NATIONAL ENERGY TECHNOLOGY LABORATORY

Current and Future Technologies for Natural Gas Combined Cycle (NGCC) Power Plants

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Table of Contents

List of Exhibits

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List of Acronyms and Abbreviations

acfm	Actual cubic feet per minute
AEO	Annual Energy Outlook
AGR	Acid gas removal
Ar	Argon
ASU	Air separation unit
atm	Atmosphere
BACT	Best available control technology
BBS	Bituminous baseline study
BEC	Bare erected cost
BFD	Block flow diagram
BFW	Boiler feed water
BLS	U.S. Bureau of Labor Statistics
Btu	British thermal unit
Btu/hr	British thermal unit per hour
CCF	Capital charge factor
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization, and storage
CDR	Carbon dioxide recovery
CF	Capacity factor
CGE	Cold gas efficiency
cm	Centimeter
CM	Construction management
CO_2	Carbon dioxide
COE	Cost of electricity
COH	Cost of hydrogen
COS	Carbonyl sulfide
CTG	Combustion turbine generator
CS	Carbon Steel
CWT	Cold water temperature
DB	Dry basis
DCS	Distributed control system
DI	De-ionized
DOE	Department of Energy
EGR	Exhaust gas recycle
EIA	Energy Information Administration
EOR	Enhanced oil recovery
EPA	Environmental Protection Agency
EPC	Engineering, procurement, construction
EPRI	Electric Power Research Institute
ERC	Emission reduction credits
ETE	Effective thermal efficiency
FD	Forced draft
FG	Flue gas
ft	Foot, Feet
FW	Feedwater
FOAK	First of a kind
FO&M	Fixed operations and maintenance
gal	Gallon
gal/MWh	Gallon per megawatt hour
gpm	Gallons per minute
GEE	General Electric Energy
GJ	Gigajoule
GT	Gas turbine
H_2	Hydrogen
HHV	Higher heating value
HCl	Hydrogen chloride
H.O.	Home office
hp	Horsepower
HP	High pressure
hr	Hour
HRSG	Heat recovery steam generator
HSS	Heat stable salts
HVAC	Heating, ventilating, and air conditioning
HWT	Hot water temperature
Hz	Hertz
ID	Induced draft
IEA	International Energy Agency
IGCC	Integrated coal gasification combined cycle
in	Inch, inches
in H_2O	Inches water
in Hga	Inches mercury (absolute pressure)
in W.C.	Inches water column
IOU	Investor-owned utility
IRROE	Internal rate of return on equity
ISO	Internaltional organization of standards standard reference conditions and ratings
kg/hr	Kilogram per hour
kJ	Kilojoules
kJ/hr	Kilojoules per hour
KO	Knockout
kPa	Kilopascal absolute
kV	Kilovolt
kW	Kilowatt
kWe	Kilowatts electric
kWh	Kilowatt-hour
kWt	Kilowatts thermal
LAER	Lowest achievable emission rate
LCOE	Levelized cost of electricity
lb	Pound
lb/hr	Pounds per hour
lb/ft^2	Pounds per square foot
LHV	Lower heating value
LIBOR	London Interbank Offered Rate
LNB	Low NOx burner
LP	Low pressure
lpm	Liters per minute
LV	Low voltage
NOx	Oxides of Nitrogen
NSPS	New Source Performance Standards
m	Meters
m/min	Meters per minute
m^3/min	Cubic meter per minute
MAF	Moisture and Ash Free

MCR	Maximum continuous rate
md	millidarcy, is a measure of permeability defined as roughly 10^{-12} Darcy
MEA	Monoethanolamine
MHI	Mitsubishi Heavy Industries, Ltd.
MHz	Megahertz
million $	Millions of dollars
MJ	Megajoules
MMBtu	Million British thermal units (also shown as 10^6 Btu)
MMBtu/hr	Million British thermal units (also shown as 10^6 Btu) per hour
MMSCFD	Million standard cubic feet per day
mole%	Mole percent (percent by mole)
MPa	Megapascals absolute
MVA	Megavolt (average)
MWe	Megawatts electric
MWh	Megawatt-hour
MWt	Megawatts thermal
N_2	Nitrogen
Neg.	Negligible
NETL	National Energy Technology Laboratory
N/A	Not applicable
NGCC	Natural gas combined cycle
nm^3	Normal cubic meter
NOAK	N^{th} of a kind
NOx	Oxides of nitrogen
NSPS	New Source Performance Standards
NSR	New Source Review
O_2	Oxygen
O&M	Operation and maintenance
OC	Operating cost
OEM	Original equipment manufacturer
Oper. Qty	Operating quantity
OSU	Ohio State University
PM	Particulate matter
POTW	Publicly owned treatment works
ppm	Parts per million
ppmd	Parts per million, dry basis
ppmv	Parts per million volume
ppmvd	Parts per million volume, dry
ppmw	Parts per million weight
PR	Pressure ratio
PSFM	Power Systems Financial Model
psia	Pounds per square inch absolute
psid	Pounds per square inch differential
psig	Pounds per square inch gage
QGESS	Quality Guidelines for Energy System Studies
Qty	Quantity
Ref.	Reference
scf	Standard cubic feet
scfd	Standard cubic feet per day
scfm	Standard cubic feet per minute
Sch.	Schedule
SCR	Selective catalytic reduction
scm	Standard cubic meter
SG	Specific gravity
SNG	Synthetic/substitute natural gas
SO_2	Sulfur dioxide
SOA	State-of-the-art
SOx	Oxides of sulfur
SS	Stainless steel
ST	Steam turbine
STG	Steam turbine generator
Stm	Steam
SWS	Sour water scrubber
T&S	Transport and storage
TASC	Total as-spent cost
TET	Turbine exhaust temperature
TEWAC	Totally Enclosed Water-to-Air-Cooled
TGTU	Tail gas treatment unit
TIT	Turbine inlet temperature
TOC	Total overnight cost
TPC	Total plant cost
tpd	Tons per day
tph	Tons per hour
TPI	Total plant investment
tonne	Metric ton (1000 kg)
T&S	Transport and storage
U.S.	United States
Vert.	Vertical
V-L	Vapor and liquid portion of stream (excluding solids)
VO&M	Variable operations and maintenance
vol%	Volume percent (percent by volume)
WB	Wet bulb
WG	Water gauge
WGS	Water gas shift
wt%	Weight percent (percent by weight)
WTI	West Texas intermediate crude oil
$M	Millions of dollars
°C	Degrees Celsius
°F	Degrees Fahrenheit

Executive Summary

The purpose of this study is to present the cost and performance of natural gas combined cycle (NGCC) power plants using state-of-the-art (SOA) and advanced gas turbines, both non-capture configurations and with post combustion carbon capture based on an advanced solvent process.

The NGCC cases included in this study consist of four gas turbine designs: F-frame (GE 7FA.05), H-frame (based on Siemens H), advanced J-frame (based on MHI J), and a conceptual advanced future design (designated as X-frame). Each turbine is modeled in three process configurations: without CO_2 capture, with CO_2 capture, and with CO_2 capture and exhaust gas recycle (EGR). The case designations are listed in Exhibit ES-1.

Exhibit ES-1 Case descriptions

Turbine	Turbine Basis	Non-Capture Target Efficiency (%LHV)	Case #	CO_2 Capture Configuration
SOA F-Frame	GE 7FA.05	~58%	1a	None
			1b	CO_2 capture
			1c	capture + EGR
SOA H-Frame	Siemens H Turbine	~60%	2a	None
			2b	CO_2 capture
			2c	capture + EGR
Advanced J-Frame	Enhanced MHI J Turbine	~62%	3a	None
			3b	CO_2 capture
			3c	capture + EGR
Advanced Future X-Frame	X-Frame	~65%	4a	None
			4b	CO_2 capture
			4c	capture + EGR

NGCC simulations were developed for each case using GT PRO and THERMOFLEX software. [1] The 7FA.05 turbine was based on a Thermoflow turbine library model supplied in the software. The performance model for each of the more advanced turbines was developed by tuning an existing Thermoflow turbine library model with properties close to those estimated for each case. Each simulation was then tuned to match the expected overall performance of the NGCC without capture.

The methodology used in this study was similar to that used in earlier National Energy Technology Laboratory (NETL) Department of Energy (DOE) studies [2, 3], except for the modeling software, Thermoflow's GT-PRO and THERMOFLEX were used instead of Aspen Plus®. The resulting mass and energy balance data from the GT-PRO and THERMOFLEX models were used to size major pieces of equipment. Capital and operating costs for the Cases 1a, 1b, and 1c using the 7FA.05 turbine as well as Cases 4a, 4b, and 4c using the advanced future X-frame turbine were estimated by WorleyParsons based on simulation results and vendor quotes/discussions, costing software, or a combination of the two. All costs are in June 2011 dollars. The turbine costs for each of the other cases were also estimated by WorleyParsons based on simulation results and vendor quotes/discussions. The remaining capital and operating costs were scaled from the initial estimates based on simulation results and current NETL Quality Guidelines for Energy System Studies (QGESS). [4] Owner's costs are included in the present estimates in a manner consistent with earlier NETL/DOE studies. [2, 3, 5] The natural gas cost was assumed to be $5.81/GJ ($6.13/MMBtu) as specified in "QGESS: Fuel Prices for Selected Feedstocks in NETL Studies" [6] for natural gas delivered to large combined cycle plants operating at high capacity factors in the Midwest. The price is on a higher heating value (HHV) basis and in 2011 dollars. A sensitivity evaluation to the natural gas price is included that varied from $2.94/GJ ($3.00/MMBtu) to $7.58/GJ ($8.00/MMBtu).

All plant configurations are evaluated based on installation at a Greenfield site. The overall availability/capacity factor was set at 85 percent for all cases to be consistent with earlier NETL/DOE studies. [2, 3] The power system for each case includes two gas turbines (GT), two heat recovery steam generators (HRSG), and one steam turbine (ST) (2 x 2 x 1).

The performance and cost estimation results for the cases in this study are summarized in Exhibit ES-2. The net power output ranges from 634 to 1,108 MWe for the non-capture cases. Adding carbon capture reduces the power output by 12 to 15 percent due to the increasing auxiliary power requirements (i.e., due to the solvent process and CO_2 compression). The further addition of EGR results in a slightly smaller decrease of 10 to 13 percent by increasing the efficiency of the carbon capture section. The major parameters that change as the turbine performance increases are the turbine inlet/firing temperature (TIT) and the pressure ratio (PR). As the TIT increases, more fuel and compressor inlet air are required which results in the power increase noted above. The pressure ratio increases with the TIT to maintain approximately the same percentage of the total power generation in the more efficient Brayton Cycle rather than in the bottoming Rankine Cycle.

The results for each turbine with the addition of CO_2 capture alone and CO_2 capture with EGR are approximately equal for the projected cost of electricity (COE) and the overall process efficiency. CO_2 transport and storage (T&S) costs were independently estimated by NETL to be $10/tonne for a 100 km (62 mile) pipeline to a representative Midwest saline formation [7] and added to the COE estimates for an overall value.

The addition of EGR at 35 percent of the flue gas exhaust improves the efficiencies by approximately 0.5 percentage point and decreases the COE by approximately 3 percent. The net power output and efficiency both increase with each turbine design improvement.

As a result of the improvements, the normalized total overnight cost (TOC) and cost of electricity (COE) values decrease as the turbine design improves.

Exhibit ES-2 Case results summary
(Values shown are for total 2 GT x 2 HRSG x 1 ST system)

Turbine	Case / Technology		Efficiency (% HHV/ LHV)	Net Power (MWe)	TOC ($/kW)	COE without CO_2 T&S ($/MWh)	COE with CO_2 T&S ($/MWh)	Cost of CO_2 avoided ($/tonne)	Cost of CO_2 captured ($/tonne)
SOA (based on "7FA.05")	1a	w/o CO_2 capture	51.8 / 57.4	634	829	57.14	57.14	n/a	n/a
	1b	w CO_2 capture	45.2 / 50.1	553	1,674	80.62	84.27	86.59	64.24
	1c	w CO_2 +EGR	45.7 / 50.6	563	1,568	78.32	81.92	78.94	58.75
SOA (based on "H")	2a	w/o CO_2 capture	53.7 / 59.5	820	756	54.19	54.19	n/a	n/a
	2b	w CO_2 capture	47.2 / 52.2	721	1,499	75.03	78.53	80.45	59.53
	2c	w CO_2 +EGR	47.7 / 52.9	738	1,396	72.71	76.16	72.48	53.70
Advanced (based on "J")	3a	w/o CO_2 capture	56.5 / 62.6	982	684	50.73	50.73	n/a	n/a
	3b	w CO_2 capture	50.1 / 55.5	870	1,343	69.17	72.47	75.60	56.02
	3c	w CO_2 +EGR	50.6 / 56.1	889	1,251	67.17	70.42	68.35	50.56
Advanced Future turbine	4a	w/o CO_2 capture	58.8 / 65.2	1,108	661	49.17	49.17	n/a	n/a
	4b	w CO_2 capture	52.5 / 58.1	989	1,271	66.21	69.35	73.00	54.23
	4c	w CO_2 +EGR	52.8 / 58.5	1,004	1,190	64.56	67.67	66.86	49.44

COEs based on a natural gas price of $6.13/MMBtu and 85% capacity factor in June 2011 dollars

CO_2 capture technology represents an advanced solvent process

COE = (Annual Capital Charges + O&M + Fuel ($/yr)) / (Annual MWh_{net})

CO_2 T&S = $10/tonne for a 100 km (62 mile) pipeline to a representative Midwest saline formation

Cost of CO_2 avoided = ($COE_{with\ capture}$ – $COE_{w/o\ capture}$ ($/MWh)) / ($Emissions_{w/o\ capture}$ – $Emissions_{with\ capture}$) (tons/MWh)), includes CO_2 T&S

Cost of CO_2 captured = ($COE_{with\ capture}$ – $COE_{w/o\ capture}$ ($/MWh)) / ($CO_{2\ captured}$ (tons/MWh)), excludes CO_2 T&S

Reference case for Cost of CO_2 avoided and Cost of CO_2 captured calculation = Matching turbine without capture case.

See Section 2.8 for calculation details.

The normalized capital costs (TOC) are shown by component for each case in Exhibit ES-3. All values are in June 2011 dollars. As the turbine design improves, the capital costs per MW decrease. The reduction in TOC for modifications from SOA to the advanced future turbine design is approximately 20 percent for the without capture cases and 25 percent for the cases with capture. The capital costs for the capture cases (both with and without EGR) are approximately twice the amount as the non-capture cases for each turbine design. This is due primarily to the high additional capital costs for the capture technology.

The COE values are shown by component for each case in Exhibit ES-4. All values are in June 2011 dollars. As the turbine design (performance efficiency) improves, the COE decreases. The COE for the capture cases (both with and without EGR) are 38 to 46 percent higher than the COE for the non-capture cases for each turbine design. The difference decreases slightly as the turbine design improves.

The fuel component accounts for the largest portion of the COE for NGCC plants (approximately 72 percent for without capture and 58 percent for with capture cases.) This is a major difference when compared with coal power plants. The sensitivities of the COEs to the price of natural gas are shown in Exhibit ES-5. The $6.13/MMBtu price assumed for this study is along the vertical line shown in the chart. As the price increases, the COEs increase. The non-capture cases are slightly more sensitive than the capture cases; primarily because the capital component becomes more significant in the capture cases. A natural gas cost reduction of 51 percent (to $3/MMBtu) results in an average of 37 percent decrease in the non-capture values but only a 29 percent decrease in the capture case values. An increase of 31 percent (to $8/MMBtu) results in an average of 22 percent increase in the non-capture values but only an 18 percent increase in the capture case values. The impact of the price on the COE is approximately the same for all turbine designs since the annual fuel costs are a large portion of the COEs (71 to 73 percent of the non-capture cases and 55 to 59 percent of the capture cases).

The sensitivities of the first year COEs to capacity factor are shown in Exhibit ES-6. The values at the 85 percent capacity factor assumed for this study are along the vertical line shown in the chart. As the capacity factor increases, the COEs decrease. The calculations were made with the assumption that no addition or reduction in equipment or capital would be needed to operate at higher or lower capacity factors. The capacity factor has a smaller impact as the turbine design improves.

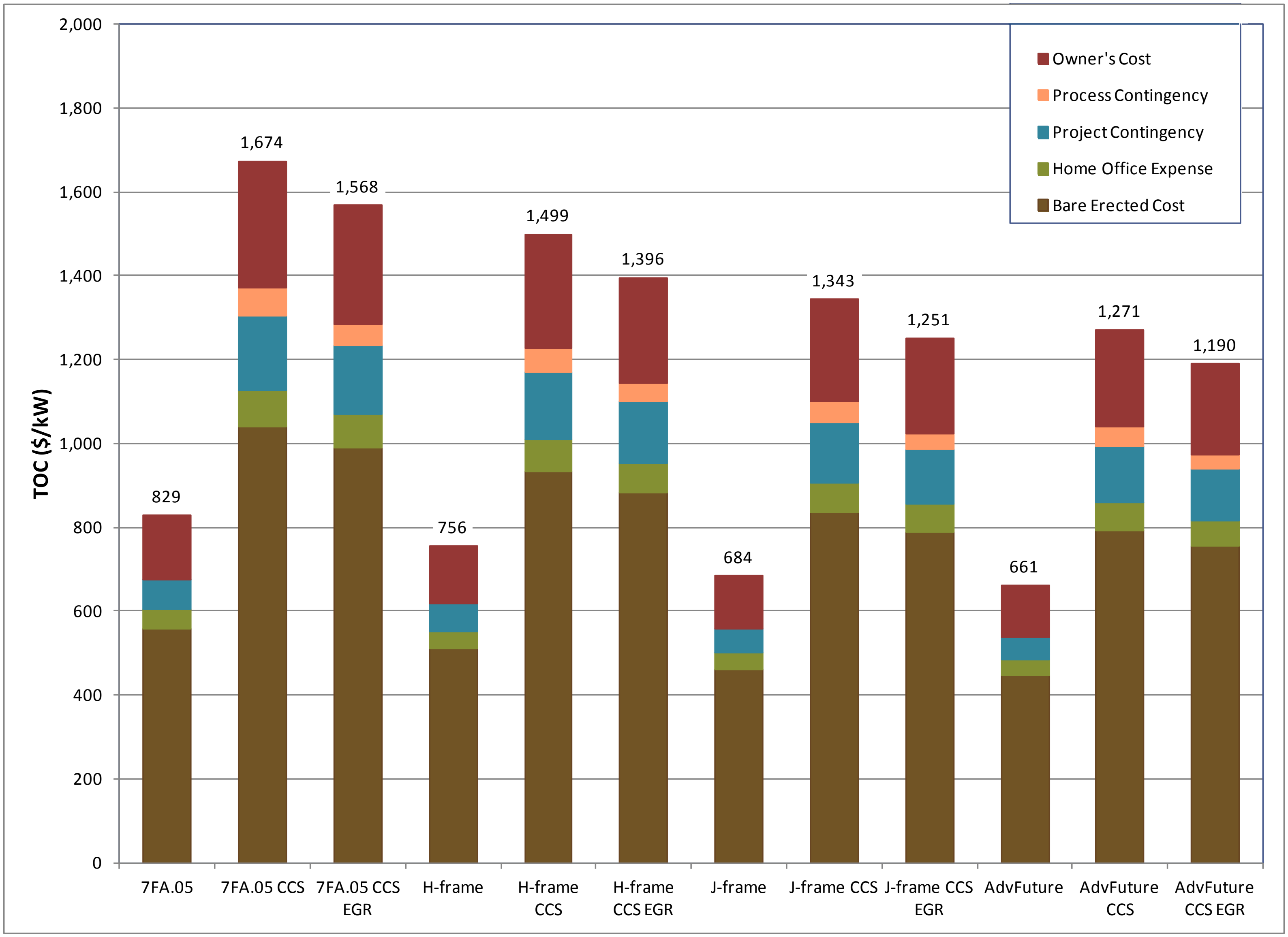
Options for carbon dioxide storage include both a saline reservoir and storage/use in enhanced oil recovery (EOR). The EOR option may be attractive even without the passage of regulations depending on the price of oil. The higher oil prices climb, the more incentive there is to recover more oil using enhanced techniques, like CO_2 injection, which could result in an increase of the sale price for CO_2 to oil recovery operations. The sensitivities of the COEs (excluding CO_2 T&S) to CO_2 plant gate sales price are shown in Exhibit ES-7. The horizontal lines represent the non-capture case values. As the CO_2 sales price increases, COEs for the capture cases decrease and approach the non-capture values. The CO_2 sales price value at the point where each capture case line crosses the corresponding non-capture line is equal to the cost of CO_2 captured for that capture case.

The normalized annual CO_2 emissions for each case are shown in Exhibit ES-8. The emissions per MWh decrease by approximately 3.5 to 5.8 percent for each turbine design improvement with the overall decrease of 12 to 14 percent going from the current SOA to the advanced future turbine design. The emissions from the current SOA turbine without capture case are estimated at 760 lb/MWh_{gross}. The Environmental Protection Agency (EPA) recently proposed a CO_2 emissions limit of 1,000 lb/MWh_{gross} for new power plants. This rule would result in carbon capture not being required for NGCC.

This study provides the following analysis tools and findings:

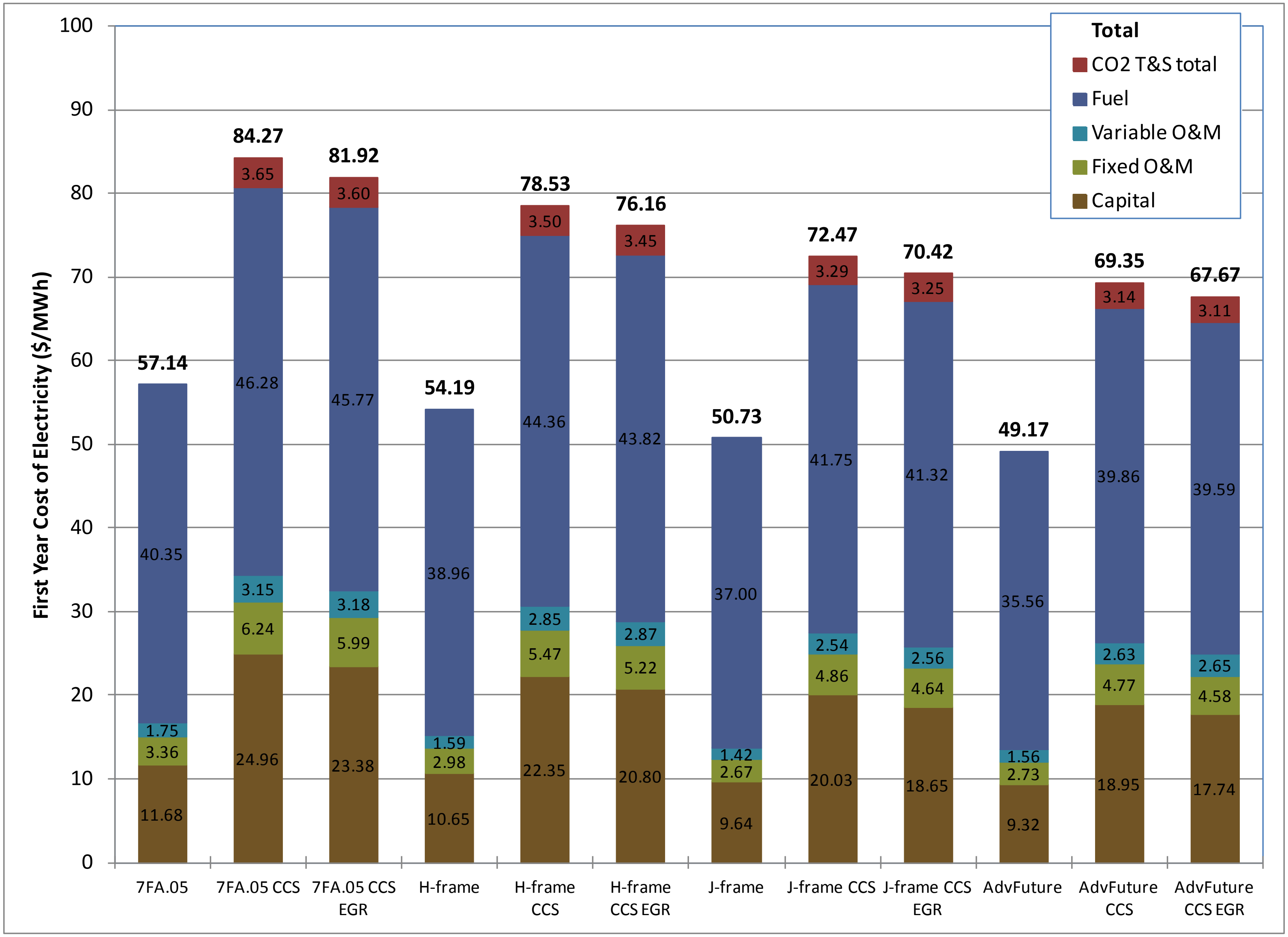
- Process simulation models of NGCC plants representing both SOA and advanced gas turbines, with and without an advanced post combustion capture system, are available to compare with coal power plants. Additionally, as new and evolving capture technologies develop, the models can be easily modified to evaluate the benefits.
- The performance penalty for carbon capture is approximately 6-7 absolute percentage points for the advanced solvent process represented.
- EGR greater than 35 percent may be required to further improve results.
- Natural gas fuel costs account for approximately 72 percent of the COE for the non-capture cases and approximately 57 percent for the CO_2 capture cases when based on a price of $5.81/GJ ($6.13/MMBtu). This implies that comparisons with coal power plants, which are less sensitive to fuel costs, will be greatly influenced by natural gas prices.
- The EPA recently proposed CO_2 emissions limit of 1,000 lb/MWh_{gross} for new power plants, which would result in carbon capture not being required for NGCC.
- Carbon capture plants require a sales price for CO_2 of approximately $50 to $65/tonne for capture cases to have a COE equivalent to non-capture cases.

