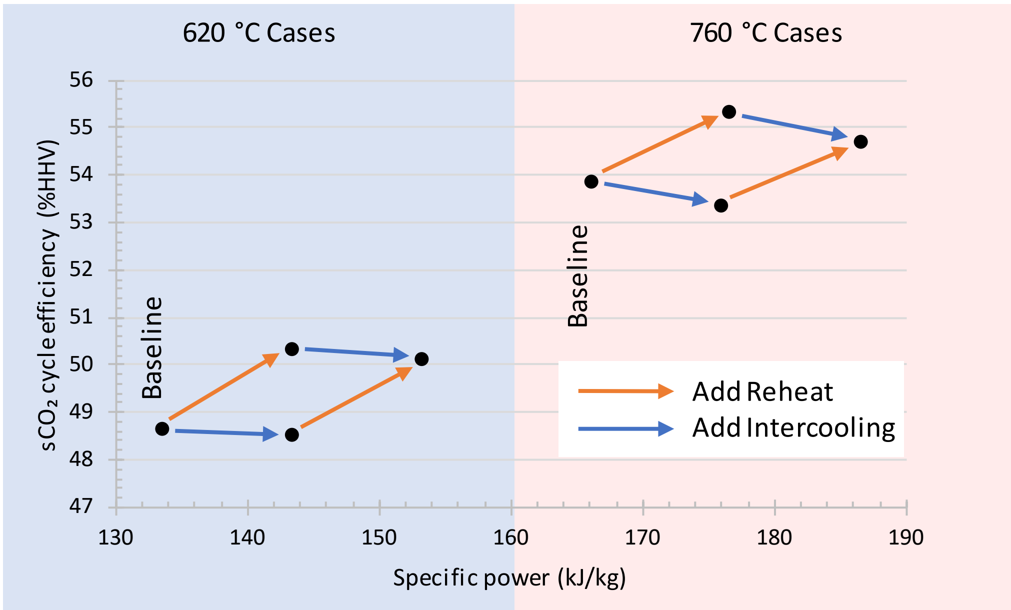
Prior studies have suggested that specific power is a useful surrogate for cost estimates for sCO_2 power cycles and power plants. [1] The justification for this is that specific power relates to cycle power density and the greater the specific power, the smaller the equipment needs to be, all other things being equal. To explore how well specific power correlates with cost, several of the key economic results from this study were plotted against the specific power for the corresponding case. Exhibit 7-1 shows a plot of the sCO_2 power cycle TPC ($MM) versus specific power. Since overall process efficiency is strong determinant of cost, the dependence of this variable on specific power was also examined with the plot shown in Exhibit 7-2. Combining the effects of TPC and efficiency, Exhibit 7-3 shows a plot of COE without T&S versus specific power.