Exhibit ES-3 Plant capital costs



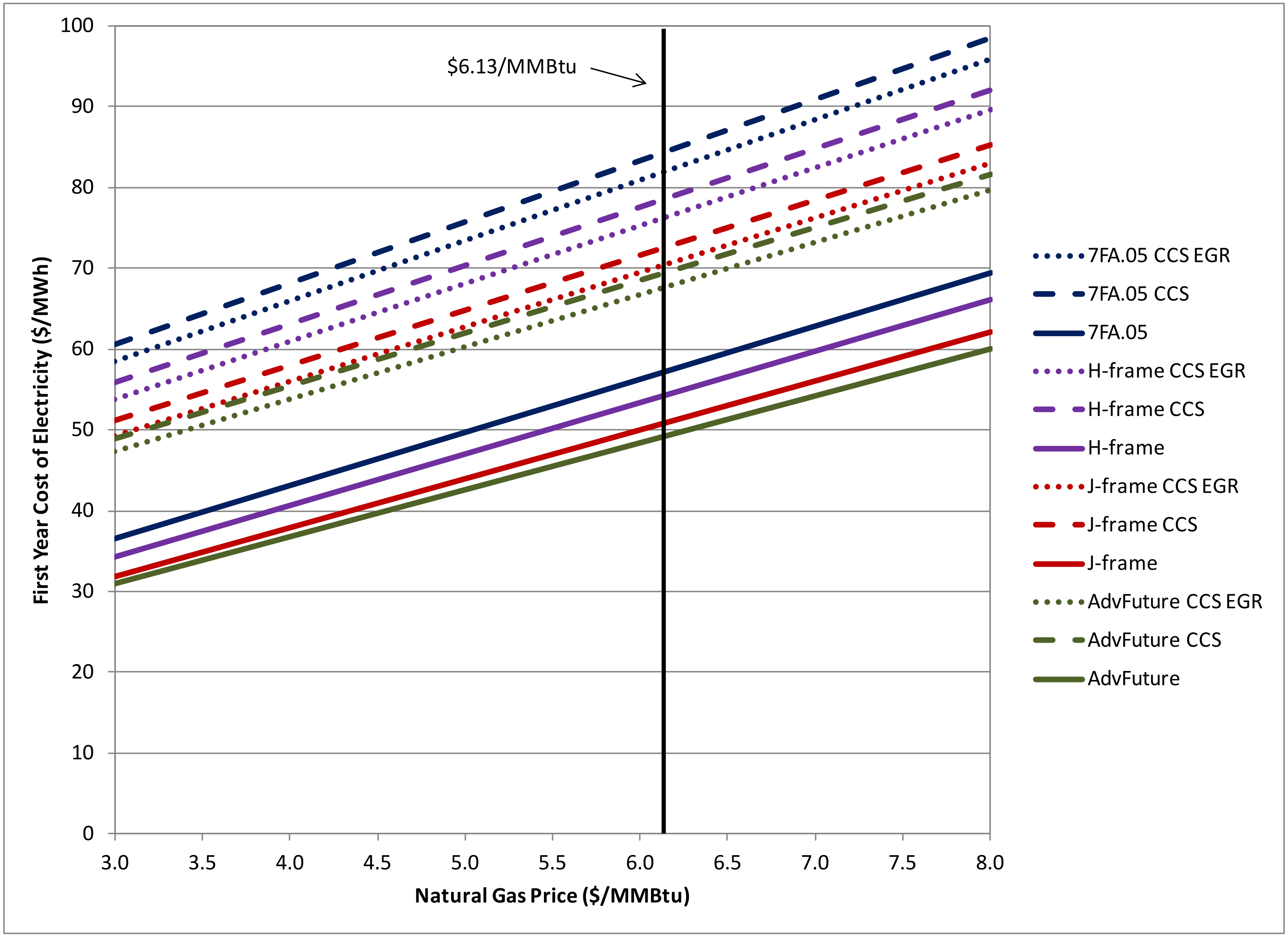
Source: NETL (All Costs are in June 2011 dollars)

Exhibit ES-4 COE by cost component



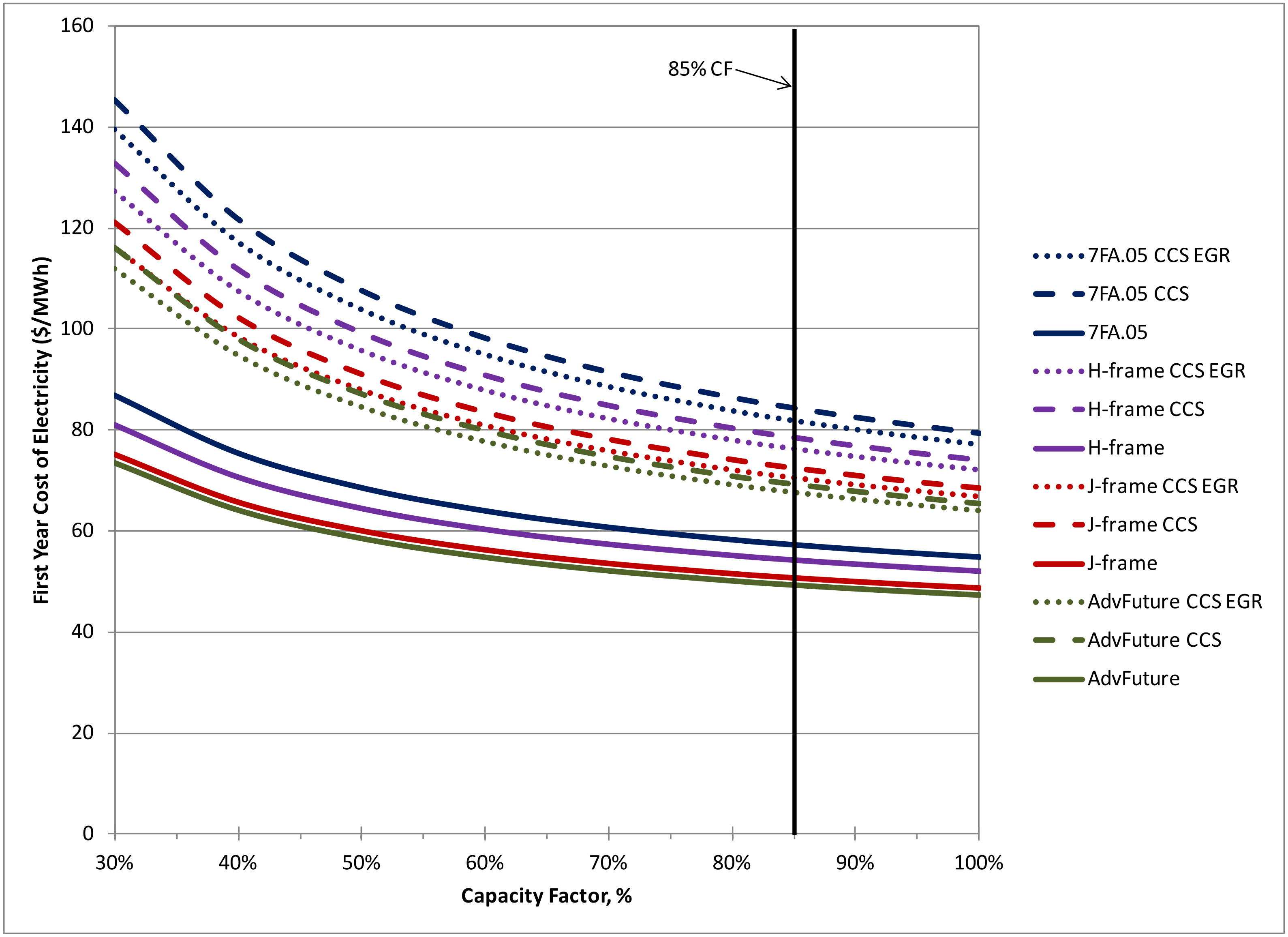
Source: NETL (All Costs are in June 2011 dollars, 85% capacity factor)

Exhibit ES-5 COE sensitivity to natural gas price



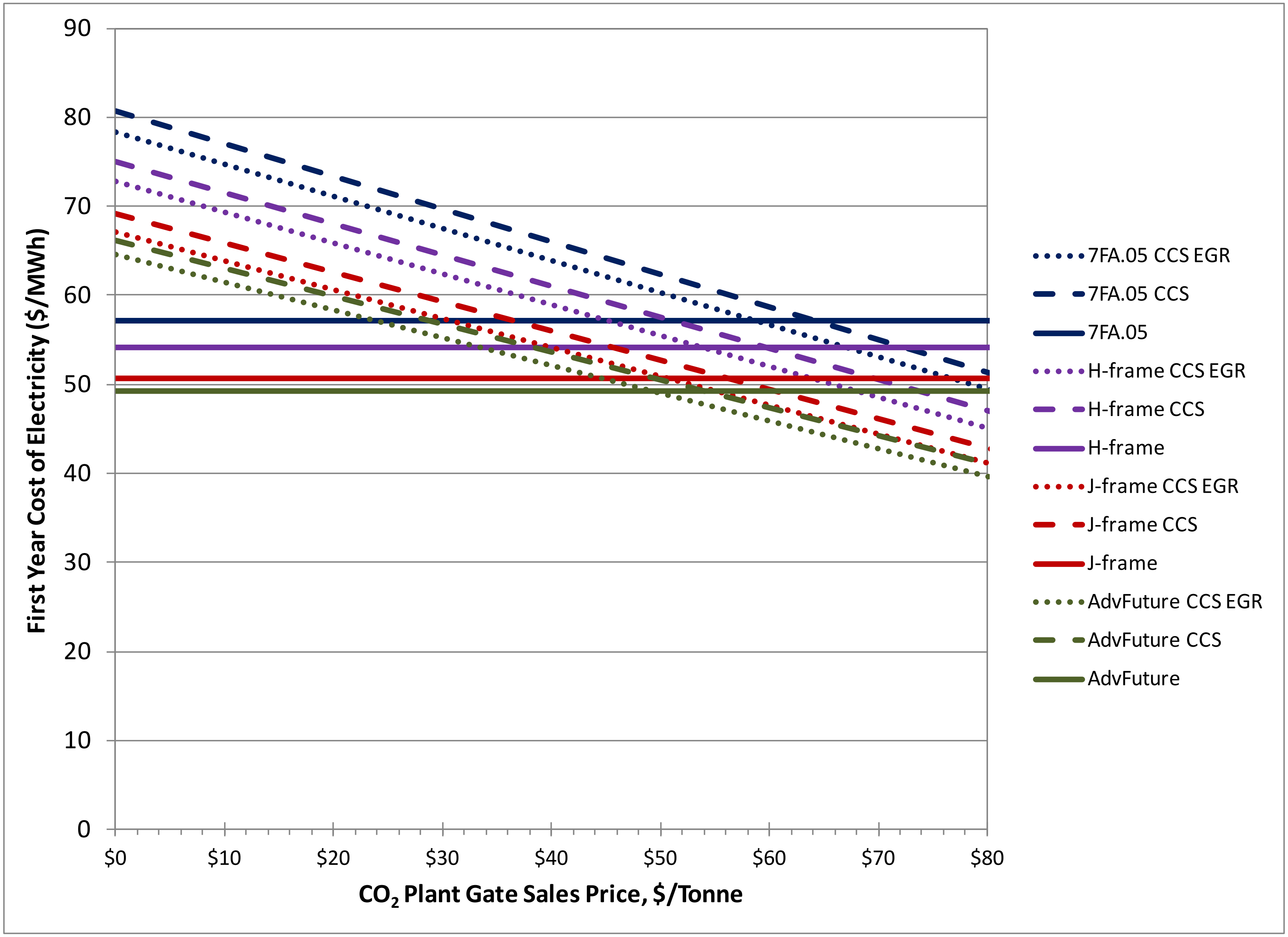
Source: NETL (All Costs are in June 2011 dollars, 85% capacity factor)

Exhibit ES-6 COE sensitivity to capacity factor



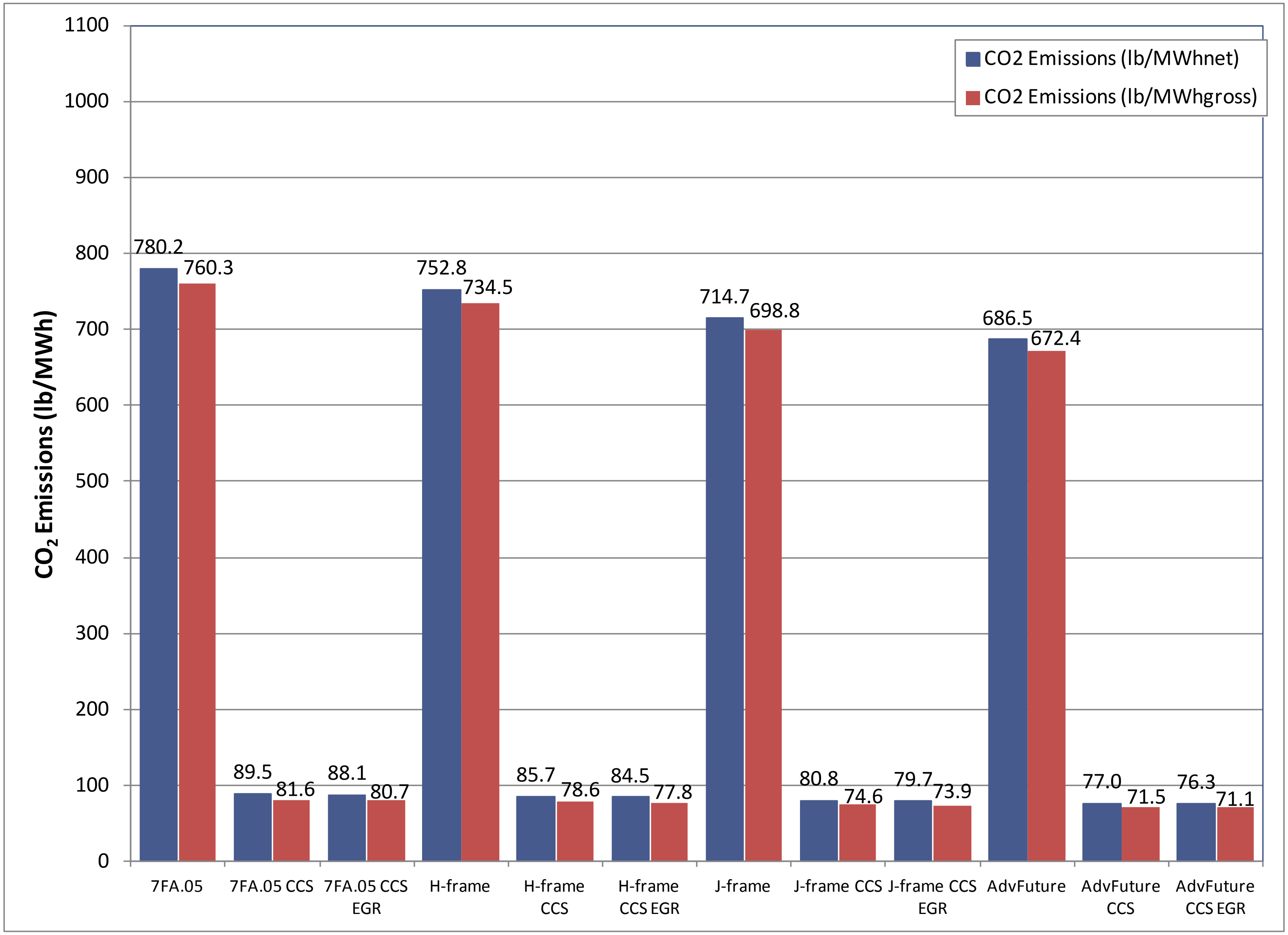
Source: NETL (All Costs are in June 2011 dollars)

Exhibit ES-7 COE sensitivity to CO_2 plant gate sales price



Source: NETL (All Costs are in June 2011 dollars, 85% capacity factor)

Exhibit ES-8 CO_2 emission rates



Source: NETL

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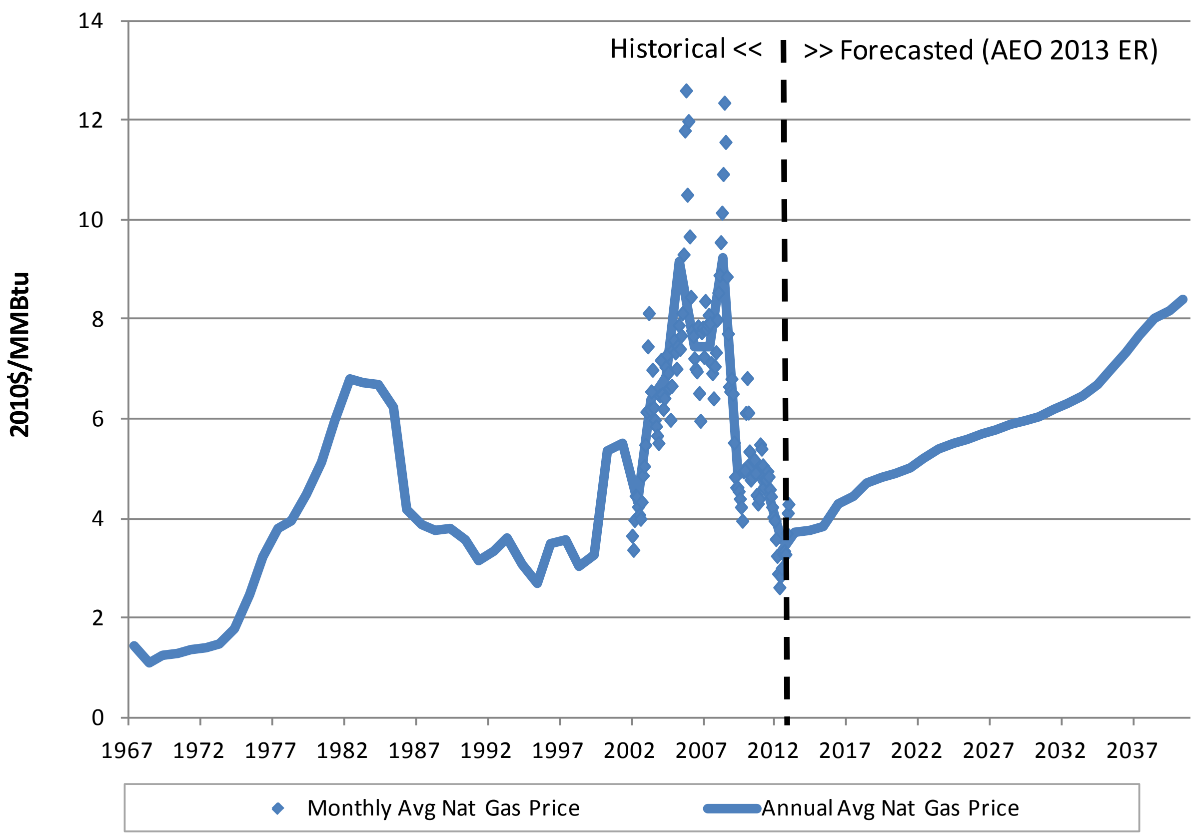
1 Introduction

Natural gas prices have seen significant variability in the last five years (see Exhibit 1-1). As carbon regulations become more likely, natural gas is the favored fossil fuel because of its lower carbon intensity relative to coal. The use of carbon capture can further reduce the carbon emissions from a natural gas-fueled power plant. Options for carbon dioxide sequestration include both storage in a saline reservoir and usage in enhanced oil recovery (EOR). The EOR option may be attractive even without the passage of regulations.

Exhibit 1-1 Historical and projected natural gas prices delivered to U.S. electric utilities



Source: EIA – AEO 2013ER [8,9]

There are potential sources of renewable natural gas, including landfills and biomass-derived synthetic/substitute natural gas (SNG). Landfill gas is currently being tapped at many locations, and gasification-based processes can be used to convert biomass into syngas, which can then be used to produce SNG. The quantity of available landfill gas is relatively small compared to the requirements of large scale electricity generation. Biomass-derived SNG is not currently cost competitive and is still many years from commercialization. Until clean coal plants and other alternative energy sources become more feasible, conventional natural gas will continue to be used as a means of reducing emissions and generating electricity.

The objective of this report is to present a case study of the performance of state-of-the-art (SOA) and advanced natural gas combined cycle (NGCC) plants with carbon capture in a consistent technical manner that accurately reflects current market conditions for future turbine developmental technologies.

The NGCC cases included in this study are based on four gas turbine designs: F-frame (GE 7FA.05), H-frame (based on Siemens H), advanced J-frame (based on MHI J), and a conceptual advanced future design (designated as X-frame). Each turbine is modeled in three process configurations: without CO_2 capture, with CO_2 capture, and with CO_2 capture and exhaust gas recycle (EGR). The case designations are listed in Exhibit 1-2. The power system for each case includes two gas turbines (GT), two heat recovery steam generators (HRSG), and one steam turbine (ST) (2 x 2 x 1).

Exhibit 1-2 Case descriptions

Turbine	Turbine Basis	Non-Capture Target Efficiency (%LHV)	Case #	CO_2 Capture Configuration
SOA F-Frame	GE 7FA.05	~58%	1a	None
			1b	CO_2 capture
			1c	capture + EGR
SOA H-Frame	Siemens H Turbine	~60%	2a	None
			2b	CO_2 capture
			2c	capture + EGR
Advanced J-Frame	Enhanced MHI J Turbine	~62%	3a	None
			3b	CO_2 capture
			3c	capture + EGR
Advanced Future X-Frame	X-Frame	~65%	4a	None
			4b	CO_2 capture
			4c	capture + EGR

2 Design Criteria

This section presents the design criteria used to estimate the cost and performance of the various configurations of NGCC power plant included in this study.

2.1 Site Description

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

Exhibit 2-1 Site ambient conditions

Elevation, m, (ft)	0, (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

Location	Greenfield, Midwestern USA
Topography	Level
Size, acres	300
Transportation	Rail
Ash Disposal	Off Site
Water	Municipal
Access	Land locked, having access by rail and highway
CO_2 Storage	Compressed to 15.3 MPa (2,215 psia), transported 100 kilometers (62 miles) and stored in a representative saline formation in the Midwest

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

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

2.2 Product Specifications

Carbon Dioxide Specification for Capture Cases

The study assumed that CO_2 is transported to the plant boundary as a supercritical fluid. The CO_2 and pipeline requirements are presented in Exhibit 2-3.

Exhibit 2-3 Carbon dioxide pipeline specification

Inlet Pressure	~15.3 MPa (~2,200 psig)
Water Content	-40°C (-40°F) dew point
N_2	< 300 ppmv
O_2	< 40 ppmv
Ar	< 10 ppmv

2.3 Natural Gas Design Fuel

Natural gas composition is presented in Exhibit 2-4.

Exhibit 2-4 Natural gas composition

Component		Volume Percentage	
Methane	CH_4	93.1	
Ethane	C_2H_6	3.2	
Propane	C_3H_8	0.7	
n-Butane	C_4H_{10}	0.4	
Carbon Dioxide	CO_2	1.0	
Nitrogen	N_2	1.6	
	Total	100.0	
	LHV		**HHV**
kJ/kg	47,220		52,314
MJ/scm	34.54		38.26
Btu/lb	20,301		22,491
Btu/scf	927		1,027

Note: Fuel composition is normalized and heating values are calculated

2.4 Plant Capacity Factor and Availability

The overall availability of the natural gas combined cycle plant was assumed to be 85 percent, which is consistent with baseline studies. The power system for each case includes two gas turbines (GT), two heat recovery steam generators (HRSG), and one steam turbine (ST) (2 x 2 x 1).

2.5 Environmental Requirements

Best available control technology (BACT) was applied to the NGCC cases and the resulting emissions compared to New Source Performance Standards (NSPS) limits. The NGCC environmental targets were chosen based on reasonably obtainable limits given the control technologies employed and are summarized in Exhibit 2-5.

Exhibit 2-5 BACT environmental design basis for natural gas cases

	Environmental Design Basis	
Pollutant	**Control Technology**	**Environmental Target**
Sulfur Oxides (SO_2)	Low sulfur content fuel	Negligible
Nitrogen Oxides (NOx)	Low NOx Burners and SCR	2.5 ppmv (dry) @ 15% O_2
Particulate Matter (PM)	N/A	Negligible
Mercury (Hg)	N/A	Negligible

The following regulatory assumptions were used for assessing environmental control technologies:

- NOx emission reduction credits (ERC) and allowances were not available for the project emission requirements when located in the ozone attainment area.
- Raw water was available to meet technology needs.
- Wastewater discharge met effluent guidelines rather than water quality standards.
- Capture of carbon in design fuel for capture cases was set at 90 percent.

2.6 Modeling Methodology

Models for each case were developed by the National Energy Technology Laboratory (NETL) using GT PRO and THERMOFLEX software by Thermoflow, Inc. [1] for thermodynamic process simulation models.

The 'With CO_2 capture' and 'Without CO_2 capture' cases were modeled using GT PRO by selecting the appropriate gas turbine model from the GT PRO data library of machine performance specifications. The models for Cases 1a and 1b used the state-of-the-art (SOA) commercial GE 7FA.05 (Physical Model #426 in GT PRO) gas turbine data. The other cases used Mitsubishi 501 GAC (Physical Model #422) as the basis with user modifications to reflect the expected performance improvements anticipated for the future designs in this study. The performance for the SOA gas turbines is available from published information from the original equipment manufacturers (OEM). [10, 11] The advanced J turbine design was based on the projected improvement for the performance of the initial MHI J turbines. [12, 13] The future turbine's performance was based on proposed turbine research program goals. [14, 15] The targeted overall performance for the non-capture cases is shown in Exhibit 2-6 which was based on available OEM information and assumed for advanced cases.

The 'With CO_2 capture and exhaust gas recycle' case models were created by importing the 'With CO_2 capture' models from GT PRO into THERMOFLEX, adding the recycle streams and modifying other specifications as needed. The power system for each case includes two gas turbines, two HRSGs, and one steam turbine (2 x 2 x 1). The steam cycle type specified in each model is a GT PRO Cycle 9 - Triple pressure level single reheat cycle with a condensing turbine. The temperatures to the steam turbines were increased for the advanced turbine cases to reflect boiler optimization. These increases resulted in approximately one percent improvement in the steam turbine outputs. The CO_2 capture technology is assumed to be an advanced solvent (e.g., amine) process using the generic representation included in the Thermoflow software, set to achieve 90 percent capture. [16] The primary change involved using a lower steam requirement for the solvent reboiler (with capture: approximately 17 percent lower and with capture plus EGR: approximately 22 percent lower) when compared with the reference value (3,556 kJ/kg [1,530 Btu/lb]) used in earlier NETL Department of Energy (DOE) studies. [2, 3] This assumption was made due to emerging improvements by OEMs in reducing the steam requirements. [2, 3, 16, 17] The resulting performance estimates in the NGCC models for each case are shown in Exhibit 2-6. Starting in Section 3, the cases are outlined and results are presented.

The cases in this study are based on the original NGCC designs presented in earlier NETL/DOE studies. [2, 3] The NGCC cases in the previous reports were modeled using Aspen Plus® [18] and standardized Excel spreadsheet applications for generating comparable/scalable performance and cost estimation results. For this study, the data for each GT PRO and THERMOFLEX model were extracted into similar templates. These templates were used to generate performance tables and equipment lists for cost estimation.

The methodology used in this study combined the data extraction, equipment list development, and cost estimation approaches used in earlier studies with modeling using the GT PRO and THERMOFLEX software. Small discrepancies between flow rates and balances in some of the tables in this report are due to round off error in the data extracted from the models. Additional minor discrepancies are due to variations in the calculation methods and assumptions inherent in the modeling software versus those in the Excel spreadsheets used for data extraction, equipment list development, and cost estimation.

Exhibit 2-6 Turbine model specifications

Case Turbine		Technology	Efficiency (% HHV / LHV)	2x GT (MWe)	TIT (F)	TET (F)	PR	ST (MWe)	Stm Cycle, psig/ °F/°F	Gross (MWe)	Aux (MWe)	Net (MWe)
1 SOA Based on 7FA.05	a	w/o CO_2 capture	51.8 / 57.4	420.8	2,479	1,120	17	229.6	2400/ 1050/1050	650.4	16.5	633.9
	b	w/CO_2 capture	45.2 / 50.1	420.8	2,479	1,120	17	185.5	2400/ 1050/1050	606.3	53.5	552.8
	c	w/CO_2 capture +EGR	45.7/50.6	418.6	2,486	1,139	17	196.6	2400/ 1050/1050	615.2	52.0	563.2
2 SOA Based on H-frame	a	w/o CO_2 capture	53.7 / 59.5	551.2	2,709	1,146	20	289.7	2400/ 1075/1075	841.0	20.5	820.5
	b	w/CO_2 capture	47.2 / 52.2	551.2	2,709	1,146	20	235.1	2400/ 1075/1075	786.3	65.7	720.6
	c	w/CO_2 capture +EGR	47.7 / 52.9	553.9	2,709	1,146	20	247.6	2400/ 1075/1075	801.5	63.9	737.6
3 Advanced Based on J-frame	a	w/o CO_2 capture	56.5 / 62.6	689.8	2,949	1,177	23	314.5	2400/ 1100/1100	1004.3	22.4	982.0
	b	w/CO_2 capture	50.1 / 55.5	689.8	2,949	1,177	23	252.1	2400/ 1100/1100	941.9	71.7	870.3
	c	w/CO_2 capture +EGR	50.6 / 56.1	694.4	2,944	1,191	23	264.0	2400/ 1100/1100	958.4	69.8	888.5
4 Advanced conceptual X-frame	a	w/o CO_2 capture	58.8 / 65.2	810.9	3,107	1,182	30	320.5	2400/ 1100/1100	1131.4	23.3	1,108.1
	b	w/CO_2 capture	52.5 / 58.1	810.9	3,107	1,182	30	252.8	2400/ 1100/1100	1063.6	75.1	989.5
	c	w/CO_2 capture +EGR	52.8 / 58.5	811.2	3,104	1,197	30	266.1	2400/ 1100/1100	1077.3	73.5	1,003.9

TIT = Turbine inlet temperature
TET = Turbine exhaust temperature
PR = Pressure Ratio

2.7 Balance of Plant

Assumed balance of plant requirements are shown in Exhibit 2-7.