Exhibit 7-1 sCO_2 power cycle TPC versus specific power



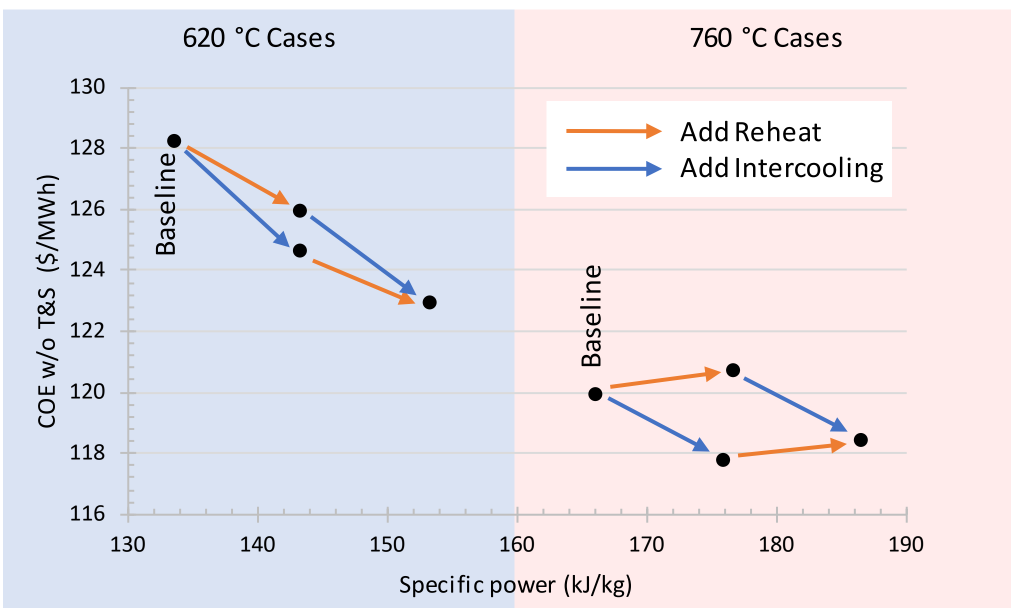
Source: NETL

Exhibit 7-2 Cycle efficiency versus specific power



Source: NETL

Exhibit 7-3 COE without T&S versus specific power



Source: NETL

While Exhibit 7-1 does not show a clear overall trend relating specific power to sCO_2 power cycle TPC, considering the effects of intercooling and reheating separately allows a few generalizations to be made. In particular, the addition of one stage of reheat to a given sCO_2 cycle generally increases specific power by 9-10 kJ/kg, but also increases sCO_2 cycle TPC. This is due primarily to the increase in sCO_2 piping costs, but also results from increased HTR duty and cost, as well as a slightly increased sCO_2 turbine cost. This effect is amplified in the 760 °C cases, where material cost premiums for reheat sections are higher than for the 620 °C cases.

Per Exhibit 7-1, the addition of one stage of main compressor intercooling has a similar effect as reheating in increasing specific power of a given cycle by about 10 kJ/kg. In contrast to reheating, however, intercooling serves to reduce sCO_2 cycle TPC in all cases. This is primarily driven by the lower sCO_2 cycle flow rate for a given power output (i.e., higher specific power), but is also significantly affected by reductions in the bypass compressor costs, which are generally about half of the bypass compressor costs in the non-intercooled cases. This bypass compressor cost reduction is due to three contributing effects: the beneficial effect of main compressor intercooling on reducing bypass compressor power requirements, per the discussion in Section 3.7.3; a reduction in the volumetric flowrate at the bypass compressor inlet, thereby reducing the size of the compressor; and a reduction in the bypass split fraction, also reducing the required duty of the compressor.

The overall sCO_2 cycle efficiency (Exhibit 7-2) shows a strong and consistent correlation with specific power. The plot is not monotonic because of the relatively large difference in process efficiency between Reheat and Intercooled cases at both TITs. It is particularly noteworthy that the addition of reheat is shown here to increase cycle efficiency in all cases, which in turn increases specific power. With the addition of main compressor intercooling, cycle efficiency may or may not increase, but specific power always increases, and is the primary driver for the sCO_2 cycle cost reductions seen in Exhibit 7-1.

The combined effects of sCO_2 cycle TPC (Exhibit 7-1) and cycle efficiency (Exhibit 7-2) on overall plant COE (without CO_2 T&S) are shown in Exhibit 7-3. Here, COE reductions resulting from the addition of main compressor intercooling are shown to be correlated to the increase in specific power for these cases. The effects of adding reheat are less clear, and are a combination of fuel savings from increased cycle efficiency (Exhibit 7-2), and increased sCO_2 cycle costs required for the addition of reheat (Exhibit 7-1), which are more severe for the 760 °C TIT cases. Considering all cases, the reductions in COE with respect to specific power are due more to the correlation between specific power and cycle efficiency (Exhibit 7-2) than on the effect of specific power on sCO_2 cycle TPC (Exhibit 7-1), which shows no clear trend as a function of TIT.