Exhibit 2-7 Balance of plant requirements

Parameter	Assumption
Ambient Conditions	0.101 MPa (14.7 psia), 15.5°C (60°F)
Cooling System	Recirculating, Evaporative Cooling Tower
Natural Gas	On-site pipeline
Plant Distribution Voltage	
Motors below 1 hp	110/220 volt
Motors 250 hp and below	480 volt
Motors above 250 hp	4,160 volt
Motors above 5,000 hp	13,800 volt
Steam and Gas Turbine generators	24,000 volt
Grid Interconnection voltage	345 kV
Water and Waste	
Makeup Water	The water supply is assumed to be 50% from a local Publicly Owned Treatment Works (POTW) and 50% from groundwater and is assumed to be in sufficient quantities to meet plant makeup requirements. Makeup for potable, process, and de-ionized (DI) water is drawn from municipal sources.
Feed water	The quality of feedwater (i.e., water treatment systems) required is assumed to be similar regardless of the technology.
Process Wastewater	Water associated with process activity and storm water that contacts equipment surfaces is collected and treated for discharge through a permitted discharge permit.
Sanitary Waste Disposal	Design includes a packaged domestic sewage treatment plant with effluent discharged to the industrial wastewater treatment system. Sludge is hauled off site.
Water Discharge	Most of the wastewater is recycled for plant needs. Blowdown is treated for chloride and metals, and discharged.

2.8 Cost Estimation Approach

The performance results for each case and the equipment lists for Cases 1a, 1b, and 1c (7FA.05 without CO_2 capture, with CO_2 capture, and without CO_2 capture plus EGR) are presented in this report. Detailed cost estimates were generated for Cases 1a, 1b, and 1c. The turbine costs for each of the other cases were also estimated based on simulation results and vendor quotes/discussions. All other capital and operating costs for the remaining cases were scaled from these estimates using the same approach presented in the initial ESPA/NETL study of NGCC systems. [2] All costs are estimated in or adjusted to 2011 dollars.

The capital cost estimates include the bare erected costs (BEC) for the equipment; engineering, construction management, home office & fees (Eng'g CM, H.O. & Fee); and contingency values applied based on recommendations in Quality Guidelines for Energy System Studies (QGESS): Cost Estimation Methodology for NETL Assessments of Power Plant Performance. [5] All the capital costs are then summed to calculate the total plant cost (TPC). Owner's costs were subsequently calculated as recommended in the QGESS [5] and added to the TPC, the result of which is total overnight cost (TOC). Additionally, financing costs were estimated by applying a factor (shown in Exhibit 2-8) to the TOC value to calculate total as-spent costs (TASC).

Fixed and variable operation and maintenance (O&M) costs were estimated for each case. The natural gas cost was assumed to be $5.81/GJ ($6.13/MMBtu) as specified in "QGESS: Fuel Prices for Selected Feedstocks in NETL Studies." [6] The price is on a higher heating value (HHV) basis and in 2011 U.S. dollars. The sensitivity of the results of this study to the price of natural gas is included in the summary section of this report.

The cost metric used in this study is the cost of electricity (COE), which is the revenue received by the generator per net megawatt-hour during the power plant's first year of operation. The COE was estimated for each case using the method specified in the QGESS [5] and described in the reference reports. [2, 3] The owner/developer was assumed to be an investor-owned utility (IOU) and the base NGCC plants were assumed to have financial structures consistent with low risk projects and three-year capital expenditure periods. The cases with CO_2 capture were assumed to be high risk projects. The first year capital charge factors (CCF) shown in Exhibit 2-8, derived using the power systems financial model (PSFM), were used to calculate COE using the simplified equation shown below and detailed in the QGESS. [5] The levelized cost of electricity (LCOE) was estimated by applying a levelization factor (1.268) to each COE value as described in the QGESS. [5] All first-year costs (COE and O&M) are equivalent to base-year costs when expressed in base-year (2011) dollars.

Exhibit 2-8 Capital charge and TASC factors used to calculate COE

	CCF	TASC/TOC
Low Risk Projects (all NGCC cases without CO_2 recovery systems)	0.105	1.075
High Risk Projects (all NGCC cases with CO_2 recovery systems)	0.111	1.078

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

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

where:

COE =	revenue received by the generator (\$/MWh, equivalent to mills/kWh) during the power plant's first year of operation (*but expressed in base-year dollars*), assuming that the COE escalates thereafter at a nominal annual rate equal to the general inflation rate (i.e., that it remains constant in real terms over the operational period of the power plant)
CCF =	capital charge factor taken from Exhibit 2-8 that matches the applicable finance structure and capital expenditure period
TOC =	total overnight capital, expressed in *base-year dollars*
OC_{FIX} =	the sum of all fixed annual operating costs, *expressed in base-year dollars*
OC_{VAR} =	the sum of all variable annual operating costs, including fuel at 100 percent capacity factor, *expressed in base-year dollars*
CF =	plant capacity factor, assumed to be constant over the operational period
MWh =	annual net megawatt-hours of power generated at 100 percent capacity factor

The capital and operating costs for CO_2 transport and storage (T&S) were independently estimated by NETL to be \$10/tonne for a 100 km (62 mile) pipeline to a representative Midwest saline formation. Those costs were combined with the plant capital and operating costs to produce an overall COE. The T&S cost estimation methodology is explained in more detail in QGESS: Estimating Carbon Dioxide Transport and Storage Costs. [7]

The cost of CO_2 capture was calculated in two ways, the cost of CO_2 captured and the cost of CO_2 avoided, as illustrated in the following equations.

$$Captured\ Cost = \frac{\{COE_{with\ capture} - COE_{w/o\ capture}\}\ \$/MWh}{\{CO_2\ captured\}\ tonnes/MWh}$$

$$Avoided\ Cost = \frac{\{COE_{with\ capture} - COE_{w/o\ capture}\}\ \$/MWh}{\{Emissions_{w/o\ capture} - Emissions_{with\ capture}\}\ tonnes/MWh}$$

Sensitivity analyses were performed on the COE to determine the impact of capacity factor and natural gas price as well as the impact of selling the captured CO_2 for enhanced oil recovery (EOR) instead of sequestering it. These are discussed in the report summary.

3 Case 1 – State-of-the-art Gas Turbine – (7FA.05)

The 7FA.05 is GE's latest introduction in their "F" frame design that has an ISO output of 211 MW and LHV heat rate of 9,360 kJ/kWh (8,872 Btu/kWh) on natural gas fuel. Compared to the 7FA.03 model, the output is increased by approximately 18.5 percent and heat rate reduced by approximately 2.7 percent. The 7FA.05 model includes new compressor designs with approximately 14 percent more air flow, and approximately 9 percent higher pressure ratio than the 7FA.03 design. The design also includes improved hot gas path cooling system, better turndown capability, larger generator, and fast start capability.

For case 1a, 1b, and 1c using the 7FA.05 turbine, performance summaries, block flow diagrams, stream tables, carbon balances, water balances, and overall energy balances are presented in this section. The equipment lists generated for these three cases are also included in this section. Detailed process flow diagrams from the Thermoflow software are provided in the appendix.

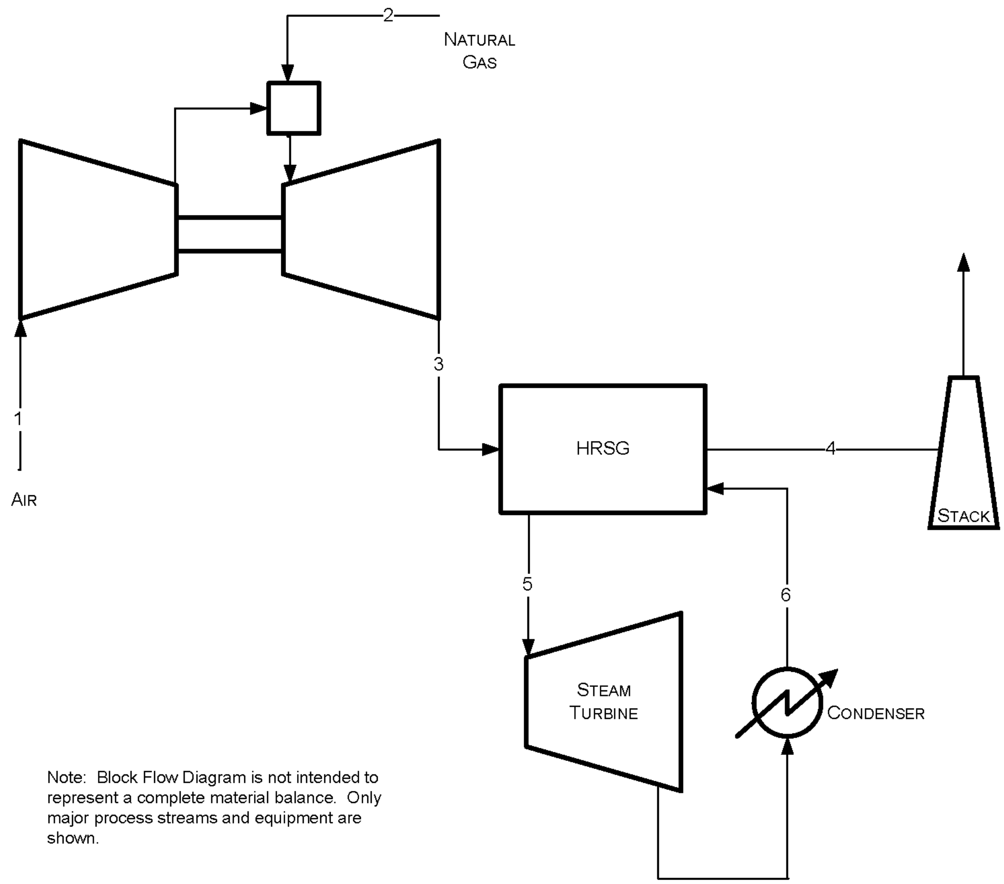
Capital and operating costs for these cases were estimated by WorleyParsons based on simulation results and vendor quotes/discussions, costing software, or a combination of the two. All costs are in June 2011 dollars. The capital and operating cost estimation results based on the simulation results and equipment lists are included at the end of each case section.

3.1 Case 1a – NGCC without CO_2 Capture Modeling Results

The block flow diagram (BFD) of the combined cycle is shown in Exhibit 3-1. This includes two GE 7FA.05 gas turbines, two triple pressure level single reheat type HRSGs, and one condensing steam turbine with evaporative cooling tower. Exhibit 3-2 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems.

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry Low NOx burner (LNB), which is operated to control the rotor inlet temperature at 1,359°C (2,479°F). The flue gas exits the turbine at 604°C (1,120°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine. Flue gas exits the HRSG (stream 4) at 88°C (190°F) and passes to the plant stack. Cooling is supplied to the condenser via water from the cooling tower.

Exhibit 3-1 Case 1a - SOA turbine without CO_2 capture block flow diagram



Source: NETL

Exhibit 3-2 Case 1a - SOA turbine without CO_2 capture stream table

	1	2	3	4	5	6
V-L Mole Fraction						
Ar	0.0092	0.0000	0.0089	0.0090	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0404	0.0391	0.0000	0.0000
H_2O	0.0099	0.0000	0.0867	0.0844	1.0000	1.0000
N_2	0.7732	0.0160	0.7432	0.7439	0.0000	0.0000
O_2	0.2074	0.0000	0.1209	0.1237	0.0000	0.0000
SO_2	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
V-L Flowrate (kg_{mol}/hr)	125,544	4,857	130,607	130,525	22,207	31,933
V-L Flowrate (kg/hr)	3,622,824	84,161	3,706,757	3,706,920	400,068	575,282
Solids Flowrate (kg/hr)	0	0	0	0	0	0
Temperature (°C)	15	38	604	88	566	32
Pressure (MPa, abs)	0.10	2.76	0.10	0.10	16.65	0.00
Enthalpy (kJ/kg)[A]	30.98	52,530.38	802.94	226.32	3,476.21	2,376.01
Density (kg/m^3)	1.2	22.2	0.4	0.9	47.7	992.9
V-L Molecular Weight	28.857	17.328	28.381	28.400	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	276,778	10,708	287,938	287,759	48,958	70,400
V-L Flowrate (lb/hr)	7,986,960	185,544	8,172,000	8,172,360	882,000	1,268,280
Solids Flowrate (lb/hr)	0	0	0	0	0	0
Temperature (°F)	59	100	1,120	190	1,050	90
Pressure (psia)	14.6	399.7	15.2	14.7	2,415.0	0.7
Enthalpy (Btu/lb)[A]	13.3	22,584.0	345.2	97.3	1,494.5	1,021.5
Density (lb/ft^3)	0.076	1.384	0.025	0.057	2.977	61.982

A - Reference conditions are 32.02 F & Liquid Water

Note: Total flow rates shown equal the sum for all process trains

3.1.1 Performance Results

The performance results are summarized in Exhibit 3-3 and are in general agreement with GE published values. [10] The overall efficiency of 57.4 percent can be improved slightly if the natural gas fuel is preheated using intermediate pressure boiler feed water from the steam cycle. This option is a customer option that GE can provide. Further improvement is also possible if the steam cycle is optimized for performance by reducing boiler pinch points. Additional tables below provide overall energy balance (Exhibit 3-4), water balance (Exhibit 3-5), carbon balance (Exhibit 3-6), and an emissions summary (Exhibit 3-7).

Exhibit 3-3 Case 1a - SOA turbine without CO_2 capture plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	420,816	kW_e
Steam Turbine Power	229,607	kW_e
Total	**650,423**	kW_e
Auxiliary Load		
Condensate Pumps	416	kW_e
Boiler Feedwater Pumps	4,577	kW_e
Amine CO_2 Capture System Auxiliaries	0	kW_e
CO_2 Compression	0	kW_e
Circulating Water Pump	2,337	kW_e
Ground Water Pumps	240	kW_e
Cooling Tower Fans	1,747	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	860	kW_e
Steam Turbine Auxiliaries	488	kW_e
Miscellaneous Balance of Plant[2]	2,603	kW_e
Transformer Losses	3,252	kW_e
Total	**16,530**	**kW_e**
Plant Performance		
Net Plant Power	**633,892**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	51.8%	
Net Plant Efficiency (LHV)[1]	57.4%	
Net Plant Heat Rate (HHV)[1]	6,946 (6,583)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	6,269 (5,942)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	84,161 (185,544)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,223,006	kW_t
Thermal Input (LHV)[1]	1,103,919	kW_t
Condenser Duty	1,287 (1,220)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	10.1 (2,665)	m^3/min (gpm)
Raw Water Consumption	8.4 (2,210)	m^3/min (gpm)

[1] *HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)*
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] *Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads*

Exhibit 3-4 Case 1a - SOA turbine without CO_2 capture overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	4,403 (4,173)	2.9 (2.8)	0 (0)	4,406 (4,176)
GT Air	0 (0)	112.2 (106.4)	0 (0)	112 (106)
Raw Water Withdrawal	0 (0)	37.9 (36.0)	0 (0)	38 (36)
Auxiliary Power	0 (0)	0.0 (0.0)	60 (56)	60 (56)
TOTAL	**4,403 (4,173)**	**153.1 (145.1)**	**60 (56)**	**4,616 (4,375)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	16.9 (16.0)	0 (0)	17 (16)
Stack Gas	0 (0)	839 (795)	0 (0)	839 (795)
Condenser	0 (0)	1,291 (1,224)	0 (0)	1,291 (1,224)
Process Losses*	*0 (0)*	*127 (121)*	*0 (0)*	*127 (121)*
Power	0 (0)	0.0 (0.0)	2,342 (2,219)	2,342 (2,219)
TOTAL	**0 (0)**	**2,274 (2,155)**	**2,342 (2,219)**	**4,616 (4,375)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 3-5 Case 1a - SOA turbine without CO_2 capture water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Condenser Makeup	**0.06 (16)**	**0.0 (0)**	**0.06 (16)**	**0.0 (0)**	**0.1 (16)**
BFW Makeup	0.06 (16)	0.0 (0)	0.06 (16)	0.0 (0)	0.0 (0)
Cooling Tower	**10.09 (2,665)**	**0.06 (16)**	**10.03 (2,649)**	**1.7 (455)**	**8.3 (2,194)**
BFW Blowdown	0.00 (0)	0.06 (16)	-0.06 (16)	0.00 (0)	0.00 (0)
Flue Gas Condensate	0.00 (0)	0.0 (0)	0.00 (0)	0.00 (0)	0.00 (0)
Total	**10.1 (2,681)**	**0.06 (16)**	**10.1 (2,665)**	**1.7 (455)**	**8.4 (2,210)**

Exhibit 3-6 Case 1a - SOA turbine without CO_2 capture carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	60,789 (134,016)	Stack Gas	61,220 (134,968)
Air (CO_2)	493 (1,086)		
		Convergence Tolerance*	61 (135)
Total	**61,281 (135,102)**	**Total**	**61,281 (135,102)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 3-7 Case 1a - SOA turbine without CO_2 capture air emissions

	kg/GJ ($lb/10^6$ Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.004 (0.009)	128 (141)	0.026 (0.058)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	50.9 (118.5)	1,670,276 (1,841,165)	345 (760)
CO_2[1]			354 (780)

[1] CO_2 emissions based on net power instead of gross power

3.1.2 Major Equipment List

This section contains the equipment list corresponding to the 7FA.05 GT without CO_2 capture plant configuration for case 1a. This list, along with the heat and material balance and supporting performance data, was used to generate plant costs. The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as N/A.

Account 1 – Coal and Sorbent Handling

N/A

Account 2 – Coal and Sorbent Preparation and Feed

N/A

Account 3 - Feedwater and Miscellaneous Systems and Equipment

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	477,193 liters (126,060 gal)	2 (0)
2	Condensate Pumps	Vertical canned	5,300 lpm @ 49 m H_2O (1,400 gpm @ 160 ft H_2O)	2 (1)
3	Boiler Feedwater Pump	Horizontal, split case, multi-stage, centrifugal, with interstage bleed for IP and LP feedwater	HP water: 3,710 lpm @ 1,878 m H_2O (980 gpm @ 6,160 ft H_2O) IP water: 4,656 lpm @ 500 m H_2O (1,230 gpm @ 1,640 ft H_2O) LP water: 681 lpm @ 0.0 m H_2O (180 gpm @ 00 ft H_2O)	2 (1)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
4	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg /hr, 2.8 MPa, 343°C (40,000 lb /hr, 400 psig, 650°F)	1 (0)
5	Service Air Compressors	Flooded Screw	13 m^3/min @ 0.7 MPa (450 scfm @ 100 psig)	2 (1)
6	Instrument Air Dryers	Duplex, regenerative	13 m^3/min (450 scfm)	2 (1)
7	Closed Cycle Cooling Heat Exchangers	Plate and frame	13 GJ/hr (13 MMBtu/hr)	2 (0)
8	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	5,300 lpm @ 21 m H_2O (1,400 gpm @ 70 ft H_2O)	2 (1)
9	Engine-driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1 (1)
10	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1 (1)
11	Raw Water Pumps	Stainless steel, single suction	5,678 lpm @ 18 m H_2O (1,500 gpm @ 60 ft H_2O)	2 (1)
12	Filtered Water Pumps	Stainless steel, single suction	163 lpm @ 49 m H_2O (43 gpm @ 160 ft H_2O)	2 (1)
13	Filtered Water Tank	Vertical, cylindrical	158,989 liter (42,000 gal)	1 (0)
14	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly and electro-deionization unit	379 lpm (100 gpm)	1 (0)
15	Liquid Waste Treatment System	--	10 years, 24-hour storm	1 (0)
16	Gas Pipeline	Underground, coated carbon steel, wrapped cathodic protection	70 m^3/min @ 2.8 MPa (2,457 acfm @ 399.7 psia) 41 cm (16 in) standard wall pipe	16 km 10 mile
17	Gas Metering Station	--	70 m^3/min (2,457 acfm)	1 (0)

Account 4 – Gasifier, Boiler, and Accessories

N/A

Account 5 – Flue Gas Cleanup

N/A

Account 6 – Combustion Turbine Generators and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Gas Turbine	7FA.05 Advanced F frame w/ dry low-NOx burner	205 MW	2 (0)
2	Gas Turbine Generator	TEWAC	230 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2 (0)

Account 7 – Waste Heat Boiler, Ducting, and Stack

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Stack	CS plate, type 409SS liner	46 m (150 ft) high x 8.0 m (26 ft) diameter	2 (0)
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 220,038 kg/hr, 16.5 MPa/566°C (485,100 lb/hr, 2,400 psig/1,050°F) Reheat steam - 268,356 kg/hr, 2.4 MPa/566°C (591,624 lb/hr, 345 psig/1,050°F)	2 (0)
3	SCR Reactor	Space for spare layer	2,036,632 kg/hr (4,490,000 lb/hr)	2 (0)
4	SCR Catalyst	--	Space available for an additional catalyst layer	1 layer (0)
5	Dilution Air Blowers	Centrifugal	12 m^3/min @ 107 cm WG (440 scfm @ 42 in WG)	2 (1)
6	Ammonia Feed Pump	Centrifugal	3.8 lpm @ 91 m H_2O (1 gpm @ 300 ft H_2O)	2 (1)
7	Ammonia Storage Tank	Horizontal tank	75,709 liter (20,000 gal)	1 (0)

Account 8 – Steam Turbine Generator and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Steam Turbine	Tandem compound, HP, IP, and two-flow LP turbines	242 MW 16.5 MPa/566°C/566°C (2,400 psig/ 1,050°F/1,050°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	270 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
3	Steam Bypass	One per HRSG	50% steam flow @ design steam conditions	2 (0)
4	Surface Condenser	Single pass, divided waterbox including vacuum pumps	1,423 GJ/hr, (1,350 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

Account 9 – Cooling Water System

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	261,195 lpm @ 30.5 m (69,000 gpm @ 100 ft)	2 (1)
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT 1,448 GJ/hr (1,374 MMBtu/hr) heat load	1 (0)

Account 10 – Ash Spent Sorbent Recovery and Handling

N/A

Account 11 – Accessory Electric Plant

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	CTG Transformer	Oil-filled	24 kV/345 kV, 230 MVA, 3-ph, 60 Hz	2 (0)
2	STG Transformer	Oil-filled	24 kV/345 kV, 250 MVA, 3-ph, 60 Hz	1 (0)
3	Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 15 MVA, 3-ph, 60 Hz	1 (1)
4	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 2 MVA, 3-ph, 60 Hz	1 (1)
5	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2 (0)
6	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1 (0)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
7	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1 (1)
8	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1 (1)
9	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

Account 12 – Instrumentation and Control

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	DCS - Main Control	Monitor/keyboard; Operator printer; Engineering printer	Operator stations/printers and engineering stations/printers	1 (0)
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1 (0)
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1 (0)

3.1.3 Cost Estimate Results

Capital and operating costs for Case 1a using the 7FA.05 turbine were estimated by WorleyParsons based on simulation results and vendor quotes/discussions, costing software, or a combination of the two. All costs are in June 2011 dollars.

The cost estimation results for this case are summarized in Exhibit 3-8. The summary and detailed capital cost estimates are shown in Exhibit 3-9 and Exhibit 3-10, respectively. The annual operating cost estimates are shown in Exhibit 3-11.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 3-8 Case 1a - SOA turbine without CO_2 capture cost estimation summary

Case	1a
Total Plant Cost (2011$/kW)	**676**
Total Overnight Cost (2011$/kW)	**829**
Total As-spent Capital (2011$/kW)	**891**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	11.68
Fixed O&M	3.36
Variable O&M	1.75
Fuel	40.35
CO_2 T&S	0.00
COE[1] Total	**57.14**
LCOE[1], total (including T&S)	72.44

[1] *Capacity factor assumed to be 85 percent*

Exhibit 3-9 Case 1a - SOA turbine without CO_2 capture capital cost estimate summary

	Client:	USDOE/NETL							**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 1a - 7FA.05										
	Plant Size:	633.9	MW,net	**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)	
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Sales Tax**	**Bare Erected Cost**	**Eng'g CM H.O.& Fee**	**Contingencies Process**	**Contingencies Project**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$27,642	$5,576	$8,270	$0	$0	**$41,488**	$3,405	$0	$7,186	**$52,079**	**$82**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
5B	CO2 REMOVAL & COMPRESSION	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	**$0**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$104,200	$0	$6,364	$0	$0	**$110,564**	$9,132	$0	$11,970	**$131,665**	$208
6.2-6.9	Combustion Turbine Other	$0	$881	$952	$0	$0	**$1,833**	$153	$0	$397	**$2,384**	$4
	SUBTOTAL 6	**$104,200**	**$881**	**$7,316**	**$0**	**$0**	**$112,397**	**$9,285**	**$0**	**$12,367**	**$134,049**	**$211**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$36,230	$0	$6,374	$0	$0	**$42,604**	$3,538	$0	$4,614	**$50,755**	$80
7.2-7.9	SCR System, Ductwork and Stack	$1,973	$1,370	$1,663	$0	$0	**$5,006**	$419	$0	$871	**$6,295**	$10
	SUBTOTAL 7	**$38,203**	**$1,370**	**$8,037**	**$0**	**$0**	**$47,609**	**$3,957**	**$0**	**$5,485**	**$57,050**	**$90**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$36,130	$0	$5,104	$0	$0	**$41,234**	$3,249	$0	$4,448	**$48,931**	$77
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$13,209	$1,002	$7,649	$0	$0	**$21,860**	$1,615	$0	$3,387	**$26,862**	$42
	SUBTOTAL 8	**$49,339**	**$1,002**	**$12,752**	**$0**	**$0**	**$63,094**	**$4,863**	**$0**	**$7,836**	**$75,793**	**$120**
9	COOLING WATER SYSTEM	$5,070	$5,719	$5,229	$0	$0	**$16,018**	$1,288	$0	$2,541	**$19,846**	$31
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$22,033	$5,668	$12,307	$0	$0	**$40,008**	$3,001	$0	$4,622	**$47,630**	$75
12	INSTRUMENTATION & CONTROL	$7,148	$809	$6,060	$0	$0	**$14,017**	$1,150	$0	$1,741	**$16,909**	$27
13	IMPROVEMENTS TO SITE	$2,072	$1,126	$5,866	$0	$0	**$9,064**	$803	$0	$1,973	**$11,841**	$19
14	BUILDINGS & STRUCTURES	$0	$5,311	$5,655	$0	$0	**$10,966**	$873	$0	$1,776	**$13,614**	$21
	TOTAL COST	**$255,707**	**$27,461**	**$71,493**	**$0**	**$0**	**$354,661**	**$28,625**	**$0**	**$45,526**	**$428,812**	**$676**

Exhibit 3-10 Case 1a - SOA turbine without CO_2 capture capital cost estimate detail

	Client:	USDOE/NETL							**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 1a - 7FA.05										
	Plant Size:	633.9 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)	
Acct		**Equipment**	**Material**	**Labor**		**Sales**	**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**	
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Tax**	**Cost**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$2,938	$3,042	$2,484	$0	$0	$8,464	$682	$0	$1,372	$10,517	$17
3.2	Water Makeup & Pretreating	$1,945	$201	$999	$0	$0	$3,145	$260	$0	$681	$4,086	$6
3.3	Other Feedwater Subsystems	$1,376	$455	$380	$0	$0	$2,211	$171	$0	$357	$2,739	$4
3.4	Service Water Systems	$235	$469	$1,509	$0	$0	$2,213	$188	$0	$480	$2,881	$5
3.5	Other Boiler Plant Systems	$1,583	$591	$1,360	$0	$0	$3,535	$288	$0	$573	$4,396	$7
3.6	Natural Gas, incl. pipeline	$17,710	$661	$573	$0	$0	$18,944	$1,562	$0	$3,076	$23,582	$37
3.7	Waste Treatment Equipment	$679	$0	$393	$0	$0	$1,073	$93	$0	$233	$1,398	$2
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,176	$157	$571	$0	$0	$1,904	$163	$0	$413	$2,480	$4
	SUBTOTAL 3.	**$27,642**	**$5,576**	**$8,270**	**$0**	**$0**	**$41,488**	**$3,405**	**$0**	**$7,186**	**$52,079**	**$82**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$104,200	$0	$6,364	$0	$0	$110,564	$9,132	$0	$11,970	$131,665	$208
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$881	$952	$0	$0	$1,833	$153	$0	$397	$2,384	$4
	SUBTOTAL 6.	**$104,200**	**$881**	**$7,316**	**$0**	**$0**	**$112,397**	**$9,285**	**$0**	**$12,367**	**$134,049**	**$211**