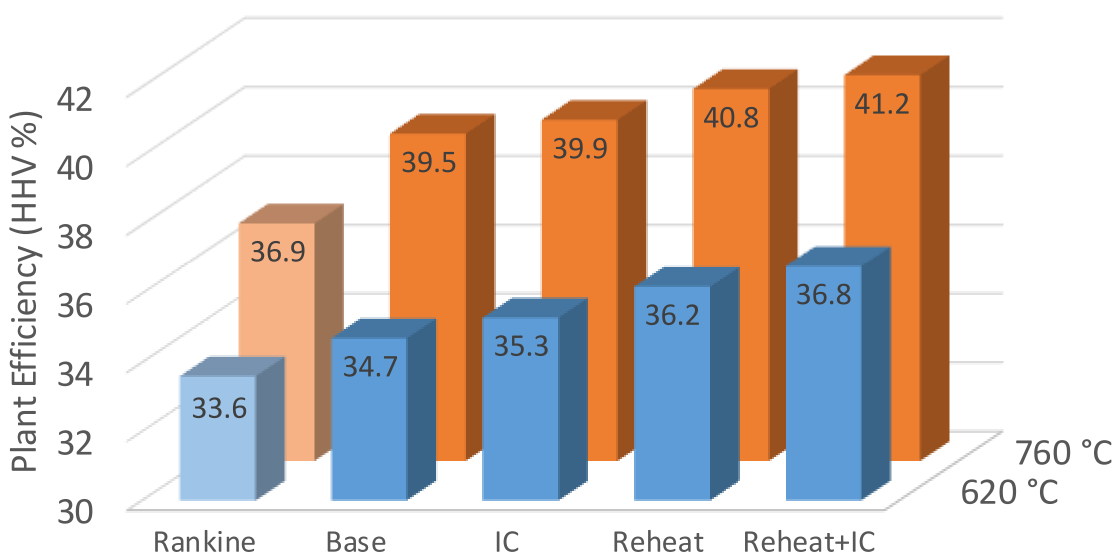
8 SUMMARY AND CONCLUSIONS

This report has presented the results of a TEA of a coal-fired utility scale power plant based on the indirect sCO_2 Brayton cycle using an oxy-fired CFB. A Baseline plant configuration was examined as well as three variations to the sCO_2 power cycle examining the impact of reheat, main compressor intercooling, and a combination of reheat and main compressor intercooling. Each plant configuration was assessed at two TITs of 620 °C and 760 °C.

Exhibit 8-1 shows the overall process efficiency (HHV basis) for the cases including reference Rankine plants at both TITs. The cases run at a TIT of 620 °C are shown in blue while the cases run at a TIT of 760 °C are shown in red. Exhibit 8-2 shows the COE without T&S for the cases in the same order and with the same color scheme as used in Exhibit 8-1.

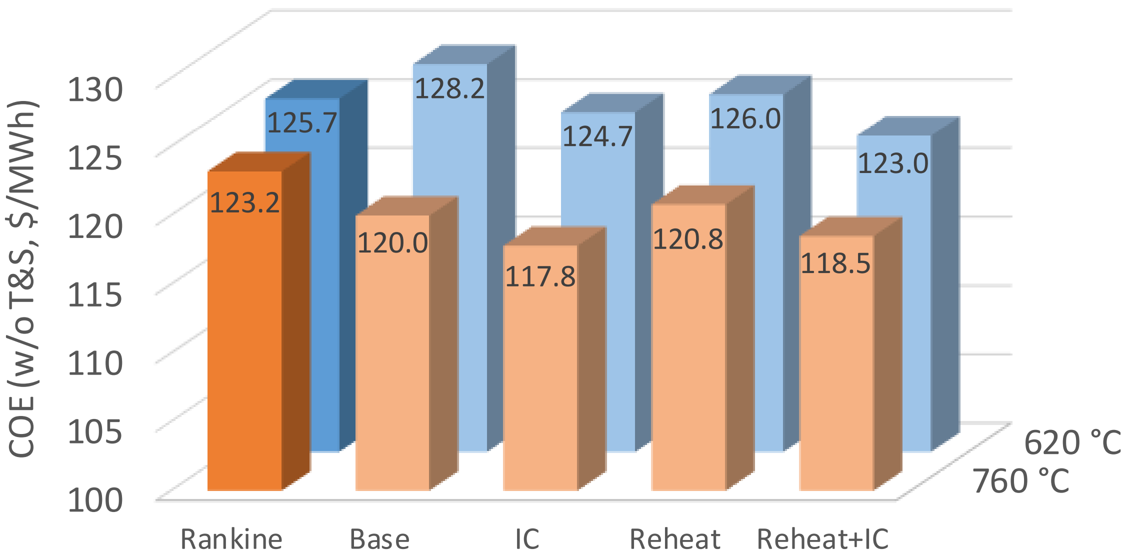
The results show that increasing the TIT from 620 °C (1148 °F) to 760 °C (1400 °F) increases process efficiency by 4.4 to 4.8 percentage points. This result is consistent with prior sensitivity analyses on indirect sCO_2 cycle sensitivity to TIT temperature. [1]

Exhibit 8-1 Summary of overall plant HHV efficiencies



Source: NETL

Exhibit 8-2 Summary of COEs without T&S



Source: NETL

The use of reheat and compressor intercooling, either singly or in combination, increases process efficiency moderately from 0.4 to 2.1 percentage points. The efficiency boost from both reheat and main compressor intercooling is greater for the 620 °C cases than for the 760 °C cases. The increase in process efficiency is due to both an increase in the intrinsic efficiency of the sCO_2 cycle and an increase in the amount of recovered heat.