Exhibit 3-10 Case 1a - SOA turbine without CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL — Report Date: 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 1a - 7FA.05
Plant Size: 633.9 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$36,230	$0	$6,374	$0	$0	$42,604	$3,538	$0	$4,614	$50,755	$80
7.2	HRSG Accessories	$1,973	$828	$1,155	$0	$0	$3,956	$331	$0	$643	$4,931	$8
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$541	$508	$0	$0	$1,049	$88	$0	$227	$1,364	$2
	SUBTOTAL 7.	**$38,203**	**$1,370**	**$8,037**	**$0**	**$0**	**$47,609**	**$3,957**	**$0**	**$5,485**	**$57,050**	**$90**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$36,130	$0	$5,104	$0	$0	$41,234	$3,249	$0	$4,448	$48,931	$77
8.2	Turbine Plant Auxiliaries	$213	$0	$484	$0	$0	$697	$60	$0	$76	$832	$1
8.3	Condenser & Auxiliaries	$2,980	$0	$1,450	$0	$0	$4,430	$372	$0	$480	$5,282	$8
8.4	Steam Piping	$10,016	$0	$4,060	$0	$0	$14,076	$959	$0	$2,255	$17,290	$27
8.9	TG Foundations	$0	$1,002	$1,655	$0	$0	$2,657	$224	$0	$576	$3,457	$5
	SUBTOTAL 8.	**$49,339**	**$1,002**	**$12,752**	**$0**	**$0**	**$63,094**	**$4,863**	**$0**	**$7,836**	**$75,793**	**$120**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$2,960	$0	$900	$0	$0	$3,860	$322	$0	$418	$4,600	$7
9.2	Circulating Water Pumps	$1,443	$0	$85	$0	$0	$1,528	$116	$0	$164	$1,808	$3
9.3	Circ.Water System Auxiliaries	$121	$0	$16	$0	$0	$137	$11	$0	$15	$163	$0
9.4	Circ.Water Piping	$0	$3,743	$847	$0	$0	$4,590	$344	$0	$740	$5,674	$9
9.5	Make-up Water System	$306	$0	$393	$0	$0	$699	$58	$0	$114	$870	$1
9.6	Component Cooling Water Sys	$241	$288	$185	$0	$0	$713	$57	$0	$116	$886	$1
9.9	Circ.Water System Foundations	$0	$1,688	$2,803	$0	$0	$4,492	$379	$0	$974	$5,845	$9
	SUBTOTAL 9.	**$5,070**	**$5,719**	**$5,229**	**$0**	**$0**	**$16,018**	**$1,288**	**$0**	**$2,541**	**$19,846**	**$31**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$5,374	$0	$3,179	$0	$0	$8,553	$702	$0	$694	$9,950	$16
11.2	Station Service Equipment	$1,761	$0	$151	$0	$0	$1,913	$158	$0	$155	$2,225	$4
11.3	Switchgear & Motor Control	$2,167	$0	$376	$0	$0	$2,544	$211	$0	$275	$3,030	$5
11.4	Conduit & Cable Tray	$0	$1,133	$3,263	$0	$0	$4,395	$366	$0	$714	$5,476	$9
11.5	Wire & Cable	$0	$3,639	$2,069	$0	$0	$5,709	$343	$0	$908	$6,960	$11
11.6	Protective Equipment	$0	$730	$2,533	$0	$0	$3,263	$281	$0	$354	$3,898	$6
11.7	Standby Equipment	$129	$0	$120	$0	$0	$250	$21	$0	$27	$298	$0
11.8	Main Power Transformers	$12,601	$0	$192	$0	$0	$12,794	$869	$0	$1,366	$15,029	$24
11.9	Electrical Foundations	$0	$166	$422	$0	$0	$588	$50	$0	$127	$765	$1
	SUBTOTAL 11.	**$22,033**	**$5,668**	**$12,307**	**$0**	**$0**	**$40,008**	**$3,001**	**$0**	**$4,622**	**$47,630**	**$75**

Exhibit 3-10 Case 1a - SOA turbine without CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL — Report Date: 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 1a - 7FA.05
Plant Size: 633.9 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$909	$0	$579	$0	$0	$1,488	$125	$0	$242	$1,855	$3
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$272	$0	$166	$0	$0	$438	$37	$0	$71	$545	$1
12.7	Computer & Accessories	$4,347	$0	$133	$0	$0	$4,480	$368	$0	$485	$5,332	$8
12.8	Instrument Wiring & Tubing	$0	$809	$1,431	$0	$0	$2,240	$161	$0	$360	$2,761	$4
12.9	Other I & C Equipment	$1,621	$0	$3,752	$0	$0	$5,373	$460	$0	$583	$6,416	$10
	SUBTOTAL 12.	**$7,148**	**$809**	**$6,060**	**$0**	**$0**	**$14,017**	**$1,150**	**$0**	**$1,741**	**$16,909**	**$27**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$111	$2,352	$0	$0	$2,462	$215	$0	$536	$3,213	$5
13.2	Site Improvements	$0	$1,015	$1,341	$0	$0	$2,356	$209	$0	$513	$3,078	$5
13.3	Site Facilities	$2,072	$0	$2,174	$0	$0	$4,246	$379	$0	$925	$5,549	$9
	SUBTOTAL 13.	**$2,072**	**$1,126**	**$5,866**	**$0**	**$0**	**$9,064**	**$803**	**$0**	**$1,973**	**$11,841**	**$19**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$304	$161	$0	$0	$464	$36	$0	$75	$575	$1
14.2	Steam Turbine Building	$0	$2,548	$3,390	$0	$0	$5,938	$478	$0	$962	$7,378	$12
14.3	Administration Building	$0	$571	$387	$0	$0	$957	$74	$0	$155	$1,186	$2
14.4	Circulation Water Pumphouse	$0	$191	$94	$0	$0	$285	$22	$0	$46	$353	$1
14.5	Water Treatment Buildings	$0	$413	$376	$0	$0	$789	$62	$0	$128	$979	$2
14.6	Machine Shop	$0	$495	$316	$0	$0	$811	$63	$0	$131	$1,006	$2
14.7	Warehouse	$0	$320	$193	$0	$0	$512	$40	$0	$83	$635	$1
14.8	Other Buildings & Structures	$0	$96	$70	$0	$0	$165	$13	$0	$27	$205	$0
14.9	Waste Treating Building & Str.	$0	$375	$669	$0	$0	$1,043	$85	$0	$169	$1,297	$2
	SUBTOTAL 14.	**$0**	**$5,311**	**$5,655**	**$0**	**$0**	**$10,966**	**$873**	**$0**	**$1,776**	**$13,614**	**$21**
	TOTAL COST	**$255,707**	**$27,461**	**$71,493**	**$0**	**$0**	**$354,661**	**$28,625**	**$0**	**$45,526**	**$428,812**	**$676**

Exhibit 3-10 Case 1a - SOA turbine without CO_2 capture capital cost estimate detail (continued)

	Client:	USDOE/NETL						**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses									
		TOTAL PLANT COST SUMMARY									
	Case:	Case 1a - 7FA.05									
	Plant Size:	633.9 MW,net		**Estimate Type:**	Conceptual			**Cost Base (Jun)**	2011	($x1000)	
Acct 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 $**	**TOTAL PLANT COST $/kW**
	TOTAL COST	**$255,707**	**$27,461**	**$71,493**	**$0**	**$354,661**	**$28,625**	**$0**	**$45,526**	**$428,812**	**$676**
	Owner's Costs										
	Preproduction Costs										
	6 Months All Labor									$3,643	$6
	1 Month Maintenance Materials									$525	$1
	1 Month Non-fuel Consumables									$283	$0
	1 Month Waste Disposal									$0	$0
	25% of 1 Months Fuel Cost at 100% CF									$4,668	$7
	2% of TPC									$8,576	$14
	Total									**$17,695**	**$28**
	Inventory Capital										
	60 day supply of consumables at 100% CF									$371	$1
	0.5% of TPC (spare parts)									$2,144	$3
	Total									**$2,515**	**$4**
	Initial Cost for Catalyst and Chemicals									$0	$0
	Land									$300	$0
	Other Owner's Costs									$64,322	$101
	Financing Costs									$11,578	$18
	Total Overnight Costs (TOC)									**$525,222**	**$829**
	TASC Multiplier								(IOU, low-risk, 33 year)	1.075	
	Total As-Spent Cost (TASC)									**$564,613**	**$891**

Exhibit 3-11 Case 1a - SOA turbine without CO_2 capture operating cost estimate

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun)	2011
Case 1a - 7FA.05					Heat Rate-net (Btu/kWh):	6,583
					MWe-net:	634
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	2.0		2.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	5.0		5.0			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$2,260,518	$3.566
Maintenance Labor Cost					$3,568,153	$5.629
Administrative & Support Labor					$1,457,168	$2.299
Property Taxes and Insurance					$8,576,235	$13.529
TOTAL FIXED OPERATING COSTS					**$15,862,074**	**$25.023**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					**$5,352,229**	**$0.00113**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0.00	1,918.80	1.67	**$0**	**$996,542**	**$0.00021**
Chemicals						
MU & WT Chem.(lbs)	0.00	11,431.65	0.27	$0	$949,937	$0.00020
MEA Solvent (ton)	0.00	0.00	3,481.91	$0	$0	$0.00000
Activated Carbon (lb)	0.00	0.00	1.63	$0	$0	$0.00000
Corrosion Inhibitor	0.00	0.00	0.00	$0	$0	$0.00000
SCR Catalyst (m3)	w/equip.	0.08	8,938.80	$0	$229,367	$0.00005
Ammonia (19% NH3) (ton)	0.00	6.96	330.00	$0	$712,171	$0.00015
Subtotal Chemicals				**$0**	**$1,891,475**	**$0.00040**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$8,240,246**	**$0.00174**
Fuel (MMBtu)	0	100,150	6.13	**$0**	**$190,468,388**	**$0.04033**

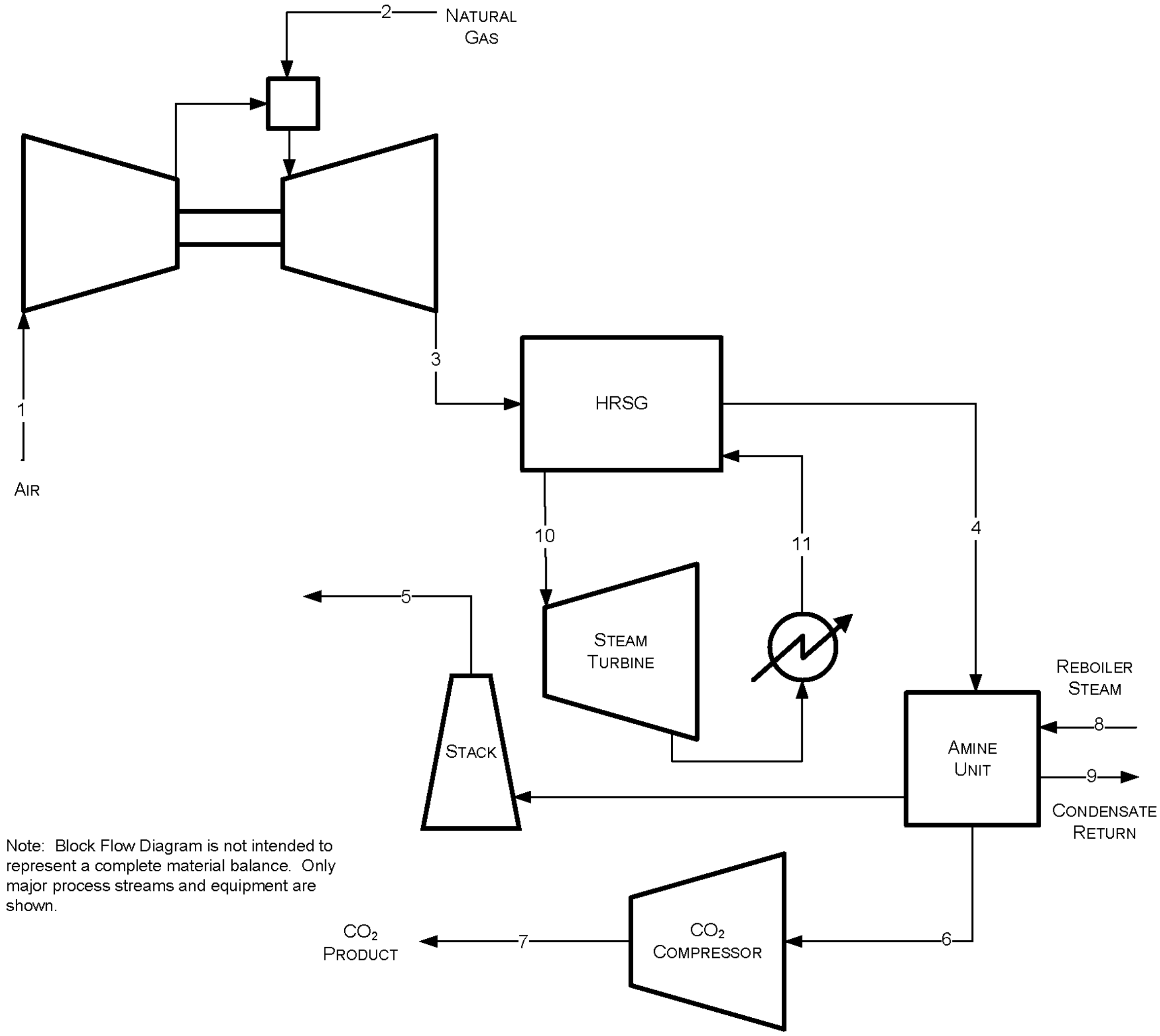
3.2 Case 1b – NGCC with CO_2 Capture Modeling Results

The block flow diagram of the combined cycle with CO_2 capture is shown in Exhibit 3-12. This case also uses the same 7FA.05 gas turbine model as that of Case 1a with the addition of CO_2 capture at the back end. Exhibit 3-13 provides process data for the numbered streams in the BFD. The heat required for the solvent (amine) system in the CO_2 capture system is supplied from the Rankine cycle. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems.

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,359°C (2,479°F). The flue gas exits the turbine at 604°C (1,120°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine as well as the steam required for the capture process (stream 8). Flue gas exits the HRSG (stream 4) at 110°C (231°F) and passes to the capture system where the CO_2 is captured and compressed (stream 7). Cooling is supplied to the steam turbine condenser via water from the cooling tower.

The gas turbine (Brayton cycle) performance is not impacted due to the CO_2 capture addition. However, the Rankine cycle performance and the overall plant output and efficiency are reduced due to heat integration requirements and increased auxiliary loads for the CO_2 capture process.

Exhibit 3-12 Case 1b - SOA turbine with CO_2 capture block flow diagram



Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Source: NETL

Exhibit 3-13 Case 1b - SOA turbine with CO_2 capture stream table

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0000	0.0089	0.0090	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0404	0.0391	0.0042	0.9674	1.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0099	0.0000	0.0867	0.0844	0.0555	0.0326	0.0000	1.0000	1.0000	1.0000	1.0000
N_2	0.7732	0.0160	0.7432	0.7439	0.7980	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.2074	0.0000	0.1209	0.1237	0.1327	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)	125,544	4,857	130,607	130,525	121,702	4,744	4,590	13,406	17,887	22,216	18,890
V-L Flowrate (kg/hr)	3,622,824	84,161	3,706,757	3,706,920	3,428,342	204,770	201,994	241,511	241,511	400,232	340,303
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	38	604	110	35	35	38	152	151	566	32
Pressure (MPa, abs)	0.10	2.76	0.10	0.10	0.10	0.17	15.27	0.51	0.49	16.65	0.00
Enthalpy (kJ/kg)^A	30.98	52,530.38	802.94	250.28	103.15	91.58	-164.90	2,746.79	635.72	3,476.21	2,377.17
Density (kg/m^3)	1.2	22.2	0.4	0.8	0.9	2.9	653.5	2.7	915.8	47.7	992.9
V-L Molecular Weight	28.857	17.328	28.381	28.400	28.170	43.160	44.010	18.015	18.015	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	276,778	10,708	287,938	287,759	268,307	10,460	10,119	29,555	39,435	48,978	41,645
V-L Flowrate (lb/hr)	7,986,960	185,544	8,172,000	8,172,360	7,558,200	451,440	445,320	532,440	532,440	882,360	750,240
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	100	1,120	231	95	95	101	306	304	1,050	90
Pressure (psia)	14.6	399.7	15.2	14.7	14.7	25.0	2,214.7	73.5	71.0	2,415.0	0.7
Enthalpy (Btu/lb)^A	13.3	22,584.0	345.2	107.6	44.3	39.4	-70.9	1,180.9	273.3	1,494.5	1,022.0
Density (lb/ft^3)	0.076	1.384	0.025	0.052	0.056	0.183	40.800	0.169	57.172	2.977	61.982

A - Reference conditions are 32.02 F & Liquid Water

Note: Total flow rates shown equal the sum for all process trains

3.2.1 Performance Results

The performance results are summarized in Exhibit 3-14 and when compared with Case 1a show that adding carbon capture reduces the efficiency by approximately seven percentage points. This is based on using an assumed advanced solvent process that has a lower steam requirement for the reboiler of 2,960 kJ/kg CO_2 (1,272 Btu/lb CO_2) or 17 percent lower when compared with earlier NETL/DOE system studies (i.e. 3,560 kJ/kg CO_2 (1,530 Btu/lb CO_2)).

Additional tables below provide overall energy balance (Exhibit 3-15), water balance (Exhibit 3-16), carbon balance (Exhibit 3-17), and an emissions summary (Exhibit 3-18).

Exhibit 3-14 Case 1b - SOA turbine with CO_2 capture plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	420,816	kW_e
Steam Turbine Power	185,503	kW_e
Total	**606,319**	kW_e
Auxiliary Load		
Condensate Pumps	248	kW_e
Boiler Feedwater Pumps	4,580	kW_e
Amine CO_2 Capture System Auxiliaries	15,971	kW_e
CO_2 Compression	18,977	kW_e
Circulating Water Pump	4,030	kW_e
Ground Water Pumps	350	kW_e
Cooling Tower Fans	2,704	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	860	kW_e
Steam Turbine Auxiliaries	395	kW_e
Miscellaneous Balance of Plant[2]	2,346	kW_e
Transformer Losses	3,032	kW_e
Total	**53,503**	**kW_e**
Plant Performance		
Net Plant Power	**552,816**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	45.2%	
Net Plant Efficiency (LHV)[1]	50.1%	
Net Plant Heat Rate (HHV)[1]	7,964 (7,549)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	7,189 (6,814)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	84,161 (185,544)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,223,006	kW_t
Thermal Input (LHV)[1]	1,103,919	kW_t
Condenser Duty	770 (730)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	14.4 (3,823)	m^3/min (gpm)
Raw Water Usage	11.8 (3,126)	m^3/min (gpm)

[1] HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 3-15 Case 1b - SOA turbine with CO_2 capture overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	4,403 (4,173)	2.9 (2.8)	0 (0)	4,406 (4,176)
GT Air	0 (0)	112.2 (106.4)	0 (0)	112 (106)
Raw Water Withdrawal	0 (0)	54.4 (51.6)	0 (0)	54 (52)
Auxiliary Power	0 (0)	0.0 (0.0)	193 (183)	193 (183)
TOTAL	**4,403 (4,173)**	**169.6 (160.8)**	**193 (183)**	**4,765 (4,516)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	26.2 (24.9)	0 (0)	26 (25)
Stack Gas	0 (0)	354 (335)	0 (0)	354 (335)
Condenser	0 (0)	765 (726)	0 (0)	765 (726)
CO_2 Product	0 (0)	-33.3 (-31.6)	0 (0)	-33 (-32)
CO_2 Intercoolers	0 (0)	93.8 (88.9)	0 (0)	94 (89)
Amine System Losses	0 (0)	738.0 (699.5)	0 (0)	738 (700)
Process Losses*	*0 (0)*	*-638 (-605)*	*0 (0)*	*-638 (-605)*
Power	0 (0)	0.0 (0.0)	2,183 (2,069)	2,183 (2,069)
TOTAL	**0 (0)**	**2,582 (2,448)**	**2,183 (2,069)**	**4,765 (4,516)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 3-16 Case 1b - SOA turbine with CO_2 capture water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Amine CO_2 capture system	0.05 (13)	0.0 (0)	0.05 (13)	0.0 (0)	0.05 (13)
Condenser Makeup	**0.06 (16)**	**0.0 (0)**	**0.06 (16)**	**0.0 (0)**	**0.1 (16)**
BFW Makeup	0.06 (16)	0.0 (0)	0.06 (16)	0.0 (0)	0.0 (0)
Cooling Tower	**15.7 (4,148)**	**1.34 (354)**	**14.36 (3,795)**	**2.6 (697)**	**11.7 (3,098)**
BFW Blowdown	0.00 (0)	0.0 (16)	-0.06 (-16)	0.00 (0)	0.00 (0)
Flue Gas/CO_2 Condensate	0.00 (0)	1.28 (338)	-1.28 (-338)	0.00 (0)	0.00 (0)
Total	**15.8 (4,177)**	**1.34 (354)**	**14.5 (3,823)**	**2.6 (697)**	**11.8 (3,126)**

Exhibit 3-17 Case 1b - SOA turbine with CO_2 capture carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	60,789 (134,016)	Stack Gas	6,123 (13,500)
Air (CO_2)	493 (1,086)	CO_2 Product	55,127 (121,535)
		Convergence Tolerance*	31 (68)
Total	**61,281 (135,102)**	**Total**	**61,281 (135,102)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 3-18 Case 1b - SOA turbine with CO_2 capture air emissions

	kg/GJ (lb/10^6 Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.003 (0.008)	114 (126)	0.025 (0.056)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	5.1 (11.9)	167,063 (184,155)	37 (82)
CO_2[1]			41 (89)

[1] CO_2 emissions based on net power instead of gross power

3.2.2 Major Equipment List

This section contains the equipment list corresponding to the 7FA.05 GT with CO_2 capture plant configuration for case 1b. This list, along with the heat and material balance and supporting performance data, was used to generate plant costs. The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as N/A.

Account 1 – Coal and Sorbent Handling

N/A

Account 2 – Coal and Sorbent Preparation and Feed

N/A

Account 3 - Feedwater and Miscellaneous Systems and Equipment

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	469,395 liters (124,000 gal)	2 (0)
2	Condensate Pumps	Vertical canned	3,142 lpm @ 49 m H_2O (830 gpm @ 160 ft H_2O)	2 (1)
3	Boiler Feedwater Pump	Horizontal, split case, multi-stage, centrifugal, with interstage bleed for IP and LP feedwater	HP water: 3,710 lpm @ 1,878 m H_2O (980 gpm @ 6,160 ft H_2O) IP water: 4,656 lpm @ 500 m H_2O (1,230 gpm @ 1,640 ft H_2O) LP water: 757 lpm @ 0.0 m H_2O (200 gpm @ 00 ft H_2O)	2 (1)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
4	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg /hr, 2.8 MPa, 343°C (40,000 lb /hr, 400 psig, 650°F)	1 (0)
5	Service Air Compressors	Flooded Screw	13 m^3/min @ 0.7 MPa (450 scfm @ 100 psig)	2 (1)
6	Instrument Air Dryers	Duplex, regenerative	13 m^3/min (450 scfm)	2 (1)
7	Closed Cycle Cooling Heat Exchangers	Plate and frame	13 GJ/hr (13 MMBtu/hr)	2 (0)
8	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	5,300 lpm @ 21 m H_2O (1,400 gpm @ 70 ft H_2O)	2 (1)
9	Engine-driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1 (1)
10	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1 (1)
11	Raw Water Pumps	Stainless steel, single suction	7,949 lpm @ 18 m H_2O (2,100 gpm @ 60 ft H_2O)	2 (1)
12	Filtered Water Pumps	Stainless steel, single suction	167 lpm @ 49 m H_2O (44 gpm @ 160 ft H_2O)	2 (1)
13	Filtered Water Tank	Vertical, cylindrical	158,989 liter (42,000 gal)	1 (0)
14	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly and electro-deionization unit	379 lpm (100 gpm)	1 (0)
15	Liquid Waste Treatment System	--	10 years, 24-hour storm	1 (0)
16	Gas Pipeline	Underground, coated carbon steel, wrapped cathodic protection	70 m^3/min @ 2.8 MPa (2,457 acfm @ 399.7 psia) 41 cm (16 in) standard wall pipe	16 km 10 mile
17	Gas Metering Station	--	70 m^3/min (2,457 acfm)	1 (0)

Account 4 – Gasifier, Boiler, and Accessories

N/A

Account 5 – Flue Gas Cleanup

N/A

Account 5B – CO_2 Capture and Compression

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Amine CO_2 Capture System	Amine-based CO_2 capture technology	2,038,900 kg/hr (4,495,000 lb/hr) 6.1 wt % CO_2 concentration	2 (0)
2	CO_2 Compressor	Integrally geared, multi-stage centrifugal	111,130 kg/hr @ 15.3 MPa (245,000 lb/hr @ 2,215 psia)	2 (0)

Account 6 – Combustion Turbine Generators and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Gas Turbine	7FA.05 Advanced F frame w/ dry low-NOx burner	205 MW	2 (0)
2	Gas Turbine Generator	TEWAC	230 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2 (0)

Account 7 – Waste Heat Boiler, Ducting, and Stack

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Stack	CS plate, type 409SS liner	46 m (150 ft) high x 8.0 m (26 ft) diameter	2 (0)
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 220,128 kg/hr, 16.5 MPa/566°C (485,298 lb/hr, 2,400 psig/1,050°F) Reheat steam - 267,818 kg/hr, 2.4 MPa/566°C (590,436 lb/hr, 345 psig/1,050°F)	2 (0)
3	SCR Reactor	Space for spare layer	1,886,947 kg/hr (4,160,000 lb/hr)	2 (0)
4	SCR Catalyst	--	Space available for an additional catalyst layer	1 layer (0)
5	Dilution Air Blowers	Centrifugal	12 m^3/min @ 107 cm WG (440 scfm @ 42 in WG)	2 (1)
6	Ammonia Feed Pump	Centrifugal	3.8 lpm @ 91 m H_2O (1 gpm @ 300 ft H_2O)	2 (1)
7	Ammonia Storage Tank	Horizontal tank	75,709 liter (20,000 gal)	1 (0)

Account 8 – Steam Turbine Generator and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Steam Turbine	Tandem compound, HP, IP, and two-flow LP turbines	195 MW 16.5 MPa/566°C/566°C (2,400 psig/ 1,050°F/1,050°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	220 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)
3	Steam Bypass	One per HRSG	50% steam flow @ design steam conditions	2 (0)
4	Surface Condenser	Single pass, divided waterbox including vacuum pumps	843 GJ/hr, (800 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

Account 9 – Cooling Water System

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	405,042 lpm @ 30.5 m (107,000 gpm @ 100 ft)	2 (1)
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT 2,254 GJ/hr (2,138 MMBtu/hr) heat load	1 (0)

Account 10 – Ash Spent Sorbent Recovery and Handling

N/A

Account 11 – Accessory Electric Plant

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	CTG Transformer	Oil-filled	24 kV/345 kV, 230 MVA, 3-ph, 60 Hz	2 (0)
2	STG Transformer	Oil-filled	24 kV/345 kV, 180 MVA, 3-ph, 60 Hz	1 (0)
3	High Voltage Auxiliary Transformer	Oil-filled	345 kV/13.8 kV, 11 MVA, 3-ph, 60 Hz	2 (0)
4	Medium Voltage Transformer	Oil-filled	24 kV/4.16 kV, 15 MVA, 3-ph, 60 Hz	1 (1)
5	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 2 MVA, 3-ph, 60 Hz	1 (1)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
6	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2 (0)
7	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1 (0)
8	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1 (1)
9	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1 (1)
10	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

Account 12 – Instrumentation and Control

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	DCS - Main Control	Monitor/keyboard; Operator printer; Engineering printer	Operator stations/printers and engineering stations/printers	1 (0)
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1 (0)
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1 (0)

3.2.3 Cost Estimate Results

Capital and operating costs for Cases 1b using the 7FA.05 turbine were estimated by WorleyParsons based on simulation results and vendor quotes/discussions, costing software, or a combination of the two. All costs are in June 2011 dollars.

The cost estimation results for this case are summarized in Exhibit 3-19. The summary and detail capital cost estimates for this case are shown in Exhibit 3-20 and Exhibit 3-21, respectively. The annual operating cost estimates are shown in Exhibit 3-22.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 3-19 Case 1b - SOA turbine with CO_2 capture cost estimation summary

Case	1b
Total Plant Cost (2011$/kW)	**1,372**
Total Overnight Cost (2011$/kW)	**1,674**
Total As-spent Capital (2011$/kW)	**1,805**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	24.96
Fixed O&M	6.24
Variable O&M	3.15
Fuel	46.28
CO_2 T&S total	3.65
COE[1] Total	**84.27**
LCOE[1], total (including T&S)	106.82
Cost[1,2] of CO_2 avoided, $/tonne of CO_2 ($/ton of CO_2)	86.59 (78.55)
Cost[1,2] of CO_2 captured, $/tonne of CO_2 ($/ton of CO_2)	64.24 (58.28)

[1] Capacity factor assumed to be 85 percent
[2] Reference base case is 1a – 7FA.05 without capture

Exhibit 3-20 Case 1b - SOA turbine with CO_2 capture capital cost estimate summary

	Client:	USDOE/NETL							Report Date:	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 1b - 7FA.05 CCS										
	Plant Size:	552.8 MW,net		Estimate Type:	Conceptual				Cost Base (Jun)	2011	($x1000)	
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Sales Tax**	**Bare Erected Cost**	**Eng'g CM H.O.& Fee**	**Contingencies Process**	**Contingencies Project**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$28,966	$5,926	$9,512	$0	$0	**$44,403**	$3,648	$0	$7,765	**$55,815**	**$101**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
5B	CO2 REMOVAL & COMPRESSION	$157,956	$0	$49,757	$0	$0	**$207,713**	$17,339	$35,870	$52,184	**$313,106**	**$566**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$104,200	$0	$6,364	$0	$0	**$110,564**	$9,132	$0	$11,970	**$131,665**	$238
6.2-6.9	Combustion Turbine Other	$0	$881	$952	$0	$0	**$1,833**	$153	$0	$397	**$2,384**	$4
	SUBTOTAL 6	**$104,200**	**$881**	**$7,316**	**$0**	**$0**	**$112,397**	**$9,285**	**$0**	**$12,367**	**$134,049**	**$242**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$35,170	$0	$6,187	$0	$0	**$41,357**	$3,434	$0	$4,479	**$49,270**	$89
7.2-7.9	SCR System, Ductwork and Stack	$1,973	$1,345	$1,640	$0	$0	**$4,958**	$415	$0	$860	**$6,233**	$11
	SUBTOTAL 7	**$37,143**	**$1,345**	**$7,827**	**$0**	**$0**	**$46,315**	**$3,849**	**$0**	**$5,339**	**$55,504**	**$100**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$30,390	$0	$4,949	$0	$0	**$35,339**	$2,790	$0	$3,813	**$41,941**	$76
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$12,289	$858	$7,163	$0	$0	**$20,310**	$1,485	$0	$3,178	**$24,973**	$45
	SUBTOTAL 8	**$42,679**	**$858**	**$12,112**	**$0**	**$0**	**$55,648**	**$4,275**	**$0**	**$6,991**	**$66,914**	**$121**
9	COOLING WATER SYSTEM	$6,851	$7,445	$6,855	$0	$0	**$21,152**	$1,701	$0	$3,338	**$26,191**	$47
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$27,476	$8,326	$16,640	$0	$0	**$52,443**	$3,935	$0	$6,150	**$62,528**	$113
12	INSTRUMENTATION & CONTROL	$7,863	$890	$6,667	$0	$0	**$15,420**	$1,265	$771	$2,004	**$19,460**	$35
13	IMPROVEMENTS TO SITE	$2,104	$1,143	$5,958	$0	$0	**$9,205**	$816	$0	$2,004	**$12,025**	$22
14	BUILDINGS & STRUCTURES	$0	$5,169	$5,398	$0	$0	**$10,567**	$840	$0	$1,711	**$13,118**	$24
	TOTAL COST	**$415,239**	**$31,983**	**$128,042**	**$0**	**$0**	**$575,263**	**$46,953**	**$36,641**	**$99,853**	**$758,709**	**$1,372**

Exhibit 3-21 Case 1b - SOA turbine with CO_2 capture capital cost estimate detail

Client: USDOE/NETL Report Date: 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 1b - 7FA.05 CCS
Plant Size: 552.8 MW,net Estimate Type: Conceptual Cost Base (Jun) 2011 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost	H.O.& Fee	Process	Project	$	$/kW
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$2,940	$3,045	$2,486	$0	$0	$8,471	$682	$0	$1,373	$10,526	$19
3.2	Water Makeup & Pretreating	$2,514	$260	$1,290	$0	$0	$4,063	$335	$0	$880	$5,279	$10
3.3	Other Feedwater Subsystems	$1,377	$455	$380	$0	$0	$2,213	$171	$0	$358	$2,741	$5
3.4	Service Water Systems	$304	$605	$1,950	$0	$0	$2,859	$243	$0	$620	$3,723	$7
3.5	Other Boiler Plant Systems	$2,045	$764	$1,758	$0	$0	$4,567	$372	$0	$741	$5,680	$10
3.6	Natural Gas, incl. pipeline	$17,695	$635	$549	$0	$0	$18,879	$1,557	$0	$3,065	$23,501	$43
3.7	Waste Treatment Equipment	$878	$0	$508	$0	$0	$1,386	$120	$0	$301	$1,807	$3
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,213	$162	$589	$0	$0	$1,964	$168	$0	$426	$2,558	$5
	SUBTOTAL 3.	**$28,966**	**$5,926**	**$9,512**	**$0**	**$0**	**$44,403**	**$3,648**	**$0**	**$7,765**	**$55,815**	**$101**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$137,818	$0	$41,530	$0	$0	$179,348	$14,964	$35,870	$46,036	$276,219	$500
5B.2	CO2 Compression & Drying	$20,138	$0	$8,227	$0	$0	$28,365	$2,375	$0	$6,148	$36,887	$67
	SUBTOTAL 5.	**$157,956**	**$0**	**$49,757**	**$0**	**$0**	**$207,713**	**$17,339**	**$35,870**	**$52,184**	**$313,106**	**$566**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$104,200	$0	$6,364	$0	$0	$110,564	$9,132	$0	$11,970	$131,665	$238
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$881	$952	$0	$0	$1,833	$153	$0	$397	$2,384	$4
	SUBTOTAL 6.	**$104,200**	**$881**	**$7,316**	**$0**	**$0**	**$112,397**	**$9,285**	**$0**	**$12,367**	**$134,049**	**$242**

Exhibit 3-21 Case 1b - SOA turbine with CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL — Report Date: 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 1b - 7FA.05 CCS
Plant Size: 552.8 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2011 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost	H.O.& Fee	Process	Project	$	$/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$35,170	$0	$6,187	$0	$0	$41,357	$3,434	$0	$4,479	$49,270	$89
7.2	HRSG Accessories	$1,973	$828	$1,155	$0	$0	$3,956	$331	$0	$643	$4,931	$9
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$517	$485	$0	$0	$1,002	$84	$0	$217	$1,302	$2
	SUBTOTAL 7.	**$37,143**	**$1,345**	**$7,827**	**$0**	**$0**	**$46,315**	**$3,849**	**$0**	**$5,339**	**$55,504**	**$100**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$30,390	$0	$4,949	$0	$0	$35,339	$2,790	$0	$3,813	$41,941	$76
8.2	Turbine Plant Auxiliaries	$200	$0	$445	$0	$0	$645	$55	$0	$70	$771	$1
8.3	Condenser & Auxiliaries	$2,070	$0	$1,241	$0	$0	$3,311	$279	$0	$359	$3,949	$7
8.4	Steam Piping	$10,019	$0	$4,061	$0	$0	$14,079	$959	$0	$2,256	$17,294	$31
8.9	TG Foundations	$0	$858	$1,416	$0	$0	$2,274	$192	$0	$493	$2,959	$5
	SUBTOTAL 8.	**$42,679**	**$858**	**$12,112**	**$0**	**$0**	**$55,648**	**$4,275**	**$0**	**$6,991**	**$66,914**	**$121**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$4,040	$0	$1,230	$0	$0	$5,270	$440	$0	$571	$6,281	$11
9.2	Circulating Water Pumps	$1,961	$0	$118	$0	$0	$2,080	$159	$0	$224	$2,462	$4
9.3	Circ.Water System Auxiliaries	$157	$0	$21	$0	$0	$178	$15	$0	$19	$212	$0
9.4	Circ.Water Piping	$0	$4,870	$1,102	$0	$0	$5,972	$448	$0	$963	$7,382	$13
9.5	Make-up Water System	$380	$0	$488	$0	$0	$868	$72	$0	$141	$1,081	$2
9.6	Component Cooling Water Sys	$313	$375	$240	$0	$0	$928	$74	$0	$150	$1,153	$2
9.9	Circ.Water System Foundations	$0	$2,201	$3,655	$0	$0	$5,856	$494	$0	$1,270	$7,621	$14
	SUBTOTAL 9.	**$6,851**	**$7,445**	**$6,855**	**$0**	**$0**	**$21,152**	**$1,701**	**$0**	**$3,338**	**$26,191**	**$47**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$7,221	$0	$4,271	$0	$0	$11,492	$944	$0	$933	$13,369	$24
11.2	Station Service Equipment	$2,745	$0	$236	$0	$0	$2,981	$246	$0	$242	$3,469	$6
11.3	Switchgear & Motor Control	$3,378	$0	$587	$0	$0	$3,965	$328	$0	$429	$4,723	$9
11.4	Conduit & Cable Tray	$0	$1,765	$5,086	$0	$0	$6,851	$571	$0	$1,113	$8,535	$15
11.5	Wire & Cable	$0	$5,673	$3,226	$0	$0	$8,899	$535	$0	$1,415	$10,849	$20
11.6	Protective Equipment	$0	$730	$2,533	$0	$0	$3,263	$281	$0	$354	$3,898	$7
11.7	Standby Equipment	$125	$0	$116	$0	$0	$242	$20	$0	$26	$288	$1
11.8	Main Power Transformers	$14,007	$0	$183	$0	$0	$14,190	$963	$0	$1,515	$16,669	$30
11.9	Electrical Foundations	$0	$158	$402	$0	$0	$559	$47	$0	$121	$728	$1
	SUBTOTAL 11.	**$27,476**	**$8,326**	**$16,640**	**$0**	**$0**	**$52,443**	**$3,935**	**$0**	**$6,150**	**$62,528**	**$113**

Exhibit 3-21 Case 1b - SOA turbine with CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL — Report Date: 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 1b - 7FA.05 CCS
Plant Size: 552.8 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,000	$0	$637	$0	$0	$1,637	$137	$82	$278	$2,134	$4
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$299	$0	$183	$0	$0	$481	$40	$24	$82	$628	$1
12.7	Computer & Accessories	$4,782	$0	$146	$0	$0	$4,928	$405	$246	$558	$6,137	$11
12.8	Instrument Wiring & Tubing	$0	$890	$1,574	$0	$0	$2,464	$177	$123	$415	$3,178	$6
12.9	Other I & C Equipment	$1,783	$0	$4,127	$0	$0	$5,910	$506	$296	$671	$7,382	$13
	SUBTOTAL 12.	**$7,863**	**$890**	**$6,667**	**$0**	**$0**	**$15,420**	**$1,265**	**$771**	**$2,004**	**$19,460**	**$35**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$112	$2,388	$0	$0	$2,501	$218	$0	$544	$3,263	$6
13.2	Site Improvements	$0	$1,031	$1,362	$0	$0	$2,392	$213	$0	$521	$3,126	$6
13.3	Site Facilities	$2,104	$0	$2,208	$0	$0	$4,312	$384	$0	$939	$5,636	$10
	SUBTOTAL 13.	**$2,104**	**$1,143**	**$5,958**	**$0**	**$0**	**$9,205**	**$816**	**$0**	**$2,004**	**$12,025**	**$22**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$304	$161	$0	$0	$464	$36	$0	$75	$575	$1
14.2	Steam Turbine Building	$0	$2,242	$2,983	$0	$0	$5,224	$420	$0	$847	$6,491	$12
14.3	Administration Building	$0	$585	$397	$0	$0	$982	$76	$0	$159	$1,217	$2
14.4	Circulation Water Pumphouse	$0	$186	$92	$0	$0	$278	$21	$0	$45	$345	$1
14.5	Water Treatment Buildings	$0	$533	$486	$0	$0	$1,019	$81	$0	$165	$1,265	$2
14.6	Machine Shop	$0	$508	$325	$0	$0	$833	$65	$0	$135	$1,032	$2
14.7	Warehouse	$0	$328	$198	$0	$0	$526	$41	$0	$85	$651	$1
14.8	Other Buildings & Structures	$0	$98	$71	$0	$0	$170	$13	$0	$27	$210	$0
14.9	Waste Treating Building & Str.	$0	$384	$686	$0	$0	$1,070	$87	$0	$174	$1,331	$2
	SUBTOTAL 14.	**$0**	**$5,169**	**$5,398**	**$0**	**$0**	**$10,567**	**$840**	**$0**	**$1,711**	**$13,118**	**$24**
	TOTAL COST	**$415,239**	**$31,983**	**$128,042**	**$0**	**$0**	**$575,263**	**$46,953**	**$36,641**	**$99,853**	**$758,709**	**$1,372**

Exhibit 3-21 Case 1b - SOA turbine with CO_2 capture capital cost estimate detail (continued)

	Client:	USDOE/NETL							**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 1b - 7FA.05 CCS										
	Plant Size:	552.8 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)	
Acct		**Equipment**	**Material**	**Labor**		**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**		
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Cost**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**	
	TOTAL COST	**$415,239**	**$31,983**	**$128,042**	**$0**	**$575,263**	**$46,953**	**$36,641**	**$99,853**	**$758,709**	**$1,372**	
	Owner's Costs											
	Preproduction Costs											
	6 Months All Labor									$5,253	$10	
	1 Month Maintenance Materials									$815	$1	
	1 Month Non-fuel Consumables									$455	$1	
	1 Month Waste Disposal									$0	$0	
	25% of 1 Months Fuel Cost at 100% CF									$4,669	$8	
	2% of TPC									$15,174	$27	
	Total									**$26,366**	**$48**	
	Inventory Capital											
	60 day supply of consumables at 100% CF									$629	$1	
	0.5% of TPC (spare parts)									$3,794	$7	
	Total									**$4,423**	**$8**	
	Initial Cost for Catalyst and Chemicals									$1,383	$3	
	Land									$300	$1	
	Other Owner's Costs									$113,806	$206	
	Financing Costs									$20,485	$37	
	Total Overnight Costs (TOC)									**$925,473**	**$1,674**	
	TASC Multiplier							(IOU, high-risk, 33 year)		1.078		
	Total As-Spent Cost (TASC)									**$997,659**	**$1,805**	

Exhibit 3-22 Case 1b - SOA turbine with CO_2 capture operating cost estimate

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun)	2011
Case 1b - 7FA.05 CCS					Heat Rate-net (Btu/kWh):	7,549
					MWe-net:	553
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	3.3		3.3			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	6.3		6.3			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$2,861,816	$5.177
Maintenance Labor Cost					$5,542,918	$10.027
Administrative & Support Labor					$2,101,183	$3.801
Property Taxes and Insurance					$15,174,186	$27.449
TOTAL FIXED OPERATING COSTS					**$25,680,103**	**$46.453**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					**$8,314,377**	**$0.00202**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0.00	2,752.56	1.67	**$0**	**$1,429,561**	**$0.00035**
Chemicals						
MU & WT Chem.(lbs)	0.00	16,398.96	0.27	$0	$1,362,705	$0.00033
MEA Solvent (ton)	382.15	0.54	3,481.91	$1,330,624	$579,745	$0.00014
Activated Carbon (lb)	0.00	641.08	1.63	$0	$323,251	$0.00008
Corrosion Inhibitor	0.00	0.00	0.00	$52,355	$2,493	$0.00000
SCR Catalyst (m3)	w/equip.	0.08	8,938.80	$0	$229,367	$0.00006
Ammonia (19% NH3) (ton)	0.00	6.96	330.00	$0	$712,171	$0.00017
Subtotal Chemicals				**$1,382,978**	**$3,209,732**	**$0.00078**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$1,382,978**	**$12,953,669**	**$0.00315**
Fuel (MMBtu)	0	100,157	6.13	**$0**	**$190,481,718**	**$0.04625**

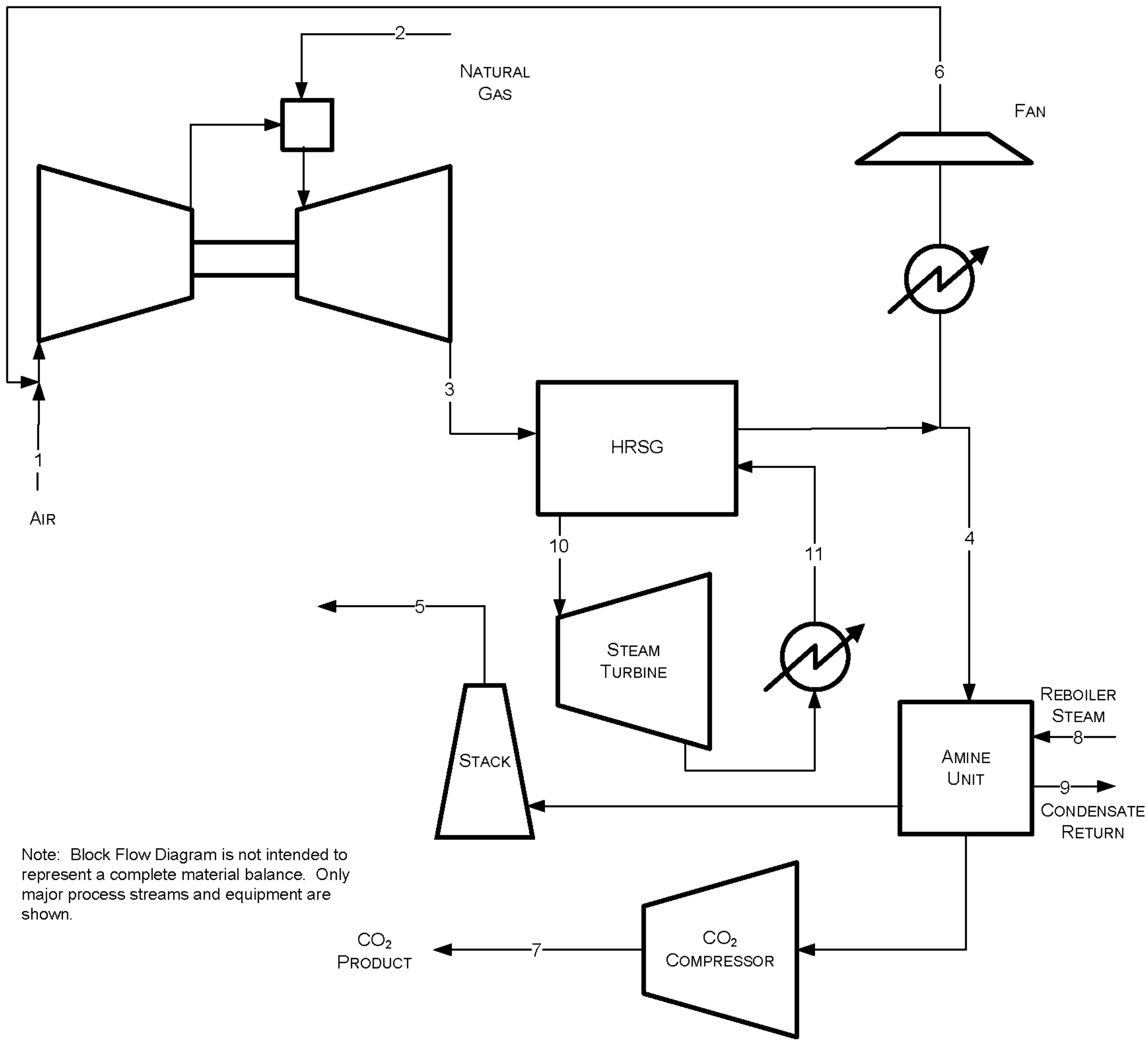
3.3 Case 1c – NGCC with CO_2 Capture and EGR Modeling Results

The block flow diagram of the combined cycle with CO_2 capture and EGR is shown in Exhibit 3-23. This case also uses the same 7FA.05 gas turbine model as that of Case 1a with the addition of EGR and CO_2 capture at the back end. Exhibit 3-24 provides process data for the numbered streams in the BFD. The heat required for the solvent (amine) system in the CO_2 capture system is supplied from the Rankine cycle similar to case 1b. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems.

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,359°C (2,479°F). The flue gas exits the turbine at 615°C (1,139°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine as well as the steam required for the capture process (stream 8). Flue gas exits the HRSG (stream 4) at 107°C (225°F). A portion of the stream (stream 6) is recycled back to the air inlet and the remainder (stream 4) passes to the capture system where the CO_2 is captured and compressed (stream 7). Cooling is supplied to the steam turbine condenser via water from the cooling tower.

The gas turbine (Brayton cycle) performance and exhaust characteristics are impacted due to addition of the EGR. Of particular interest is that the CO_2 composition at gas turbine exhaust increases from 3.9 percent in the capture only case (Case 1b) to 6.1 percent in this capture with EGR case. The O_2 composition concurrently decreases from 8.3 percent in the capture only case (Case 1b) to 7.4 percent in this capture with EGR. The higher concentration of the CO_2 in the exhaust gas stream reduces the energy consumption of the CO_2 capture system. Because of this, the EGR case provides a better output and efficiency compared to the capture case without EGR (Case 1b). However, the overall plant output and efficiency are reduced compared to the no CO_2 capture case (Case 1a) due to heat integration requirements and increased auxiliary loads for the EGR and CO_2 capture process.

Exhibit 3-23 Case 1c - SOA turbine with CO_2 capture and EGR block flow diagram



Source: NETL

Exhibit 3-24 Case 1c - SOA turbine with CO_2 capture and EGR stream table

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0093	0.0000	0.0090	0.0090	0.0101	0.0095	0.0000	0.0000	0.0000	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0607	0.0607	0.0068	0.0640	1.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0101	0.0000	0.0978	0.0978	0.0555	0.0480	0.0000	1.0000	1.0000	1.0000	1.0000
N_2	0.7729	0.0160	0.7496	0.7496	0.8353	0.7910	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.2074	0.0000	0.0829	0.0829	0.0924	0.0875	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)	81,816	4,894	129,957	84,471	75,804	43,113	4,612	12,719	12,719	23,567	20,539
V-L Flowrate (kg/hr)	2,361,220	84,815	3,697,286	2,403,187	2,127,058	1,251,153	202,974	229,133	229,133	424,562	370,023
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	38	615	107	35	33	38	292	138	566	32
Pressure (MPa, abs)	0.10	2.76	0.10	0.10	0.10	0.10	15.17	0.34	0.39	16.65	0.00
Enthalpy (kJ/kg)[A]	30.23	46.30	661.75	87.41	10.51	8.47	-225.74	3,052.41	578.94	3,476.21	2,379.03
Density (kg/m^3)	1.2	18.5	0.4	0.9	1.1	1.2	796.1	2.7	915.8	47.7	992.9
V-L Molecular Weight	28.860	17.330	28.450	28.450	28.060	29.020	44.010	18.015	18.015	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	180,374	10,790	286,507	186,226	167,119	95,049	10,168	28,040	28,040	51,956	45,282
V-L Flowrate (lb/hr)	5,205,600	186,984	8,151,120	5,298,120	4,689,360	2,758,320	447,480	505,152	505,152	936,000	815,760
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	100	1,139	225	95	92	101	557	280	1,050	90
Pressure (psia)	14.7	399.7	15.2	14.7	14.7	14.7	2,200.0	49.0	56.7	2,415.0	0.7
Enthalpy (Btu/lb)[A]	13.0	19.9	284.5	37.6	4.5	3.6	-97.1	1,312.3	248.9	1,494.5	1,022.8
Density (lb/ft^3)	0.076	1.153	0.025	0.057	0.069	0.072	49.700	0.169	57.172	2.977	61.982

A - Enthalpy is 32F (0C) with H2O as liquid

Note: Total flow rates shown equal the sum for all process trains

3.3.1 Performance Results

The performance results are summarized in Exhibit 3-25 and when compared with Case 1b show that adding exhaust gas recycle increases the efficiency only by approximately 0.6 percentage points. This is due to lowering the steam requirement for the reboiler slightly (to 2,790 kJ/kg CO_2 (1,200 Btu/lb CO_2) from the 2,960 kJ/kg CO_2 (1,272 Btu/lb CO_2) used in Case 1b) and based on the CO_2 concentration increasing and the oxygen concentration decreasing for the exhaust gas entering the solvent recovery section. An additional improvement would be expected if the exhaust gas recycle was increased from the 35 percent used to 50 percent. This was not explored in the current study since it was determined based on information from GE that 35 percent was a limit above which the gas turbine's combustor would need major redesign.

Additional tables below provide overall energy balance (Exhibit 3-26), water balance (Exhibit 3-27), carbon balance (Exhibit 3-28), and an emissions summary (Exhibit 3-29).