With regard to the economic analysis, a major goal of the study was to examine the impact of lowering the TIT from 760 °C to 620 °C on the estimated COE. Lowering the TIT has direct and secondary effects that act to both decrease and increase cost. A lower TIT acts to lower costs primarily through a reduction in CO_2 piping cost and a reduction in the duty of the high-temperature recuperator. On the other hand, it acts to increase costs by reducing process efficiency leading to increased fuel costs, increasing sCO_2 flow rates in the power cycle leading to increased sCO_2 cycle equipment costs, and increasing balance of plant (BOP) costs. The above changes result in a net increase in the COE for the lower TIT cases.

In examining the impacts on plant economics relative to the baseline cases, the effect of reheat is to increase COE (slightly) for the 760 °C turbine inlet temperature case and decrease COE for the 620 °C turbine inlet temperature case, primarily due to the impact on piping costs. Intercooling the main CO_2 compressor decreases COE for both the 760 °C case and the 620 °C case, due to the increase in specific power and secondary effects of intercooling on the bypass compressor performance and cost. Finally, using reheat and main CO_2 compressor intercooling decreases COE for both the 760 °C TIT case and the 620 °C TIT case.

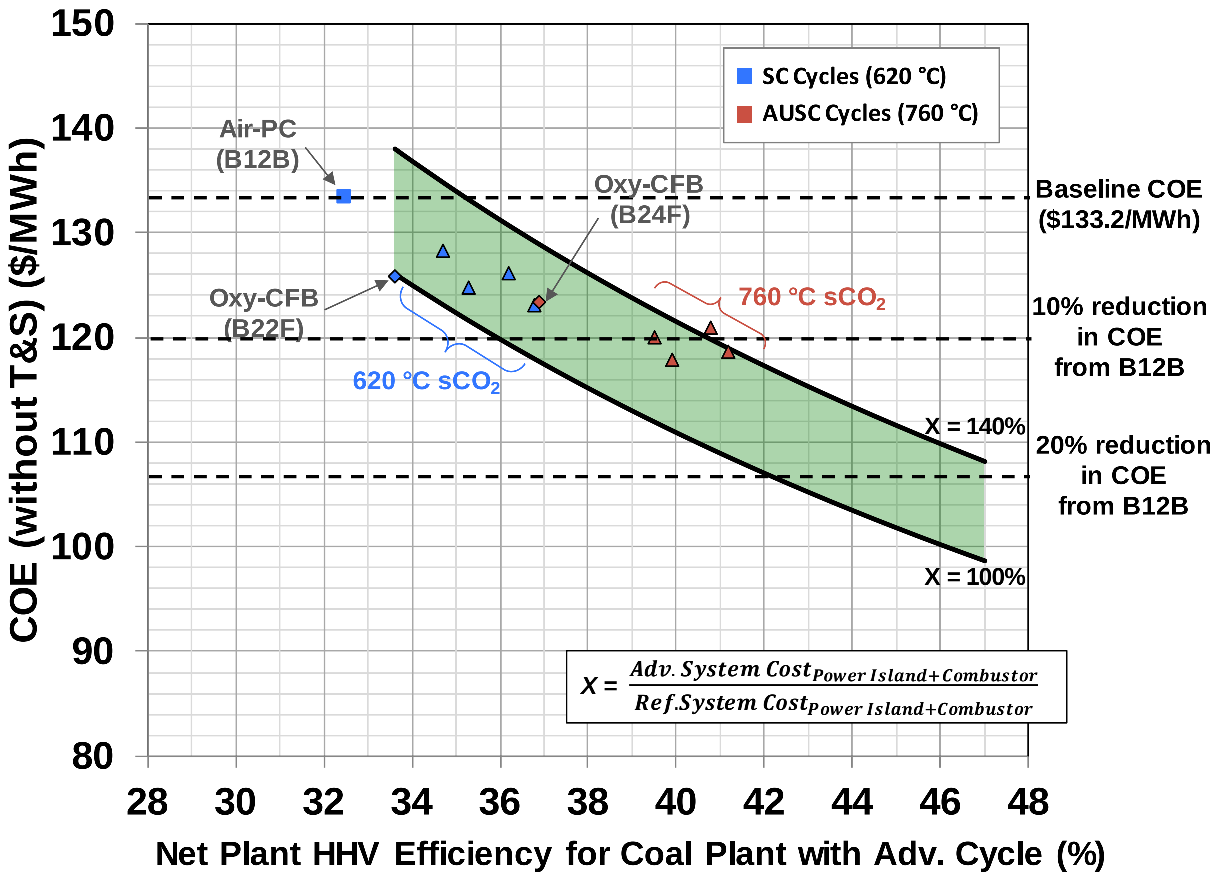
Several sensitivity analyses were performed to examine how variations in the operating state or capital cost estimates would impact the performance and economic results. The sensitivity to minimum recuperator temperature approach indicated that the value used in this study was economically attractive and that the minimum COE occurred at a minimum approach temperature of 4-5 °C. A detailed comparison of performance and cost was made for two runs of Case RhtIC760, one with a minimum temperature approach of 10 °F and the other with a minimum temperature approach of 10 °C.