Exhibit 3-25 Case 1c - SOA turbine with CO_2 capture and EGR plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	418,558	kW_e
Steam Turbine Power	196,582	kW_e
Total	**615,140**	kW_e
Auxiliary Load		
Condensate Pumps	268	kW_e
Boiler Feedwater Pumps	4,834	kW_e
Exhaust Gas Recycle Fan	376	kW_e
Amine CO_2 Capture System Auxiliaries	13,128	kW_e
CO_2 Compression	18,815	kW_e
EGR Coolant Pump	301	kW_e
Circulating Water Pump	4,463	kW_e
Ground Water Pumps	370	kW_e
Cooling Tower Fans	2,846	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	860	kW_e
Steam Turbine Auxiliaries	556	kW_e
Miscellaneous Balance of Plant[2]	2,148	kW_e
Transformer Losses	3,000	kW_e
Total	**51,975**	**kW_e**
Plant Performance		
Net Plant Power	**563,165**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	45.7%	
Net Plant Efficiency (LHV)[1]	50.6%	
Net Plant Heat Rate (HHV)[1]	7,879 (7,468)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	7,112 (6,741)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	84,815 (186,984)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,232,595	kW_t
Thermal Input (LHV)[1]	1,112,558	kW_t
Condenser Duty	833 (790)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	15.6 (4,109)	m^3/min (gpm)
Raw Water Consumption	11.6 (3,069)	m^3/min (gpm)

[1] *HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)*
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] *Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads*

Exhibit 3-26 Case 1c - SOA turbine with CO_2 capture and EGR overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	4,437 (4,206)	3.0 (2.8)	0 (0)	4,440 (4,209)
GT Air	0 (0)	71.4 (67.6)	0 (0)	71 (68)
Raw Water Withdrawal	0 (0)	58.5 (55.4)	0 (0)	58 (55)
Auxiliary Power	0 (0)	0.0 (0.0)	187 (177)	187 (177)
TOTAL	**4,437 (4,206)**	**132.8 (125.9)**	**187 (177)**	**4,757 (4,509)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	29.1 (27.6)	0 (0)	29 (28)
Stack Gas	0 (0)	22 (21)	0 (0)	22 (21)
Condenser	0 (0)	830 (787)	0 (0)	830 (787)
CO_2 Product	0 (0)	-45.8 (-43.4)	0 (0)	-46 (-43)
CO_2 Intercoolers	0 (0)	117.4 (111.3)	0 (0)	117 (111)
EGR Cooling	0 (0)	209.6 (198.7)	0 (0)	210 (199)
Amine System Losses	0 (0)	785.2 (744.2)	0 (0)	785 (744)
Process Losses*	*0 (0)*	*-595 (-564)*	*0 (0)*	*-595 (-564)*
Power	0 (0)	0.0 (0.0)	2,215 (2,099)	2,215 (2,099)
TOTAL	**0 (0)**	**2,543 (2,410)**	**2,215 (2,099)**	**4,757 (4,509)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 3-27 Case 1c - SOA turbine with CO_2 capture and EGR water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Amine CO_2 Capture System	0.05 (13)	0.0 (0)	0.05 (13)	0.0 (0)	0.05 (13)
Condenser Makeup	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**
BFW Makeup	0.06 (15)	0.0 (0)	0.06 (15)	0.0 (0)	0.0 (0)
Cooling Tower	**17.4 (4,607)**	**2.0 (527)**	**15.5 (4,081)**	**3.9 (1,040)**	**11.5 (3,041)**
BFW Blowdown	0.00 (0)	0.06 (15)	-0.06 (-15)	0.0 (0)	0.0 (0)
EGR Condensate	0.00 (0)	0.72 (189)	-0.72 (-189)	0.0 (0)	0.0 (0)
Flue Gas/CO_2 Condensate	0.00 (0)	1.22 (322)	-1.22 (-322)	0.0 (0)	0.0 (0)
Total	**17.5 (4,636)**	**2.0 (527)**	**15.6 (4,109)**	**3.9 (1,040)**	**11.6 (3,069)**

Exhibit 3-28 Case 1c - SOA turbine with CO_2 capture and EGR carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	61,252 (135,037)	Stack Gas	6,157 (13,573)
Air (CO_2)	295 (650)	CO_2 Product	55,395 (122,124)
		Convergence Tolerance*	-5 (-10)
Total	**61,547 (135,687)**	**Total**	**61,547 (135,687)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 3-29 Case 1c - SOA turbine with CO_2 capture and EGR air emissions

	kg/GJ (lb/10^6 Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.002 (0.005)	71 (78)	0.016 (0.034)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	5.1 (11.8)	167,973 (185,158)	37 (81)
CO_2[1]			40 (88)

[1] CO_2 emissions based on net power instead of gross power

3.3.2 Major Equipment List

This section contains a portion of the equipment list corresponding to the 7FA.05 GT with CO_2 capture and EGR plant configuration for case 1c. This list, along with the heat and material balance and supporting performance data, was used to generate plant costs. The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as N/A.

Account 1 – Coal and Sorbent Handling

N/A

Account 2 – Coal and Sorbent Preparation and Feed

N/A

Account 3 - Feedwater and Miscellaneous Systems and Equipment

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	454,253 liters (120,000 gal)	2 (0)
2	Condensate Pumps	Vertical canned	3,407 lpm @ 49 m H_2O (900 gpm @ 160 ft H_2O)	2 (1)
3	Boiler Feedwater Pump	Horizontal, split case, multi-stage, centrifugal, with interstage bleed for IP and LP feedwater	HP water: 3,937 lpm @ 1,878 m H_2O (1,040 gpm @ 6,160 ft H_2O) IP water: 4,845 lpm @ 311 m H_2O (1,280 gpm @ 1,020 ft H_2O) LP water: 720 lpm @ 0.0 m H_2O (190 gpm @ 00 ft H_2O)	2 (1)
4	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg /hr, 2.8 MPa, 343°C (40,000 lb /hr, 400 psig, 650°F)	1 (0)
5	Service Air Compressors	Flooded Screw	13 m^3/min @ 0.7 MPa (450 scfm @ 100 psig)	2 (1)
6	Instrument Air Dryers	Duplex, regenerative	13 m^3/min (450 scfm)	2 (1)
7	Closed Cycle Cooling Heat Exchangers	Plate and frame	13 GJ/hr (13 MMBtu/hr)	2 (0)
8	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	5,300 lpm @ 21 m H_2O (1,400 gpm @ 70 ft H_2O)	2 (1)
9	Engine-Driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1 (1)
10	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1 (1)
11	Raw Water Pumps	Stainless steel, single suction	9,842 lpm @ 18 m H_2O (2,600 gpm @ 60 ft H_2O)	2 (1)
12	Filtered Water Pumps	Stainless steel, single suction	170 lpm @ 49 m H_2O (45 gpm @ 160 ft H_2O)	2 (1)
13	Filtered Water Tank	Vertical, cylindrical	166,560 liter (44,000 gal)	1 (0)
14	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly and electro-deionization unit	379 lpm (100 gpm)	1 (0)
15	Liquid Waste Treatment System		10 years, 24-hour storm	1 (0)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
16	Gas Pipeline	Underground, coated carbon steel, wrapped cathodic protection	84 m^3/min @ 2.8 MPa (2,973 acfm @ 399.7 psia) 41 cm (16 in) standard wall pipe	16 km 10 mile
17	Gas Metering Station	--	84 m^3/min (2,973 acfm)	1 (0)

Account 4 – Gasifier, Boiler, and Accessories

N/A

Account 5 – Flue Gas Cleanup

N/A

Account 5B – CO_2 Capture and Compression

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Amine CO_2 Capture System	Amine-based CO_2 capture technology	1,321,770 kg/hr (2,914,000 lb/hr) 9.4 wt % CO_2 concentration	2 (0)
2	CO_2 Compressor	Integrally geared, multi-stage centrifugal	111,584 kg/hr @ 15.2 MPa (246,000 lb/hr @ 2,200 psia)	2 (0)
3	Exhaust Gas Recycle Blowers	Centrifugal	10,000 m^3/min @ 12.7 cm WG (353,170 acfm @ 5 in WG)	2 (0)
4	EGR Cooler	Contact Heat Exchanger	116 GJ/hr, (110 MMBtu/hr), Gas Stream 1,423,000 kg/hr, (3,138,000 lb/hr) 26,030 m^3/min, (919,000 acfm) from 107°C (225°F) to 32°C (90°F), Water Stream 4,910,000 kg/hr, (10,875,000 lb/hr) 6,691,000 lpm, (1,503,000 gpm) from 18°C (64.5°F) to 29°C (84.5°F)	1 (0)
5	EGR Cooler Pumps	Horizontal Centrifugal	41,600 lpm @ 18 m H_2O (10,990 gpm @ 60 ft H_2O)	4 (0)

Account 6 – Combustion Turbine Generators and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Gas Turbine	7FA.05 Advanced F frame w/ dry low-NOx burner	225 MW	2 (0)
2	Gas Turbine Generator	TEWAC	250 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2 (0)

Account 7 – Waste Heat Boiler, Ducting, and Stack

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Stack	CS plate, type 409SS liner	46 m (150 ft) high x 5.3 m (17 ft) diameter	2 (0)
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 233,510 kg/hr, 16.5 MPa/566°C (514,800 lb/hr, 2,400 psig/1,050°F) Reheat steam - 277,787 kg/hr, 2.4 MPa/566°C (612,414 lb/hr, 345 psig/1,050°F)	2 (0)
3	SCR Reactor	Space for spare layer	1,070,270 kg/hr (2,580,000 lb/hr)	2 (0)
4	SCR Catalyst	--	Space available for an additional catalyst layer	1 layer (0)
5	Dilution Air Blowers	Centrifugal	12 m^3/min @ 107 cm WG (440 scfm @ 42 in WG)	2 (1)
6	Ammonia Feed Pump	Centrifugal	3.8 lpm @ 91 m H_2O (1 gpm @ 300 ft H_2O)	2 (1)
7	Ammonia Storage Tank	Horizontal tank	75,709 liter (20,000 gal)	1 (0)

Account 8 – Steam Turbine Generator and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Steam Turbine	Tandem compound, HP, IP, and two-flow LP turbines	207 MW 16.5 MPa/566°C/566°C (2,400 psig / 1,050°F/1,050°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	230 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
3	Steam Bypass	One per HRSG	50% steam flow @ design steam conditions	2 (0)
4	Surface Condenser	Single pass, divided waterbox including vacuum pumps	917 GJ/hr, (870 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

Account 9 – Cooling Water System

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	450,468 lpm @ 30.5 m (119,000 gpm @ 100 ft)	2 (1)
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT 2,503 GJ/hr (2,375 MMBtu/hr) heat load	1 (0)

Account 10 – Ash Spent Sorbent Recovery and Handling

N/A

Account 11 – Accessory Electric Plant

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	CTG Transformer	Oil-filled	24 kV/345 kV, 250 MVA, 3-ph, 60 Hz	2 (0)
2	STG Transformer	Oil-filled	24 kV/345 kV, 190 MVA, 3-ph, 60 Hz	1 (0)
3	High Voltage Auxiliary Transformer	Oil-filled	345 kV/13.8 kV, 10 MVA, 3-ph, 60 Hz	2 (0)
4	Medium Voltage Transformer	Oil-filled	24 kV/4.16 kV, 34 MVA, 3-ph, 60 Hz	1 (1)
5	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 5 MVA, 3-ph, 60 Hz	1 (1)
6	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2 (0)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
7	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1 (0)
8	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1 (1)
9	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1 (1)
10	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

Account 12 – Instrumentation and Control

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	DCS - Main Control	Monitor/keyboard; Operator printer; Engineering printer	Operator stations/printers and engineering stations/printers	1 (0)
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1 (0)
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1 (0)

3.3.3 Cost Estimate Results

Capital and operating costs for Cases 1c using the 7FA.05 turbine were estimated by WorleyParsons based on simulation results and vendor quotes/discussions, costing software, or a combination of the two. All costs are in June 2011 dollars.

The cost estimation results for this case are summarized in Exhibit 3-30. The summary and detail capital cost estimates for this case are shown in Exhibit 3-31 and Exhibit 3-32, respectively. The annual operating cost estimates are shown in Exhibit 3-33.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 3-30 Case 1c - SOA turbine with CO_2 capture and EGR cost estimation summary

Case	1c
Total Plant Cost (2011$/kW)	**1,285**
Total Overnight Cost (2011$/kW)	**1,568**
Total As-spent Capital (2011$/kW)	**1,691**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	23.38
Fixed O&M	5.99
Variable O&M	3.18
Fuel	45.77
CO_2 T&S total	3.60
COE[1] Total	**81.92**
LCOE[1], total (including T&S)	103.85
Cost[1,2] of CO_2 avoided, $/tonne of CO_2 ($/ton of CO_2)	78.94 (71.61)
Cost[1,2] of CO_2 captured, $/tonne of CO_2 ($/ton of CO_2)	58.75 (53.30)

[1] *Capacity factor assumed to be 85 percent*
[2] *Reference base case is 1a – 7FA.05 without capture*

Exhibit 3-31 Case 1c - SOA turbine with CO_2 capture and EGR capital cost estimate summary

Client:	USDOE/NETL
Project:	Costing Support for NGCC with CCS Analyses
Report Date:	2012-Apr-04
Case:	Case 1c - 7FA.05 CCS EGR
Plant Size:	563.2 MW,net
Estimate Type:	Conceptual
Cost Base (Jun)	2011 ($x1000)

TOTAL PLANT COST SUMMARY

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$29,483	$6,179	$9,947	$0	$0	**$45,609**	$3,746	$0	$7,985	**$57,340**	**$102**
4	GASIFIER & ACCESSORIES											
4.1	Gasifier, Syngas Cooler & Auxiliaries	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.2	Syngas Cooling	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.3	ASU/Oxidant Compression	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
4.4-4.9	Other gasification Equipment	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0
5A	GAS CLEANUP & PIPING	$0	$9,254	$5,834	$0	$0	**$15,088**	$1,176	$0	$3,253	**$19,518**	$35
5B	CO2 REMOVAL & COMPRESSION	$122,476	$0	$39,143	$0	$0	**$161,619**	$13,493	$26,642	$40,351	**$242,106**	**$430**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$109,410	$0	$6,913	$0	$0	**$116,323**	$9,920	$0	$13,002	**$139,245**	$247
6.2-6.9	Combustion Turbine Other	$0	$881	$952	$0	$0	**$1,833**	$153	$0	$397	**$2,384**	$4
	SUBTOTAL 6	**$109,410**	**$881**	**$7,865**	**$0**	**$0**	**$118,156**	**$10,073**	**$0**	**$13,399**	**$141,628**	**$251**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$36,130	$0	$6,355	$0	$0	**$42,485**	$3,528	$0	$4,601	**$50,614**	$90
7.2-7.9	SCR System, Ductwork and Stack	$1,963	$1,354	$1,647	$0	$0	**$4,965**	$415	$0	$863	**$6,243**	$11
	SUBTOTAL 7	**$38,093**	**$1,354**	**$8,002**	**$0**	**$0**	**$47,450**	**$3,943**	**$0**	**$5,464**	**$56,857**	**$101**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$32,000	$0	$5,198	$0	$0	**$37,198**	$2,936	$0	$4,013	**$44,148**	$78
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$12,798	$897	$7,459	$0	$0	**$21,155**	$1,548	$0	$3,309	**$26,011**	$46
	SUBTOTAL 8	**$44,798**	**$897**	**$12,657**	**$0**	**$0**	**$58,352**	**$4,484**	**$0**	**$7,322**	**$70,158**	**$125**
9	COOLING WATER SYSTEM	$7,381	$7,942	$7,332	$0	$0	**$22,655**	$1,822	$0	$3,571	**$28,048**	$50
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$27,868	$8,176	$16,492	$0	$0	**$52,535**	$3,940	$0	$6,142	**$62,617**	$111
12	INSTRUMENTATION & CONTROL	$7,912	$895	$6,708	$0	$0	**$15,516**	$1,273	$776	$2,016	**$19,581**	$35
13	IMPROVEMENTS TO SITE	$2,117	$1,150	$5,994	$0	$0	**$9,261**	$821	$0	$2,016	**$12,098**	$21
14	BUILDINGS & STRUCTURES	$0	$5,291	$5,543	$0	$0	**$10,834**	$861	$0	$1,754	**$13,450**	$24
	TOTAL COST	**$389,539**	**$42,019**	**$125,518**	**$0**	**$0**	**$557,076**	**$45,633**	**$27,418**	**$93,275**	**$723,402**	**$1,285**

Exhibit 3-32 Case 1c - SOA turbine with CO_2 capture and EGR capital cost estimate detail

	Client:	USDOE/NETL								**Report Date:**	2012-Apr-04	
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 1c - 7FA.05 CCS EGR										
	Plant Size:	563.2 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)	
Acct		**Equipment**	**Material**	**Labor**		**Sales**	**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**	
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Tax**	**Cost**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,075	$3,184	$2,600	$0	$0	$8,858	$713	$0	$1,436	$11,008	$20
3.2	Water Makeup & Pretreating	$2,648	$274	$1,359	$0	$0	$4,281	$353	$0	$927	$5,562	$10
3.3	Other Feedwater Subsystems	$1,440	$476	$398	$0	$0	$2,314	$179	$0	$374	$2,867	$5
3.4	Service Water Systems	$320	$638	$2,055	$0	$0	$3,012	$256	$0	$654	$3,922	$7
3.5	Other Boiler Plant Systems	$2,155	$805	$1,852	$0	$0	$4,812	$392	$0	$781	$5,984	$11
3.6	Natural Gas, incl. pipeline	$17,698	$639	$554	$0	$0	$18,891	$1,558	$0	$3,067	$23,516	$42
3.7	Waste Treatment Equipment	$925	$0	$535	$0	$0	$1,460	$126	$0	$317	$1,904	$3
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,222	$163	$594	$0	$0	$1,979	$169	$0	$430	$2,578	$5
	SUBTOTAL 3.	**$29,483**	**$6,179**	**$9,947**	**$0**	**$0**	**$45,609**	**$3,746**	**$0**	**$7,985**	**$57,340**	**$102**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$9,254	$5,834	$0	$0	$15,088	$1,176	$0	$3,253	$19,518	$35
5A.9	HGCU Foundations	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$9,254**	**$5,834**	**$0**	**$0**	**$15,088**	**$1,176**	**$0**	**$3,253**	**$19,518**	**$35**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$102,365	$0	$30,847	$0	$0	$133,212	$11,115	$26,642	$34,194	$205,163	$364
5B.2	CO2 Compression & Drying	$20,111	$0	$8,296	$0	$0	$28,408	$2,379	$0	$6,157	$36,943	$66
	SUBTOTAL 5.	**$122,476**	**$0**	**$39,143**	**$0**	**$0**	**$161,619**	**$13,493**	**$26,642**	**$40,351**	**$242,106**	**$430**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$109,410	$0	$6,913	$0	$0	$116,323	$9,920	$0	$13,002	$139,245	$247
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$881	$952	$0	$0	$1,833	$153	$0	$397	$2,384	$4
	SUBTOTAL 6.	**$109,410**	**$881**	**$7,865**	**$0**	**$0**	**$118,156**	**$10,073**	**$0**	**$13,399**	**$141,628**	**$251**

Exhibit 3-32 Case 1c - SOA turbine with CO_2 capture and EGR capital cost estimate detail (continued)

Client: USDOE/NETL — **Report Date:** 2012-Apr-04
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 1c - 7FA.05 CCS EGR
Plant Size: 563.2 MW,net — **Estimate Type:** Conceptual — **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$36,130	$0	$6,355	$0	$0	$42,485	$3,528	$0	$4,601	$50,614	$90
7.2	HRSG Accessories	$1,963	$825	$1,150	$0	$0	$3,938	$330	$0	$640	$4,908	$9
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$530	$497	$0	$0	$1,026	$86	$0	$222	$1,334	$2
	SUBTOTAL 7.	**$38,093**	**$1,354**	**$8,002**	**$0**	**$0**	**$47,450**	**$3,943**	**$0**	**$5,464**	**$56,857**	**$101**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$32,000	$0	$5,198	$0	$0	$37,198	$2,936	$0	$4,013	$44,148	$78
8.2	Turbine Plant Auxiliaries	$209	$0	$466	$0	$0	$675	$58	$0	$73	$806	$1
8.3	Condenser & Auxiliaries	$2,190	$0	$1,298	$0	$0	$3,488	$293	$0	$378	$4,159	$7
8.4	Steam Piping	$10,399	$0	$4,215	$0	$0	$14,614	$996	$0	$2,341	$17,951	$32
8.9	TG Foundations	$0	$897	$1,481	$0	$0	$2,378	$201	$0	$516	$3,094	$5
	SUBTOTAL 8.	**$44,798**	**$897**	**$12,657**	**$0**	**$0**	**$58,352**	**$4,484**	**$0**	**$7,322**	**$70,158**	**$125**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$4,370	$0	$1,330	$0	$0	$5,700	$476	$0	$618	$6,793	$12
9.2	Circulating Water Pumps	$2,113	$0	$132	$0	$0	$2,245	$171	$0	$242	$2,657	$5
9.3	Circ.Water System Auxiliaries	$167	$0	$22	$0	$0	$189	$16	$0	$21	$226	$0
9.4	Circ.Water Piping	$0	$5,190	$1,175	$0	$0	$6,365	$477	$0	$1,026	$7,869	$14
9.5	Make-up Water System	$397	$0	$510	$0	$0	$907	$75	$0	$147	$1,130	$2
9.6	Component Cooling Water Sys	$334	$399	$256	$0	$0	$989	$79	$0	$160	$1,229	$2
9.9	Circ.Water System Foundations	$0	$2,353	$3,907	$0	$0	$6,260	$528	$0	$1,358	$8,145	$14
	SUBTOTAL 9.	**$7,381**	**$7,942**	**$7,332**	**$0**	**$0**	**$22,655**	**$1,822**	**$0**	**$3,571**	**$28,048**	**$50**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$7,275	$0	$4,304	$0	$0	$11,579	$951	$0	$940	$13,470	$24
11.2	Station Service Equipment	$2,689	$0	$231	$0	$0	$2,920	$241	$0	$237	$3,398	$6
11.3	Switchgear & Motor Control	$3,309	$0	$575	$0	$0	$3,884	$322	$0	$421	$4,626	$8
11.4	Conduit & Cable Tray	$0	$1,729	$4,982	$0	$0	$6,711	$559	$0	$1,091	$8,361	$15
11.5	Wire & Cable	$0	$5,557	$3,160	$0	$0	$8,717	$524	$0	$1,386	$10,627	$19
11.6	Protective Equipment	$0	$730	$2,533	$0	$0	$3,263	$281	$0	$354	$3,898	$7
11.7	Standby Equipment	$126	$0	$117	$0	$0	$243	$21	$0	$26	$290	$1
11.8	Main Power Transformers	$14,468	$0	$185	$0	$0	$14,653	$995	$0	$1,565	$17,213	$31
11.9	Electrical Foundations	$0	$159	$405	$0	$0	$565	$48	$0	$122	$735	$1
	SUBTOTAL 11.	**$27,868**	**$8,176**	**$16,492**	**$0**	**$0**	**$52,535**	**$3,940**	**$0**	**$6,142**	**$62,617**	**$111**

Exhibit 3-32 Case 1c - SOA turbine with CO_2 capture and EGR capital cost estimate detail (continued)

Client: USDOE/NETL | Report Date: 2012-Apr-04
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 1c - 7FA.05 CCS EGR
Plant Size: 563.2 MW,net | Estimate Type: Conceptual | Cost Base (Jun) 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,006	$0	$641	$0	$0	$1,647	$138	$82	$280	$2,147	$4
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$301	$0	$184	$0	$0	$484	$41	$24	$82	$632	$1
12.7	Computer & Accessories	$4,812	$0	$147	$0	$0	$4,959	$407	$248	$561	$6,175	$11
12.8	Instrument Wiring & Tubing	$0	$895	$1,584	$0	$0	$2,479	$178	$124	$417	$3,198	$6
12.9	Other I & C Equipment	$1,794	$0	$4,153	$0	$0	$5,947	$509	$297	$675	$7,428	$13
	SUBTOTAL 12.	**$7,912**	**$895**	**$6,708**	**$0**	**$0**	**$15,516**	**$1,273**	**$776**	**$2,016**	**$19,581**	**$35**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$113	$2,403	$0	$0	$2,516	$220	$0	$547	$3,283	$6
13.2	Site Improvements	$0	$1,037	$1,370	$0	$0	$2,407	$214	$0	$524	$3,145	$6
13.3	Site Facilities	$2,117	$0	$2,221	$0	$0	$4,338	$387	$0	$945	$5,670	$10
	SUBTOTAL 13.	**$2,117**	**$1,150**	**$5,994**	**$0**	**$0**	**$9,261**	**$821**	**$0**	**$2,016**	**$12,098**	**$21**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$304	$161	$0	$0	$464	$36	$0	$75	$575	$1
14.2	Steam Turbine Building	$0	$2,326	$3,095	$0	$0	$5,420	$436	$0	$878	$6,735	$12
14.3	Administration Building	$0	$588	$398	$0	$0	$986	$77	$0	$159	$1,222	$2
14.4	Circulation Water Pumphouse	$0	$187	$93	$0	$0	$280	$21	$0	$45	$346	$1
14.5	Water Treatment Buildings	$0	$562	$512	$0	$0	$1,074	$85	$0	$174	$1,333	$2
14.6	Machine Shop	$0	$510	$326	$0	$0	$836	$65	$0	$135	$1,036	$2
14.7	Warehouse	$0	$329	$199	$0	$0	$528	$41	$0	$85	$654	$1
14.8	Other Buildings & Structures	$0	$99	$72	$0	$0	$170	$13	$0	$28	$211	$0
14.9	Waste Treating Building & Str.	$0	$386	$689	$0	$0	$1,075	$88	$0	$174	$1,337	$2
	SUBTOTAL 14.	**$0**	**$5,291**	**$5,543**	**$0**	**$0**	**$10,834**	**$861**	**$0**	**$1,754**	**$13,450**	**$24**
	TOTAL COST	**$389,539**	**$42,019**	**$125,518**	**$0**	**$0**	**$557,076**	**$45,633**	**$27,418**	**$93,275**	**$723,402**	**$1,285**

Exhibit 3-32 Case 1c - SOA turbine with CO_2 capture and EGR capital cost estimate detail (continued)

	Client:	USDOE/NETL						**Report Date:**	2012-Apr-04		
	Project:	Costing Support for NGCC with CCS Analyses									
		TOTAL PLANT COST SUMMARY									
	Case:	Case 1c - 7FA.05 CCS EGR									
	Plant Size:	563.2 MW,net		**Estimate Type:**	Conceptual			**Cost Base (Jun)**	2011	($x1000)	
Acct 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 $**	**TOTAL PLANT COST $/kW**
	TOTAL COST	**$389,539**	**$42,019**	**$125,518**	**$0**	**$557,076**	**$45,633**	**$27,418**	**$93,275**	**$723,402**	**$1,285**
	Owner's Costs										
	Preproduction Costs										
	6 Months All Labor									$5,324	$9
	1 Month Maintenance Materials									$832	$1
	1 Month Non-fuel Consumables									$476	$1
	1 Month Waste Disposal									$0	$0
	25% of 1 Months Fuel Cost at 100% CF									$4,705	$8
	2% of TPC									$14,468	$26
	Total									**$25,804**	**$46**
	Inventory Capital										
	60 day supply of consumables at 100% CF									$650	$1
	0.5% of TPC (spare parts)									$3,617	$6
	Total									**$4,267**	**$8**
	Initial Cost for Catalyst and Chemicals									$1,390	$2
	Land									$300	$1
	Other Owner's Costs									$108,510	$193
	Financing Costs									$19,532	$35
	Total Overnight Costs (TOC)									**$883,204**	**$1,568**
	TASC Multiplier							(IOU, high-risk, 33 year)		1.078	
	Total As-Spent Cost (TASC)									**$952,094**	**$1,691**

Exhibit 3-33 Case 1c - SOA turbine with CO_2 capture and EGR operating cost estimate

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun)	2011
Case 1c - 7FA.05 CCS EGR					Heat Rate-net (Btu/kWh):	7,468
					MWe-net:	563
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	3.3		3.3			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	6.3		6.3			
					Annual Cost $	Annual Unit Cost $/kW-net
Annual Operating Labor Cost					$2,861,816	$5.082
Maintenance Labor Cost					$5,655,968	$10.043
Administrative & Support Labor					$2,129,446	$3.781
Property Taxes and Insurance					$14,468,036	$25.691
TOTAL FIXED OPERATING COSTS					**$25,115,266**	**$44.597**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					**$8,483,952**	**$0.00202**
Consumables	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost		
Water (/1000 gallons)	0.00	2,958.58	1.67	**$0**	**$1,536,558**	**$0.00037**
Chemicals						
MU & WT Chem.(lbs)	0.00	17,626.35	0.27	$0	$1,464,698	$0.00035
MEA Solvent (ton)	384.01	0.54	3,481.91	$1,337,078	$582,557	$0.00014
Activated Carbon (lb)	0.00	644.19	1.63	$0	$324,818	$0.00008
Corrosion Inhibitor	0.00	0.00	0.00	$52,609	$2,505	$0.00000
SCR Catalyst (m3)	w/equip.	0.08	8,938.80	$0	$228,781	$0.00005
Ammonia (19% NH3) (ton)	0.00	6.94	330.00	$0	$710,351	$0.00017
Subtotal Chemicals				**$1,389,687**	**$3,313,711**	**$0.00079**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$1,389,687**	**$13,334,220**	**$0.00318**
Fuel (MMBtu)	0	100,937	6.13	**$0**	**$191,965,780**	**$0.04575**

4 Case 2 – State-of-the-art Gas Turbine – ("H" frame)

Cases 2a, 2b, and 2c are based on the previous cases but use a gas turbine design primarily based on the Siemens 8000 H.

The "8000H" is Siemens's latest addition in their advanced frame design that has an ISO output of 275 MW and LHV heat rate of 9,000 kJ/kWh (8,531 Btu/kWh) on natural gas fuel. The output is approximately 30 percent more and the heat rate is approximately 3.8 percent better than the 7FA.05 model considered in Case 1a. This gas turbine model also has approximately 17 percent more exhaust flow and approximately 14°C (25°F) higher exhaust temperature than the 7FA.05 model. This model uses air cooling of hot gas path components similar to the "F" frame design. The design also includes fast start capability.

The performance summaries, block flow diagrams, stream tables, carbon balances, water balances, and overall energy balances for each of these three cases are presented in this section. Detailed process flow diagrams from the Thermoflow software are provided in the appendix.

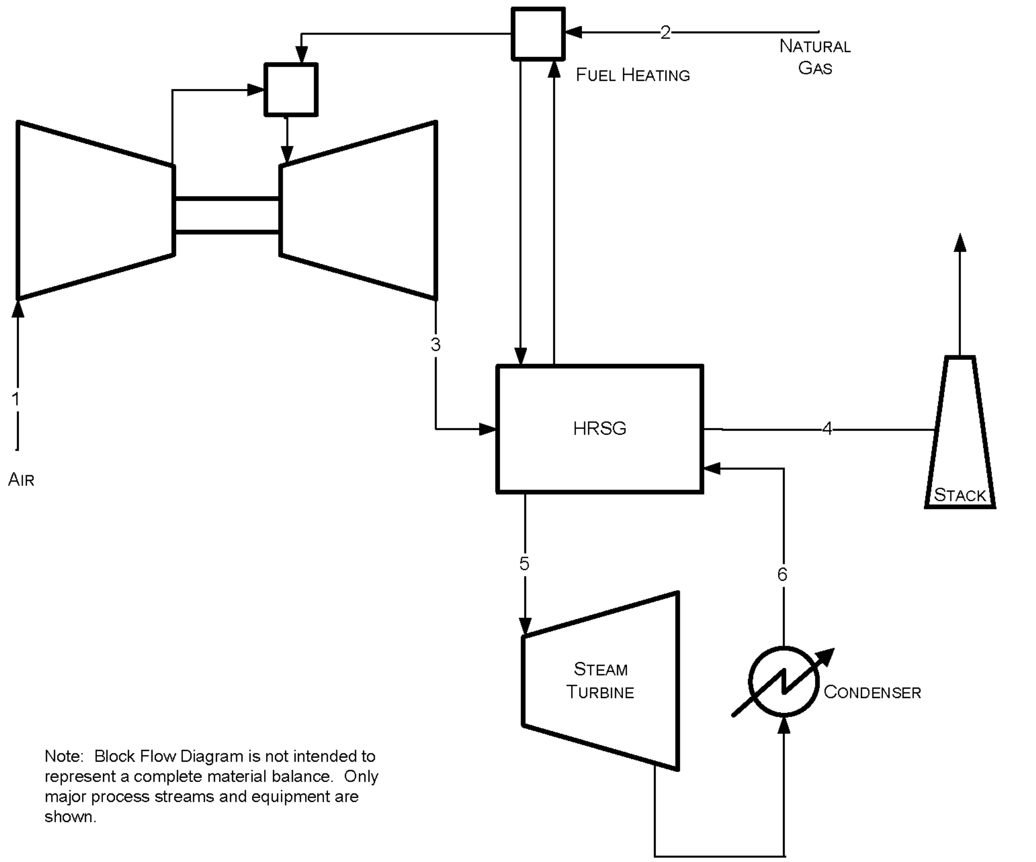
The turbine cost for each of the cases was estimated by WorleyParsons based on simulation results and vendor quotes/discussions. The remaining capital and operating cost estimation results were based on scaling from the previous Case 1 results and are included at the end of each case section. All costs are in June 2011 dollars.

4.1 Case 2a – NGCC without CO_2 Capture Modeling Results

The block flow diagram of the combined cycle is shown in Exhibit 4-1. This includes two H-frame gas turbines, two triple pressure level single reheat type HRSGs, and one condensing steam turbine with evaporative cooling tower. Exhibit 4-2 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems. A fuel gas heating system is integrated in this design for the gas turbine and overall plant heat rate improvement.

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,487°C (2,709°F). The flue gas exits the turbine at 619°C (1,146°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine. Flue gas exits the HRSG (stream 4) at 88°C (190°F) and passes to the plant stack. Cooling is supplied to the condenser via water from the cooling tower.

Exhibit 4-1 Case 2a – "H" frame turbine without CO_2 capture block flow diagram



Source: NETL

Exhibit 4-2 Case 2a – "H" frame turbine without CO_2 capture stream table

	1	2	3	4	5	6
V-L Mole Fraction						
Ar	0.0092	0.0000	0.0089	0.0089	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0404	0.0416	0.0000	0.0000
H_2O	0.0099	0.0000	0.0867	0.0893	1.0000	1.0000
N_2	0.7732	0.0160	0.7432	0.7420	0.0000	0.0000
O_2	0.2074	0.0000	0.1209	0.1182	0.0000	0.0000
SO_2	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
V-L Flowrate (kg_{mol}/hr)	146,844	6,069	153,011	153,065	28,634	37,961
V-L Flowrate (kg/hr)	4,237,460	105,161	4,342,621	4,342,457	515,843	683,872
Solids Flowrate (kg/hr)	0	0	0	0	0	0
Temperature (°C)	15	38	619	88	579	32
Pressure (MPa, abs)	0.10	2.84	0.10	0.10	16.65	0.00
Enthalpy (kJ/kg)^A	30.98	52,530.38	830.38	234.46	3,513.89	2,385.55
Density (kg/m^3)	1.2	22.2	0.4	0.9	47.7	992.9
V-L Molecular Weight	28.857	17.328	28.381	28.370	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	323,735	13,380	337,332	337,451	63,126	83,689
V-L Flowrate (lb/hr)	9,342,000	231,840	9,573,840	9,573,480	1,137,240	1,507,680
Solids Flowrate (lb/hr)	0	0	0	0	0	0
Temperature (°F)	59	100	1,146	190	1,075	90
Pressure (psia)	14.6	411.5	15.2	14.7	2,414.7	0.7
Enthalpy (Btu/lb)^A	13.3	22,584.0	357.0	100.8	1,510.7	1,025.6
Density (lb/ft^3)	0.076	1.384	0.025	0.057	2.977	61.982

A - Reference conditions are 32.02 F & Liquid Water

Note: Total flow rates shown equal the sum for all process trains

4.1.1 Performance Results

The performance results are summarized in Exhibit 4-3 and are in general agreement with Siemens published values. [11] The overall efficiency of 59.5 percent represents an increase in the overall process efficiency of 2.1 percentage points and approximately 30 percent power increase when compared with Case 1a based on the 7FA.05 gas turbine. Additional tables below provide overall energy balance (Exhibit 4-4), water balance (Exhibit 4-5), carbon balance (Exhibit 4-6), and an emissions summary (Exhibit 4-7).

Exhibit 4-3 Case 2a – "H" frame turbine without CO_2 capture plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	551,220	kW_e
Steam Turbine Power	289,730	kW_e
Total	**840,950**	kW_e
Auxiliary Load		
Condensate Pumps	0	kW_e
Boiler Feedwater Pumps	6,085	kW_e
Amine CO_2 Capture System Auxiliaries	0	kW_e
CO_2 Compression	0	kW_e
Circulating Water Pump	2,791	kW_e
Ground Water Pumps	290	kW_e
Cooling Tower Fans	2,085	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	1,097	kW_e
Steam Turbine Auxiliaries	615	kW_e
Miscellaneous Balance of Plant[2]	3,279	kW_e
Transformer Losses	4,205	kW_e
Total	**20,457**	**kW_e**
Plant Performance		
Net Plant Power	**820,493**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	53.7%	
Net Plant Efficiency (LHV)[1]	59.5%	
Net Plant Heat Rate (HHV)[1]	6,705 (6,355)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	6,052 (5,736)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	105,161 (231,840)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,528,164	kW_t
Thermal Input (LHV)[1]	1,379,364	kW_t
Condenser Duty	1,540 (1,460)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	12.0 (3,170)	m^3/min (gpm)
Raw Water Consumption	10.0 (2,629)	m^3/min (gpm)

[1] *HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)*
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] *Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads*

Exhibit 4-4 Case 2a – "H" frame turbine without CO_2 capture overall energy balance

	HHV	Sensible + Latent	Power	Total
		Energy In, GJ/hr (MMBtu/hr)		
Natural Gas	5,501 (5,214)	3.7 (3.5)	0 (0)	5,506 (5,218)
GT Air	0 (0)	131.3 (124.4)	0 (0)	131 (124)
Raw Water Withdrawal	0 (0)	45.1 (42.8)	0 (0)	45 (43)
Auxiliary Power	0 (0)	0.0 (0.0)	74 (70)	74 (70)
TOTAL	**5,501 (5,214)**	**180.4 (171.0)**	**74 (70)**	**5,755 (5,455)**
		Energy Out, GJ/hr (MMBtu/hr)		
Cooling Tower Blowdown	0 (0)	20.0 (19.0)	0 (0)	20 (19)
Stack Gas	0 (0)	1,018 (965)	0 (0)	1,018 (965)
Condenser	0 (0)	1,540 (1,460)	0 (0)	1,540 (1,460)
Process Losses*	*0 (0)*	*149 (141)*	*0 (0)*	*149 (141)*
Power	0 (0)	0.0 (0.0)	3,027 (2,869)	3,027 (2,869)
TOTAL	**0 (0)**	**2,728 (2,586)**	**3,027 (2,89)**	**5,755 (5,455)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 4-5 Case 2a – "H" frame turbine without CO_2 capture water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Condenser Makeup	**0.06 (16)**	**0.0 (0)**	**0.06 (16)**	**0.0 (0)**	**0.06 (16)**
BFW Makeup	0.06 (16)	0.0 (0)	0.06 (16)	0.0 (0)	0.0 (0)
Cooling Tower	**12.00 (3,170)**	**0.06 (16)**	**11.94 (3,154)**	**2.0 (541)**	**9.9 (2,613)**
BFW Blowdown	0.00 (0)	0.06 (16)	-0.06 (-16)	0.00 (0)	0.00 (0)
Flue Gas Condensate	0.00 (0)	0.0 (0)	0.00 (0)	0.00 (0)	0.00 (0)
Total	**12.1 (3,185)**	**0.06 (16)**	**12.0 (3,170)**	**2.0 (541)**	**10.0 (2,629)**

Exhibit 4-6 Case 2a – "H" frame turbine without CO_2 capture carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	75,956 (167,455)	Stack Gas	76,462 (168,569)
Air (CO_2)	576 (1,270)		
		Convergence Tolerance*	71 (156)
Total	**76,533 (168,726)**	**Total**	**76,533 (168,726)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 4-7 Case 2a – "H" frame turbine without CO_2 capture air emissions

	Kg/GJ (lb/10^6 Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.004 (0.009)	160 (176)	0.026 (0.058)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	50.9 (118.5)	2,086,112 (2,299,545)	333 (734)
CO_2[1]			341 (753)

[1] CO_2 emissions based on net power instead of gross power

4.1.2 Cost Estimate Results

The turbine costs for this case were estimated based on simulation results and vendor quotes/discussions on the Siemens "H" machine design. All other costs for this case were scaled from the costs in the previous cases based on simulation results using the methodology described in the initial NETL study of NGCC systems. [2] All costs are in June 2011 dollars. The cost estimation results for this case are summarized in Exhibit 4-8. The summary and detailed capital cost estimates are shown in Exhibit 4-9 and Exhibit 4-10, respectively. The annual operating cost estimates are shown in Exhibit 4-11.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 4-8 Case 2a - "H" frame turbine without CO_2 capture cost estimation summary

Case	2a
Total Plant Cost (2011$/kW)	**617**
Total Overnight Cost (2011$/kW)	**756**
Total As-spent Capital (2011$/kW)	**812**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	10.65
Fixed O&M	2.98
Variable O&M	1.59
Fuel	38.96
CO_2 T&S total	0.00
COE[1] Total	**54.19**
LCOE[1], total (including T&S)	68.69

[1] Capacity factor assumed to be 85 percent

Exhibit 4-9 Case 2a - "H" frame turbine without CO_2 capture capital cost estimate summary

	Client:	USDOE/NETL							**Report Date:**	2011-Dec-15			
	Project:	Costing Support for NGCC with CCS Analyses											
		TOTAL PLANT COST SUMMARY											
	Case:	Case 2a - H-frame											
	Plant Size:	820.5 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)		
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Sales Tax**	**Bare Erected Cost**	**Eng'g CM H.O.& Fee**	**Contingencies Process**	**Contingencies Project**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**	
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0	
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0	
3	FEEDWATER & MISC. BOP SYSTEMS	$29,379	$6,596	$9,615	$0	$0	**$45,590**	$3,740	$0	$7,916	**$57,246**	**$70**	
4	GASIFIER & ACCESSORIES												
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0	
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0	
5B	CO2 REMOVAL & COMPRESSION	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	**$0**	
6	COMBUSTION TURBINE/ACCESSORIES												
6.1	Combustion Turbine Generator	$132,918	$0	$7,053	$0	$0	**$139,971**	$11,561	$0	$15,153	**$166,685**	$203	
6.2-6.9	Combustion Turbine Other	$0	$1,007	$1,089	$0	$0	**$2,097**	$175	$0	$454	**$2,726**	$3	
	SUBTOTAL 6	**$132,918**	**$1,007**	**$8,142**	**$0**	**$0**	**$142,068**	**$11,736**	**$0**	**$15,608**	**$169,411**	**$206**	
7	HRSG, DUCTING & STACK												
7.1	Heat Recovery Steam Generator	$41,422	$0	$7,286	$0	$0	**$48,708**	$4,045	$0	$5,275	**$58,028**	$71	
7.2-7.9	SCR System, Ductwork and Stack	$2,567	$1,683	$2,071	$0	$0	**$6,320**	$529	$0	$1,091	**$7,940**	$10	
	SUBTOTAL 7	**$43,989**	**$1,683**	**$9,357**	**$0**	**$0**	**$55,029**	**$4,574**	**$0**	**$6,366**	**$65,968**	**$80**	
8	STEAM TURBINE GENERATOR												
8.1	Steam TG & Accessories	$43,452	$0	$6,148	$0	$0	**$49,600**	$3,908	$0	$5,351	**$58,858**	$72	
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$15,231	$1,188	$8,939	$0	$0	**$25,358**	$1,871	$0	$3,946	**$31,174**	$38	
	SUBTOTAL 8	**$58,683**	**$1,188**	**$15,087**	**$0**	**$0**	**$74,958**	**$5,778**	**$0**	**$9,297**	**$90,033**	**$110**	
9	COOLING WATER SYSTEM	$5,718	$6,310	$5,832	$0	$0	**$17,859**	$1,436	$0	$2,826	**$22,121**	$27	
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0	
11	ACCESSORY ELECTRIC PLANT	$23,528	$6,637	$14,519	$0	$0	**$44,683**	$3,370	$0	$5,177	**$53,231**	$65	
12	INSTRUMENTATION & CONTROL	$8,134	$920	$6,897	$0	$0	**$15,951**	$1,309	$0	$1,981	**$19,242**	$23	
13	IMPROVEMENTS TO SITE	$2,361	$1,283	$6,685	$0	$0	**$10,329**	$915	$0	$2,249	**$13,493**	$16	
14	BUILDINGS & STRUCTURES	$0	$5,999	$6,406	$0	$0	**$12,405**	$987	$0	$2,009	**$15,402**	$19	
	TOTAL COST	**$304,709**	**$31,622**	**$82,540**	**$0**	**$0**	**$418,872**	**$33,845**	**$0**	**$53,429**	**$506,146**	**$617**	

Exhibit 4-10 Case 2a - "H" frame turbine without CO_2 capture capital cost estimate detail

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2a - H-frame
Plant Size: 820.5 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,529	$3,655	$2,984	$0	$0	$10,168	$819	$0	$1,648	$12,635	$15
3.2	Water Makeup & Pretreating	$2,201	$227	$1,130	$0	$0	$3,557	$294	$0	$770	$4,621	$6
3.3	Other Feedwater Subsystems	$1,653	$546	$456	$0	$0	$2,656	$205	$0	$429	$3,291	$4
3.4	Service Water Systems	$266	$530	$1,707	$0	$0	$2,503	$213	$0	$543	$3,259	$4
3.5	Other Boiler Plant Systems	$1,790	$669	$1,539	$0	$0	$3,998	$326	$0	$649	$4,972	$6
3.6	Natural Gas, incl. pipeline	$17,779	$783	$678	$0	$0	$19,240	$1,587	$0	$3,124	$23,950	$29
3.7	Waste Treatment Equipment	$769	$0	$445	$0	$0	$1,214	$105	$0	$264	$1,582	$2
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,392	$186	$676	$0	$0	$2,254	$193	$0	$489	$2,935	$4
	SUBTOTAL 3.	**$29,379**	**$6,596**	**$9,615**	**$0**	**$0**	**$45,590**	**$3,740**	**$0**	**$7,916**	**$57,246**	**$70**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	**$132,918**	**$0**	**$7,053**	$0	$0	$139,971	$11,561	$0	$15,153	$166,685	$203
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$1,007	$1,089	$0	$0	$2,097	$175	$0	$454	$2,726	$3
	SUBTOTAL 6.	**$132,918**	**$1,007**	**$8,142**	**$0**	**$0**	**$142,068**	**$11,736**	**$0**	**$15,608**	**$169,411**	**$206**

Exhibit 4-10 Case 2a - "H" frame turbine without CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2a - H-frame
Plant Size: 820.5 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$41,422	$0	$7,286	$0	$0	$48,708	$4,045	$0	$5,275	$58,028	$71
7.2	HRSG Accessories	$2,567	$1,078	$1,504	$0	$0	$5,148	$431	$0	$837	$6,416	$8
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$605	$567	$0	$0	$1,172	$98	$0	$254	$1,524	$2
	SUBTOTAL 7.	**$43,989**	**$1,683**	**$9,357**	**$0**	**$0**	**$55,029**	**$4,574**	**$0**	**$6,366**	**$65,968**	**$80**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$43,452	$0	$6,148	$0	$0	$49,600	$3,908	$0	$5,351	$58,858	$72
8.2	Turbine Plant Auxiliaries	$252	$0	$574	$0	$0	$826	$71	$0	$90	$986	$1
8.3	Condenser & Auxiliaries	$3,233	$0	$1,644	$0	$0	$4,877	$409	$0	$529	$5,815	$7
8.4	Steam Piping	$11,746	$0	$4,761	$0	$0	$16,507	$1,125	$0	$2,645	$20,276	$25
8.9	TG Foundations	$0	$1,188	$1,961	$0	$0	$3,149	$266	$0	$683	$4,097	$5
	SUBTOTAL 8.	**$58,683**	**$1,188**	**$15,087**	**$0**	**$0**	**$74,958**	**$5,778**	**$0**	**$9,297**	**$90,033**	**$110**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,351	$0	$1,022	$0	$0	$4,373	$365	$0	$474	$5,212	$6
9.2	Circulating Water Pumps	$1,627	$0	$101	$0	$0	$1,728	$132	$0	$186	$2,045	$2
9.3	Circ.Water System Auxiliaries	$134	$0	$18	$0	$0	$151	$13	$0	$16	$180	$0
9.4	Circ.Water Piping	$0	$4,149	$939	$0	$0	$5,088	$381	$0	$820	$6,290	$8
9.5	Make-up Water System	$340	$0	$436	$0	$0	$776	$64	$0	$126	$966	$1
9.6	Component Cooling Water Sys	$267	$288	$205	$0	$0	$760	$61	$0	$123	$943	$1
9.9	Circ.Water System Foundations	$0	$1,873	$3,111	$0	$0	$4,984	$421	$0	$1,081	$6,485	$8
	SUBTOTAL 9.	**$5,718**	**$6,310**	**$5,832**	**$0**	**$0**	**$17,859**	**$1,436**	**$0**	**$2,826**	**$22,121**	**$27**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$6,246	$0	$3,694	$0	$0	$9,940	$816	$0	$807	$11,563	$14
11.2	Station Service Equipment	$2,033	$0	$175	$0	$0	$2,208	$182	$0	$179	$2,569	$3
11.3	Switchgear & Motor Control	$2,502	$0	$435	$0	$0	$2,936	$243	$0	$318	$3,498	$4
11.4	Conduit & Cable Tray	$0	$1,307	$3,767	$0	$0	$5,074	$423	$0	$824	$6,321	$8
11.5	Wire & Cable	$0	$4,201	$2,389	$0	$0	$6,590	$396	$0	$1,048	$8,035	$10
11.6	Protective Equipment	$0	$930	$3,226	$0	$0	$4,155	$357	$0	$451	$4,964	$6
11.7	Standby Equipment	$146	$0	$136	$0	$0	$282	$24	$0	$31	$337	$0
11.8	Main Power Transformers	$12,601	$0	$192	$0	$0	$12,794	$869	$0	$1,366	$15,029	$18
11.9	Electrical Foundations	$0	$198	$505	$0	$0	$703	$60	$0	$153	$916	$1
	SUBTOTAL 11.	**$23,528**	**$6,637**	**$14,519**	**$0**	**$0**	**$44,683**	**$3,370**	**$0**	**$5,177**	**$53,231**	**$65**

Exhibit 4-10 Case 2a - “H” frame turbine without CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2a - H-frame
Plant Size: 820.5 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,034	$0	$659	$0	$0	$1,693	$142	$0	$275	$2,110	$3
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$309	$0	$189	$0	$0	$498	$42	$0	$81	$621	$1
12.7	Computer & Accessories	$4,947	$0	$151	$0	$0	$5,098	$419	$0	$552	$6,068	$7
12.8	Instrument Wiring & Tubing	$0	$920	$1,628	$0	$0	$2,549	$183	$0	$410	$3,142	$4
12.9	Other I & C Equipment	$1,844	$0	$4,270	$0	$0	$6,114	$523	$0	$664	$7,301	$9
	SUBTOTAL 12.	**$8,134**	**$920**	**$6,897**	**$0**	**$0**	**$15,951**	**$1,309**	**$0**	**$1,981**	**$19,242**	**$23**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$126	$2,680	$0	$0	$2,806	$245	$0	$610	$3,661	$4
13.2	Site Improvements	$0	$1,156	$1,528	$0	$0	$2,684	$239	$0	$585	$3,508	$4
13.3	Site Facilities	$2,361	$0	$2,477	$0	$0	$4,838	$431	$0	$1,054	$6,324	$8
	SUBTOTAL 13.	**$2,361**	**$1,283**	**$6,685**	**$0**	**$0**	**$10,329**	**$915**	**$0**	**$2,249**	**$13,493**	**$16**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$351	$185	$0	$0	$536	$41	$0	$87	$664	$1
14.2	Steam Turbine Building	$0	$2,929	$3,898	$0	$0	$6,827	$549	$0	$1,106	$8,483	$10
14.3	Administration Building	$0	$625	$423	$0	$0	$1,048	$82	$0	$169	$1,299	$2
14.4	Circulation Water Pumphouse	$0	$220	$109	$0	$0	$328	$25	$0	$53	$407	$0
14.5	Water Treatment Buildings	$0	$467	$426	$0	$0	$892	$70	$0	$144	$1,107	$1
14.6	Machine Shop	$0	$542	$346	$0	$0	$889	$69	$0	$144	$1,101	$1
14.7	Warehouse	$0	$350	$211	$0	$0	$561	$43	$0	$91	$695	$1
14.8	Other Buildings & Structures	$0	$105	$76	$0	$0	$181	$14	$0	$29	$225	$0
14.9	Waste Treating Building & Str.	$0	$410	$732	$0	$0	$1,142	$93	$0	$185	$1,421	$2
	SUBTOTAL 14.	**$0**	**$5,999**	**$6,406**	**$0**	**$0**	**$12,405**	**$987**	**$0**	**$2,009**	**$15,402**	**$19**
	TOTAL COST	**$304,709**	**$31,622**	**$82,540**	**$0**	**$0**	**$418,872**	**$33,845**	**$0**	**$53,429**	**$506,146**	**$617**

Exhibit 4-10 Case 2a - "H" frame turbine without CO_2 capture capital cost estimate detail (continued)

Client:	USDOE/NETL
Project:	Costing Support for NGCC with CCS Analyses
Report Date:	2011-Dec-15
Case:	Case 2a - H-frame
Plant Size:	820.5 MW,net
Estimate Type:	Conceptual
Cost Base (Jun)	2011 ($x1000)

TOTAL PLANT COST SUMMARY

Acct 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 $	TOTAL PLANT COST $/kW
	TOTAL COST	**$304,709**	**$31,622**	**$82,540**	**$0**	**$418,872**	**$33,845**	**$0**	**$53,429**	**$506,146**	**$617**
	Owner's Costs										
	Preproduction Costs										
	6 Months All Labor									$4,045	$5
	1 Month Maintenance Materials									$619	$1
	1 Month Non-fuel Consumables									$335	$0
	1 Month Waste Disposal									$0	$0
	25% of 1 Months Fuel Cost at 100% CF									$5,833	$7
	2% of TPC									$10,123	$12
	Total									**$20,956**	**$26**
	Inventory Capital										
	60 day supply of consumables at 100% CF									$438	$1
	0.5% of TPC (spare parts)									$2,531	$3
	Total									**$2,969**	**$4**
	Initial Cost for Catalyst and Chemicals									$0	$0
	Land									$300	$0
	Other Owner's Costs									$75,922	$93
	Financing Costs									$13,666	$17
	Total Overnight Costs (TOC)									**$619,958**	**$756**
	TASC Multiplier								(IOU, low-risk, 33 year)	1.075	
	Total As-Spent Cost (TASC)									**$666,455**	**$812**

Exhibit 4-11 Case 2a - "H" frame turbine without CO_2 capture operating cost estimate

INITIAL & ANNUAL O&M EXPENSES						Cost Base (Jun)	2011
Case 2a - H-frame						Heat Rate-net (Btu/kWh):	6,355
						MWe-net:	820
						Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR							
Operating Labor							
Operating Labor Rate(base):	39.70	$/hour					
Operating Labor Burden:	30.00	% of base					
Labor O-H Charge Rate:	25.00	% of labor					
			Total				
Skilled Operator	1.0		1.0				
Operator	2.0		2.0				
Foreman	1.0		1.0				
Lab Tech's, etc.	1.0		1.0				
TOTAL-O.J.'s	5.0		5.0				
						Annual Cost	Annual Unit Cost
						$	$/kW-net
Annual Operating Labor Cost						$2,260,518	$2.755
Maintenance Labor Cost						$4,211,649	$5.133
Administrative & Support Labor						$1,618,042	$1.972
Property Taxes and Insurance						$10,122,912	$12.338
TOTAL FIXED OPERATING COSTS						**$18,213,121**	**$22.198**
VARIABLE OPERATING COSTS							
							$/kWh-net
Maintenance Material Cost						**$6,317,474**	**$0.00103**
Consumables	Consumption		Unit	Initial Fill			
	Initial Fill	/Day	Cost	Cost			
Water (/1000 gallons)	0.00	2,282.40	1.67	**$0**	**$1,185,380**	**$0.00019**	
Chemicals							
MU & WT Chem.(lbs)	0.00	13,597.88	0.27	$0	$1,129,944	$0.00018	
MEA Solvent (ton)	0.00	0.00	3,481.91	$0	$0	$0.00000	
Activated Carbon (lb)	0.00	0.00	1.63	$0	$0	$0.00000	
Corrosion Inhibitor	0.00	0.00	0.00	$0	$0	$0.00000	
SCR Catalyst (m3)	w/equip.	0.10	8,938.80	$0	$268,713	$0.00004	
Ammonia (19% NH3) (ton)	0.00	8.15	330.00	$0	$834,338	$0.00014	
Subtotal Chemicals				**$0**	**$2,232,995**	**$0.00037**	
Other							
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000	
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000	
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000	
Subtotal Other				**$0**	**$0**	**$0.00000**	
Waste Disposal							
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000	
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000	
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**	
By-products							
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000	
Subtotal By-products				**$0**	**$0**	**$0.00000**	
TOTAL VARIABLE OPERATING COSTS				**$0**	**$9,735,849**	**$0.00159**	
Fuel (MMBtu)	0	125,142	6.13	**$0**	**$237,998,434**	**$0.03893**	