The sensitivity analysis to flue gas recycle fraction indicated that the lower the recycle fraction, the higher the process efficiency and the lower the COE. However, operability constraints limit the maximum oxygen concentration in the bed and hence limit the minimum flue gas recycle fraction. A detailed economic comparison of performance was made for two runs of Case RhtIC760, one with a flue gas recycle fraction of 0.45 and the other with a flue gas recycle fraction of 0.715.

The sensitivity analysis to flue gas cooler duty indicated that the current state point is optimum with respect to this variable. The sensitivity to CO_2 cooler temperature suggested that significant improvements in cost and efficiency may be realized with lower cooler temperatures. Finally, the sensitivity analysis to capital cost quantified the effect of uncertainty in the capital cost estimate on the estimated COE.

Exhibit 8-3 shows a plot of COE versus net plant efficiency. The results for the ten cases presented in this study are shown on the plot as well as the results for a baseline case, an air-fired supercritical pulverized coal (PC) plant with carbon capture (Case B12B). [3] The dashed horizontal lines denote the COE for the baseline case (top line) as well as the COE values that are 10 percent and 20 percent lower than the baseline. The reference case is the supercritical oxy-combustion CFB with auto-refrigerated CPU (Case B22F, Reference SC Rankine) with \$0/tonne CO_2 revenue. The solid curved lines denote the dependence of COE on efficiency for the Reference SC Rankine plant (lower line) and an advanced plant having a power island and combustor cost 40 percent greater than the Reference SC Rankine plant. The data points show the higher efficiency and lower COE for sCO_2 cycles relative to steam plants.

Exhibit 8-3 Comparison of sCO_2 versus Rankine Cases



Source: NETL

9 RECOMMENDATIONS FOR FURTHER STUDY

The biggest area of uncertainty in this TEA is in the performance and cost estimates for the sCO_2 power cycle. A second major area of uncertainty is in the performance and cost estimates for the CFB as a heat source for sCO_2. To date there have been no commercial scale power plants based on the indirect sCO_2 cycle and no commercial scale oxy-fired CFB has been built to heat sCO_2. Thus, no vendor data is available to validate either the performance or cost models for the constituents. While vendor consults and ROMs were used, there remains significant uncertainty in the cost and performance of these units. Hence a major recommendation for further work is to conduct more detailed engineering designs of the CFB and sCO_2 power cycle components, particularly the turbomachinery and VTR, in an attempt to increase the accuracy of TEAs of utility scale power plants based on the indirect sCO_2 power cycle.

Additional recommendations are focused on potential improvements to the sCO_2 power cycle. The sensitivity analyses described in Section 6 indicate that reductions in both flue gas recycle rate and the CO_2 cooler temperature could improve both cost and efficiency. Exploring further reduction in the flue gas recycle fraction would require both a detailed design for the CFB and sophisticated computational fluid dynamic (CFD) modeling to determine the likelihood of temperature hot spots in the CFB should the recycle fraction drop further leading to an increase in the feed oxygen concentration.

A system analysis study to explore the impact of a lower CO_2 cooler temperature could be performed with the currently used models. Similar to the sensitivity analysis described in Section 6.4, this sensitivity analysis would adjust the temperature of the CO_2 cooler temperature but also re-calibrate the cycle state point, particularly the compressor inlet pressure, to get maximum performance from the cycle. In conjunction with this, adjustments would be made to the heat integration scheme to better optimize the plant performance.

It is further recommended that systems analysis studies be performed on alternate process configurations than those investigated in this study and work in this area has already begun. A preliminary analysis for a cycle that extends Case RhtLC760 to include a condensing CO_2 section results in an efficiency of 41.9 percent HHV and 115.8 COE without T&S ($/MWh).

10 REFERENCES

[1] National Energy Technology Laboratory (NETL), "An Assessment of Supercritical CO2 Power Cycles Integrated with Generic Heat Sources," 4th International Symposium – Supercritical CO2 Power Cycles, Pittsburgh, September 9-10, 2014.

[2] G. Subbaraman, J. A. Mays, B. Jazayer, K. M. Sprouse and others, "ZEPS Plant Model: A High Efficiency Power Cycle with Pressurized Fluidized Bed Combustion Process," 2nd Oxyfuel Combustion Conference, Queensland, Australia, September 2011.

[3] National Energy Technology Laboratory (NETL), "Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 3," NETL, Pittsburgh, June 2015.

[4] National Energy Technology Laboratory (NETL), "Quality Guidelines for Energy System Studies, Cost Estimation Methodology for NETL Assessments of Power Plant Performance," NETL, Pittsburgh, January 2013.

[5] National Energy Technology Laboratory (NETL), "Quality Guidelines for Energy System Studies -- Fuel Prices for Selected Feedstocks in NETL Studies," NETL, Pittsburgh, November 2012.

[6] National Energy Technology Laboratory (NETL), "Quality Guidelines for Energy System Studies: Estimating Carbon Dioxide Transport and Storage Costs," NETL, Pittsburgh, 2013.

[7] National Energy Technology Laboratory (NETL), "Quality Guidelines for Energy System Studies -- Detailed Coal Specifications," NETL, Pittsburgh, January 2012.

[8] National Energy Technology Laboratory (NETL), "Quality Guidelines for Energy System Studies -- Capital Cost Scaling Methodology," NETL, Pittsburgh, January 2013.

[9] AACE International Recommended Practice Number 16R-90, "Conducting Technical and Economic Evaluations -- As Applied for the Process and Utility Industries; TCM Framework 7.3 -- Cost Estimating and Budgeting," AACE, 2003.

[10] National Energy Technology Laboratory (NETL), "NETL System Study Cost Metrics Cheat Sheet," NETL, Pittsburgh, August 2013.

[11] National Energy Technology Laboratory (NETL), "Techno-economics of Bituminous Coal Atmospheric Air and Oxy-Combustion Plants with Circulating Fluidized Bed Technology," NETL, Pittsburgh, June 2015.

[12] National Energy Technology Laboratory (NETL), "Advanced Oxy-combustion Technology for Pulverized Bituminous Coal Power Plants," NETL, Pittsburgh, November 2013.

[13] AUSC Consortium, "Engineering and Economic Analysis of an Advanced Ultra-Supercritical Pulverized Coal Power Plant with and without Post-Combustion Carbon Capture, Topical Report Task 7: Design and Economic Studies," 2015.

[14] D. Fleming, T. Conboy, J. Pasch, G. Rochau, R. Fuller, T. Holschuh and S. Wright, "Scaling Considerations for a Multi-Megawatt Class Supercritical CO2 Brayton Cycle and Path Forward for Commercialization," SAND2013-9106, November 2013.

[15] National Energy Technology Laboratory (NETL), "Analysis of Brayton Cycles Utilizing Supercritical Carbon Dioxide," NETL, Pittsburgh, July 2014.

[16] National Energy Technology Laboratory (NETL), "Techno-economic Analysis for 10 MW Supercritical CO2 Pilot Plant," NETL, Pittsburgh, April 2015.

[17] Aerojet Rocketdyne, "Turbine Technology Program Phase III - Task 2(b): Supercritical CO2 Turbomachinery (SCOT) System Studies Recuperator Development," DOE Contract No. DE-FE0004002, August 13, 2014.

[18] Y. Le Moullec, "Conceptual study of a high efficiency coal-fired power plant with CO2 capture using a supercritical CO2 Brayton cycle," *Energy,* vol. 49, 2013.

[19] National Energy Technology Laboratory (NETL), "Report on Newly Developed A-USC Materials," NETL, Pittsburgh, 2014.

[20] Alstom Power Inc., "Commercialization Development of Oxygen Fired CFB for Greenhouse Gas Control Volume 1: Pilot Scale Testing and Design Study of an Existing CFB Retrofit to Oxygen Firing and CO2 Capture Final Report," August 2007.

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