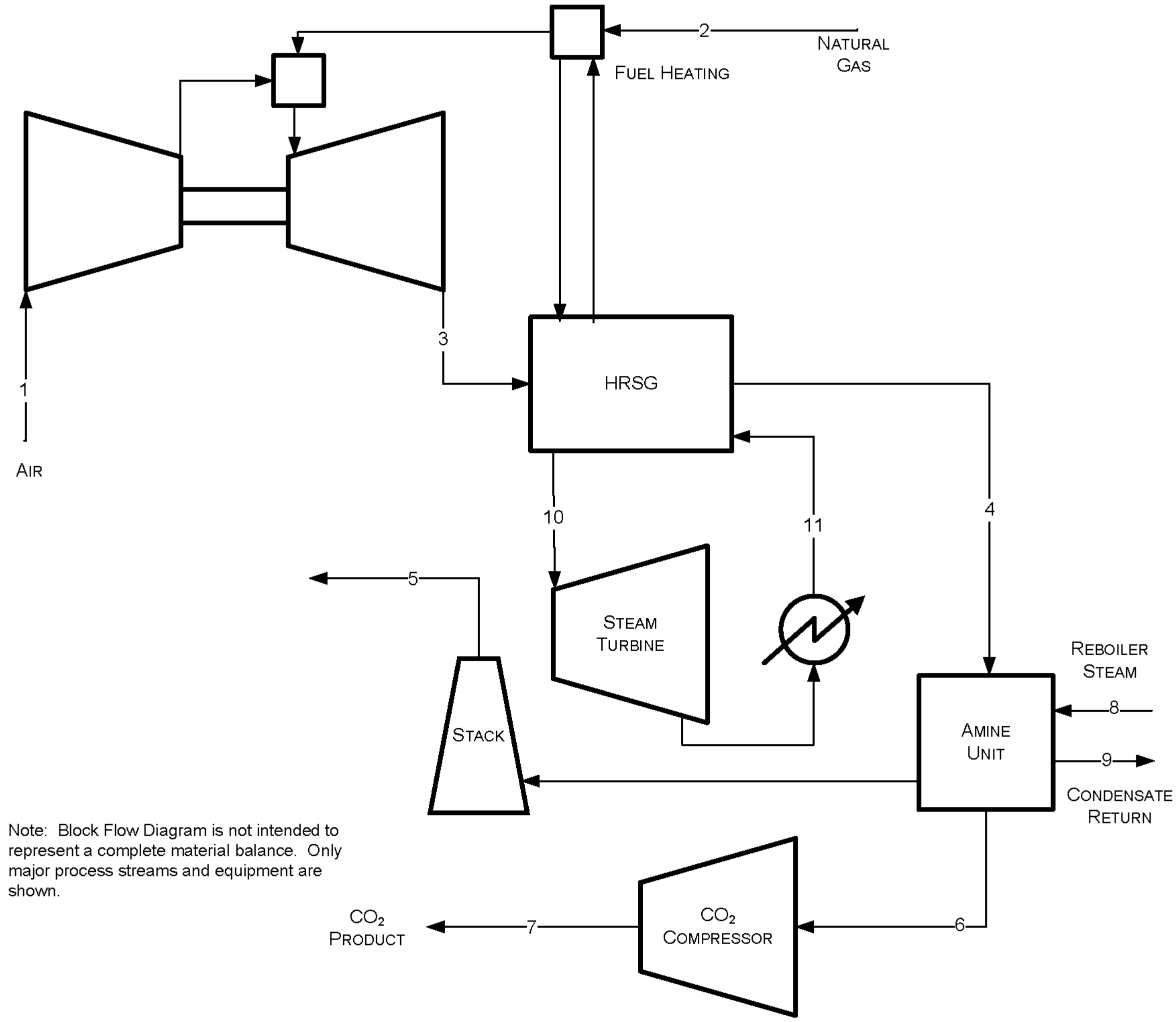
4.2 Case 2b – NGCC with CO_2 Capture Modeling Results

The block flow diagram of the combined cycle with CO_2 capture is shown in Exhibit 4-12. This case also uses the same "H" frame gas turbine model as that of Case 2a with the addition of CO_2 capture at the back end. Exhibit 4-13 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems. The heat required for the solvent (amine) system in the CO_2 capture system is supplied from the Rankine cycle (stream 4).

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,487°C (2,709°F). The flue gas exits the turbine at 619°C (1,146°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine as well as the steam required for the capture process (stream 8). Flue gas exits the HRSG (stream 4) at 109°C (229°F) and passes to the capture system where the CO_2 is captured and compressed (stream 7). Cooling is supplied to the steam turbine condenser via water from the cooling tower.

The gas turbine (Brayton cycle) performance is not impacted due to the CO_2 capture addition. However, the Rankine cycle performance and the overall plant output and efficiency are reduced due to heat integration requirements and increased auxiliary loads for the CO_2 capture process.

Exhibit 4-12 Case 2b – "H" frame turbine with CO_2 capture block flow diagram



Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Source: NETL

Exhibit 4-13 Case 2b – "H" frame turbine with CO_2 capture stream table

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0000	0.0089	0.0089	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0404	0.0416	0.0045	0.9674	1.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0099	0.0000	0.0867	0.0893	0.0555	0.0326	0.0000	1.0000	1.0000	1.0000	1.0000
N_2	0.7732	0.0160	0.7432	0.7420	0.8025	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.2074	0.0000	0.1209	0.1182	0.1279	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)	146,844	6,069	153,011	153,065	141,536	5,925	5,733	16,896	17,887	28,661	22,044
V-L Flowrate (kg/hr)	4,237,460	105,161	4,342,621	4,342,457	3,985,662	255,717	252,288	304,379	304,379	516,333	397,129
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	38	619	109	35	35	38	152	151	579	32
Pressure (MPa, abs)	0.10	2.84	0.10	0.10	0.10	0.17	15.27	0.51	0.49	16.65	0.00
Enthalpy (kJ/kg)[A]	30.98	52,530.38	830.38	257.49	106.86	91.58	-164.90	2,746.79	635.72	3,513.89	2,387.64
Density (kg/m^3)	1.2	22.2	0.4	0.8	0.9	2.9	653.5	2.7	915.8	47.7	992.9
V-L Molecular Weight	28.857	17.328	28.381	28.370	28.160	43.160	44.010	18.015	18.015	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	323,735	13,380	337,332	337,451	312,034	13,062	12,638	37,248	39,435	63,186	48,599
V-L Flowrate (lb/hr)	9,342,000	231,840	9,573,840	9,573,480	8,786,880	563,760	556,200	671,040	671,040	1,138,320	875,520
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	100	1,146	229	95	95	101	306	304	1,075	90
Pressure (psia)	14.6	411.5	15.2	14.7	14.7	25.0	2,214.7	73.5	71.0	2,414.7	0.7
Enthalpy (Btu/lb)[A]	13.3	22,584.0	357.0	110.7	45.9	39.4	-70.9	1,180.9	273.3	1,510.7	1,026.5
Density (lb/ft^3)	0.076	1.384	0.025	0.052	0.056	0.183	40.800	0.169	57.172	2.977	61.982

A - Reference conditions are 32.02 F & 0.089 PSIA

Note: Total flow rates shown equal the sum for all process trains

4.2.1 Performance Results

The performance results are summarized in Exhibit 4-14 and when compared with Case 2a show that adding carbon capture reduces the efficiency by approximately 7 percentage points (similar results as determined for Case 1). This is based on using an assumed advanced solvent (amine) process that has a lower steam requirement for the reboiler of 2,960 kJ/kg CO_2 (1,272 Btu/lb CO_2) or 17 percent lower when compared with earlier NETL/DOE system studies (i.e., 3,560 kJ/kg CO_2 (1,530 Btu/lb CO_2)).

Additional tables below provide overall energy balance (Exhibit 4-15), water balance (Exhibit 4-16), carbon balance (Exhibit 4-17), and an emissions summary (Exhibit 4-18).

Exhibit 4-14 Case 2b – "H" frame turbine with CO_2 capture plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	551,220	kW_e
Steam Turbine Power	235,081	kW_e
Total	**786,301**	kW_e
Auxiliary Load		
Condensate Pumps	3	kW_e
Boiler Feedwater Pumps	6,157	kW_e
Amine CO_2 Capture System Auxiliaries	18,745	kW_e
CO_2 Compression	23,702	kW_e
Circulating Water Pump	4,910	kW_e
Ground Water Pumps	420	kW_e
Cooling Tower Fans	3,284	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	1,097	kW_e
Steam Turbine Auxiliaries	500	kW_e
Miscellaneous Balance of Plant[2]	2,981	kW_e
Transformer Losses	3,932	kW_e
Total	**65,741**	**kW_e**
Plant Performance		
Net Plant Power	**720,560**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	47.2%	
Net Plant Efficiency (LHV)[1]	52.2%	
Net Plant Heat Rate (HHV)[1]	7,635 (7,236)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	6,891 (6,532)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	105,161 (231,840)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,528,164	kW_t
Thermal Input (LHV)[1]	1,379,364	kW_t
Condenser Duty	897 (850)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	17.4 (4,604)	m^3/min (gpm)
Raw Water Consumption	14.2 (3,759)	m^3/min (gpm)

[1] *HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)*
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] *Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads*

Exhibit 4-15 Case 2b – "H" frame turbine with CO_2 capture overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	5,501 (5,214)	3.7 (3.5)	0 (0)	5,505 (5,218)
GT Air	0 (0)	131.3 (124.4)	0 (0)	131 (124)
Raw Water Withdrawal	0 (0)	65.5 (62.1)	0 (0)	66 (62)
Auxiliary Power	0 (0)	0.0 (0.0)	237 (224)	237 (224)
TOTAL	**5,501 (5,214)**	**206.4 (195.6)**	**237 (224)**	**5,939 (5,629)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	31.9 (30.3)	0 (0)	32 (30)
Stack Gas	0 (0)	426 (404)	0 (0)	426 (404)
Condenser	0 (0)	896 (849)	0 (0)	896 (849)
CO_2 Product	0 (0)	-41.6 (-39.4)	0 (0)	-42 (-39)
CO_2 Intercoolers	0 (0)	117.2 (111.0)	0 (0)	117 (111)
Amine System Losses	0 (0)	949.9 (900.3)	0 (0)	950 (900)
Process Losses*	*0 (0)*	*729 (691)*	*0 (0)*	*97 (92)*
Power	0 (0)	0.0 (0.0)	2,831 (2,683)	2,831 (2,683)
TOTAL	**0 (0)**	**3,108 (2,946)**	**2,831 (2,683)**	**5,939 (5,629)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 4-16 Case 2b – "H" frame turbine with CO_2 capture water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Amine Capture System	0.06 (16)	0.06 (16)	0.00 (0)	0.0 (0)	0.06 (16)
Condenser Makeup	**0.06 (16)**	**0.0 (0)**	**0.06 (16)**	**0.0 (0)**	**0.06 (16)**
BFW Makeup	0.06 (16)	0.0 (0)	0.06 (16)	0.0 (0)	0.0 (0)
Cooling Tower	**19.11 (5,048)**	**1.81 (477)**	**17.3 (4,571)**	**3.2 (845)**	**14.1 (3,726)**
BFW Blowdown	0.00 (0)	0.06 (16)	-0.06 (-16)	0.00 (0)	0.00 (0)
Flue Gas/CO_2 Condensate	0.00 (0)	1.7 (461)	-1.74 (-461)	0.00 (0)	0.00 (0)
Total	**19.2 (5,081)**	**1.81 (477)**	**17.4 (4,604)**	**3.2 (845)**	**14.2 (3,759)**

Exhibit 4-17 Case 2b – "H" frame turbine with CO_2 capture carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	75,956 (167,455)	Stack Gas	7,647 (16,858)
Air (CO_2)	576 (1,270)	CO_2 Product	68,854 (151,796)
		Convergence Tolerance*	33 (72)
Total	**76,533 (168,726)**	**Total**	**76,533 (168,726)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 4-18 Case 2b – "H" frame turbine with CO_2 capture air emissions

	Kg/GJ ($lb/10^6$ Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.003 (0.008)	133 (146)	0.023 (0.050)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	5.1 (11.8)	208,622 (229,966)	36 (79)
CO_2[1]			39 (86)

[1] CO_2 emissions based on net power instead of gross power

4.2.2 Cost Estimate Results

The turbine costs for this case were estimated based on simulation results and vendor quotes/discussions on the Siemens "H" machine design. All other costs for this case were scaled from the costs in the previous cases based on simulation results using the methodology described in the initial NETL study of NGCC systems. [2] All costs are in June 2011 dollars. The cost estimation results for this case are summarized in Exhibit 4-19. The summary and detailed capital cost estimates are shown in Exhibit 4-20 and Exhibit 4-21, respectively. The annual operating cost estimates are shown in Exhibit 4-22.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 4-19 Case 2b - "H" frame turbine with CO_2 capture cost estimation summary

Case	2b
Total Plant Cost (2011$/kW)	**1,229**
Total Overnight Cost (2011$/kW)	**1,499**
Total As-spent Capital (2011$/kW)	**1,616**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	22.35
Fixed O&M	5.47
Variable O&M	2.85
Fuel	44.36
CO_2 T&S total	3.50
COE[1] Total	**78.53**
LCOE[1], total (including T&S)	99.55
Cost[1,2] of CO_2 avoided, $/tonne of CO_2 ($/ton of CO_2)	80.45 (72.99)
Cost[1,2] of CO_2 captured, $/tonne of CO_2 ($/ton of CO_2)	59.53 (54.00)

[1] Capacity factor assumed to be 85 percent
[2] Reference base case is 2a – "H" frame without capture

Exhibit 4-20 Case 2b - "H" frame turbine with CO_2 capture capital cost estimate summary

Client: USDOE/NETL — Report Date: 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2b - H-frame CCS
Plant Size: 720.6 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$30,981	$7,042	$11,105	$0	$0	**$49,129**	$4,034	$0	$8,615	**$61,777**	**$86**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
5B	CO2 REMOVAL & COMPRESSION	$181,838	$0	$57,324	$0	$0	**$239,162**	$19,964	$41,090	$60,043	**$360,259**	**$500**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$132,918	$0	$7,053	$0	$0	**$139,971**	$11,561	$0	$15,153	**$166,685**	$231
6.2-6.9	Combustion Turbine Other	$0	$1,007	$1,089	$0	$0	**$2,097**	$175	$0	$454	**$2,726**	$4
	SUBTOTAL 6	**$132,918**	**$1,007**	**$8,142**	**$0**	**$0**	**$142,068**	**$11,736**	**$0**	**$15,608**	**$169,411**	**$235**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$40,289	$0	$7,088	$0	$0	**$47,377**	$3,934	$0	$5,131	**$56,443**	$78
7.2-7.9	SCR System, Ductwork and Stack	$2,581	$1,658	$2,050	$0	$0	**$6,288**	$526	$0	$1,082	**$7,897**	$11
	SUBTOTAL 7	**$42,870**	**$1,658**	**$9,138**	**$0**	**$0**	**$53,666**	**$4,460**	**$0**	**$6,214**	**$64,339**	**$89**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$36,755	$0	$5,981	$0	$0	**$42,737**	$3,374	$0	$4,611	**$50,721**	$70
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$14,164	$1,020	$8,263	$0	$0	**$23,446**	$1,710	$0	$3,694	**$28,849**	$40
	SUBTOTAL 8	**$50,919**	**$1,020**	**$14,244**	**$0**	**$0**	**$66,183**	**$5,083**	**$0**	**$8,305**	**$79,571**	**$110**
9	COOLING WATER SYSTEM	$7,838	$8,324	$7,739	$0	$0	**$23,901**	$1,922	$0	$3,763	**$29,586**	$41
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$29,502	$9,551	$19,337	$0	$0	**$58,390**	$4,403	$0	$6,855	**$69,648**	$97
12	INSTRUMENTATION & CONTROL	$8,951	$1,013	$7,589	$0	$0	**$17,553**	$1,440	$878	$2,281	**$22,152**	$31
13	IMPROVEMENTS TO SITE	$2,407	$1,308	$6,815	$0	$0	**$10,530**	$933	$0	$2,293	**$13,756**	$19
14	BUILDINGS & STRUCTURES	$0	$5,836	$6,116	$0	$0	**$11,952**	$950	$0	$1,935	**$14,837**	$21
	TOTAL COST	**$488,224**	**$36,759**	**$147,550**	**$0**	**$0**	**$672,533**	**$54,926**	**$41,967**	**$115,911**	**$885,337**	**$1,229**

Exhibit 4-21 Case 2b - "H" frame turbine with CO_2 capture capital cost estimate detail

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2b - H-frame CCS
Plant Size: 720.6 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,561	$3,687	$3,011	$0	$0	$10,258	$826	$0	$1,663	$12,747	$18
3.2	Water Makeup & Pretreating	$2,868	$296	$1,472	$0	$0	$4,637	$383	$0	$1,004	$6,023	$8
3.3	Other Feedwater Subsystems	$1,668	$551	$461	$0	$0	$2,680	$207	$0	$433	$3,320	$5
3.4	Service Water Systems	$346	$691	$2,225	$0	$0	$3,262	$277	$0	$708	$4,248	$6
3.5	Other Boiler Plant Systems	$2,334	$872	$2,006	$0	$0	$5,211	$424	$0	$845	$6,481	$9
3.6	Natural Gas, incl. pipeline	$17,763	$753	$652	$0	$0	$19,168	$1,581	$0	$3,112	$23,861	$33
3.7	Waste Treatment Equipment	$1,002	$0	$580	$0	$0	$1,582	$136	$0	$344	$2,062	$3
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,439	$192	$699	$0	$0	$2,330	$199	$0	$506	$3,035	$4
	SUBTOTAL 3.	**$30,981**	**$7,042**	**$11,105**	**$0**	**$0**	**$49,129**	**$4,034**	**$0**	**$8,615**	**$61,777**	**$86**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$157,874	$0	$47,574	$0	$0	$205,448	$17,142	$41,090	$52,736	$316,415	$439
5B.2	CO2 Compression & Drying	$23,964	$0	$9,750	$0	$0	$33,714	$2,823	$0	$7,307	$43,844	$61
	SUBTOTAL 5.	**$181,838**	**$0**	**$57,324**	**$0**	**$0**	**$239,162**	**$19,964**	**$41,090**	**$60,043**	**$360,259**	**$500**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	**$132,918**	**$0**	**$7,053**	$0	$0	$139,971	$11,561	$0	$15,153	$166,685	$231
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$1,007	$1,089	$0	$0	$2,097	$175	$0	$454	$2,726	$4
	SUBTOTAL 6.	**$132,918**	**$1,007**	**$8,142**	**$0**	**$0**	**$142,068**	**$11,736**	**$0**	**$15,608**	**$169,411**	**$235**

Exhibit 4-21 Case 2b - "H" frame turbine with CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2b - H-frame CCS
Plant Size: 720.6 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$40,289	$0	$7,088	$0	$0	$47,377	$3,934	$0	$5,131	$56,443	$78
7.2	HRSG Accessories	$2,581	$1,084	$1,512	$0	$0	$5,176	$433	$0	$841	$6,451	$9
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$574	$538	$0	$0	$1,112	$93	$0	$241	$1,446	$2
	SUBTOTAL 7.	**$42,870**	**$1,658**	**$9,138**	**$0**	**$0**	**$53,666**	**$4,460**	**$0**	**$6,214**	**$64,339**	**$89**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$36,755	$0	$5,981	$0	$0	$42,737	$3,374	$0	$4,611	$50,721	$70
8.2	Turbine Plant Auxiliaries	$238	$0	$529	$0	$0	$767	$66	$0	$83	$916	$1
8.3	Condenser & Auxiliaries	$2,131	$0	$1,270	$0	$0	$3,401	$286	$0	$369	$4,056	$6
8.4	Steam Piping	$11,795	$0	$4,780	$0	$0	$16,575	$1,130	$0	$2,656	$20,360	$28
8.9	TG Foundations	$0	$1,020	$1,683	$0	$0	$2,703	$228	$0	$586	$3,517	$5
	SUBTOTAL 8.	**$50,919**	**$1,020**	**$14,244**	**$0**	**$0**	**$66,183**	**$5,083**	**$0**	**$8,305**	**$79,571**	**$110**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$4,641	$0	$1,410	$0	$0	$6,051	$505	$0	$656	$7,212	$10
9.2	Circulating Water Pumps	$2,248	$0	$144	$0	$0	$2,392	$182	$0	$257	$2,832	$4
9.3	Circ.Water System Auxiliaries	$176	$0	$23	$0	$0	$200	$17	$0	$22	$238	$0
9.4	Circ.Water Piping	$0	$5,473	$1,239	$0	$0	$6,713	$503	$0	$1,082	$8,298	$12
9.5	Make-up Water System	$420	$0	$540	$0	$0	$961	$79	$0	$156	$1,196	$2
9.6	Component Cooling Water Sys	$352	$375	$270	$0	$0	$997	$80	$0	$161	$1,238	$2
9.9	Circ.Water System Foundations	$0	$2,476	$4,112	$0	$0	$6,588	$556	$0	$1,429	$8,573	$12
	SUBTOTAL 9.	**$7,838**	**$8,324**	**$7,739**	**$0**	**$0**	**$23,901**	**$1,922**	**$0**	**$3,763**	**$29,586**	**$41**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$8,407	$0	$4,973	$0	$0	$13,380	$1,099	$0	$1,086	$15,565	$22
11.2	Station Service Equipment	$3,114	$0	$268	$0	$0	$3,382	$279	$0	$275	$3,935	$5
11.3	Switchgear & Motor Control	$3,832	$0	$666	$0	$0	$4,498	$373	$0	$487	$5,358	$7
11.4	Conduit & Cable Tray	$0	$2,003	$5,770	$0	$0	$7,772	$647	$0	$1,263	$9,683	$13
11.5	Wire & Cable	$0	$6,436	$3,659	$0	$0	$10,095	$607	$0	$1,605	$12,307	$17
11.6	Protective Equipment	$0	$924	$3,205	$0	$0	$4,128	$355	$0	$448	$4,932	$7
11.7	Standby Equipment	$142	$0	$132	$0	$0	$273	$23	$0	$30	$326	$0
11.8	Main Power Transformers	$14,007	$0	$183	$0	$0	$14,190	$963	$0	$1,515	$16,669	$23
11.9	Electrical Foundations	$0	$189	$482	$0	$0	$671	$57	$0	$146	$874	$1
	SUBTOTAL 11.	**$29,502**	**$9,551**	**$19,337**	**$0**	**$0**	**$58,390**	**$4,403**	**$0**	**$6,855**	**$69,648**	**$97**

Exhibit 4-21 Case 2b - "H" frame turbine with CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL — Report Date: 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2b - H-frame CCS
Plant Size: 720.6 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2011 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost	H.O.& Fee	Process	Project	$	$/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,138	$0	$725	$0	$0	$1,863	$156	$93	$317	$2,429	$3
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$340	$0	$208	$0	$0	$548	$46	$27	$93	$715	$1
12.7	Computer & Accessories	$5,444	$0	$166	$0	$0	$5,610	$461	$280	$635	$6,986	$10
12.8	Instrument Wiring & Tubing	$0	$1,013	$1,792	$0	$0	$2,805	$202	$140	$472	$3,618	$5
12.9	Other I & C Equipment	$2,029	$0	$4,698	$0	$0	$6,728	$576	$336	$764	$8,404	$12
	SUBTOTAL 12.	**$8,951**	**$1,013**	**$7,589**	**$0**	**$0**	**$17,553**	**$1,440**	**$878**	**$2,281**	**$22,152**	**$31**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$129	$2,732	$0	$0	$2,861	$250	$0	$622	$3,733	$5
13.2	Site Improvements	$0	$1,179	$1,558	$0	$0	$2,737	$243	$0	$596	$3,576	$5
13.3	Site Facilities	$2,407	$0	$2,525	$0	$0	$4,933	$440	$0	$1,074	$6,447	$9
	SUBTOTAL 13.	**$2,407**	**$1,308**	**$6,815**	**$0**	**$0**	**$10,530**	**$933**	**$0**	**$2,293**	**$13,756**	**$19**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$351	$185	$0	$0	$536	$41	$0	$87	$664	$1
14.2	Steam Turbine Building	$0	$2,584	$3,438	$0	$0	$6,022	$484	$0	$976	$7,483	$10
14.3	Administration Building	$0	$643	$435	$0	$0	$1,078	$84	$0	$174	$1,336	$2
14.4	Circulation Water Pumphouse	$0	$209	$103	$0	$0	$313	$24	$0	$50	$387	$1
14.5	Water Treatment Buildings	$0	$601	$548	$0	$0	$1,149	$91	$0	$186	$1,426	$2
14.6	Machine Shop	$0	$558	$356	$0	$0	$914	$71	$0	$148	$1,133	$2
14.7	Warehouse	$0	$360	$217	$0	$0	$577	$45	$0	$93	$715	$1
14.8	Other Buildings & Structures	$0	$108	$78	$0	$0	$186	$15	$0	$30	$231	$0
14.9	Waste Treating Building & Str.	$0	$422	$753	$0	$0	$1,175	$96	$0	$191	$1,461	$2
	SUBTOTAL 14.	**$0**	**$5,836**	**$6,116**	**$0**	**$0**	**$11,952**	**$950**	**$0**	**$1,935**	**$14,837**	**$21**
	TOTAL COST	**$488,224**	**$36,759**	**$147,550**	**$0**	**$0**	**$672,533**	**$54,926**	**$41,967**	**$115,911**	**$885,337**	**$1,229**

Exhibit 4-21 Case 2b - "H" frame turbine with CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2b - H-frame CCS
Plant Size: 720.6 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct 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 $	TOTAL PLANT COST $/kW
	TOTAL COST	**$488,224**	**$36,759**	**$147,550**	**$0**	**$672,533**	**$54,926**	**$41,967**	**$115,911**	**$885,337**	**$1,229**
	Owner's Costs										
	Preproduction Costs										
	6 Months All Labor									$5,831	$8
	1 Month Maintenance Materials									$951	$1
	1 Month Non-fuel Consumables									$549	$1
	1 Month Waste Disposal									$0	$0
	25% of 1 Months Fuel Cost at 100% CF									$5,833	$8
	2% of TPC									$17,707	$25
	Total									**$30,871**	**$43**
	Inventory Capital										
	60 day supply of consumables at 100% CF									$760	$1
	0.5% of TPC (spare parts)									$4,427	$6
	Total									**$5,187**	**$7**
	Initial Cost for Catalyst and Chemicals									$1,727	$2
	Land									$300	$0
	Other Owner's Costs									$132,801	$184
	Financing Costs									$23,904	$33
	Total Overnight Costs (TOC)									**$1,080,126**	**$1,499**
	TASC Multiplier								(IOU, high-risk, 33 year)	1.078	
	Total As-Spent Cost (TASC)									**$1,164,376**	**$1,616**

Exhibit 4-22 Case 2b - "H" frame turbine with CO_2 capture operating cost estimate

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun)	2011
Case 2b - H-frame CCS					Heat Rate-net (Btu/kWh):	7,236
					MWe-net:	721
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	3.3		3.3			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	6.3		6.3			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$2,861,816	$3.972
Maintenance Labor Cost					$6,468,022	$8.976
Administrative & Support Labor					$2,332,459	$3.237
Property Taxes and Insurance					$17,706,735	$24.574
TOTAL FIXED OPERATING COSTS					**$29,369,032**	**$40.759**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					$9,702,033	**$0.00181**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0.00	3,314.88	1.67	**$0**	**$1,721,605**	**$0.00032**
Chemicals						
MU & WT Chem.(lbs)	0.00	19,749.09	0.27	$0	$1,641,092	$0.00031
MEA Solvent (ton)	477.31	0.67	3,481.91	$1,661,935	$724,096	$0.00013
Activated Carbon (lb)	0.00	800.70	1.63	$0	$403,737	$0.00008
Corrosion Inhibitor	0.00	0.00	0.00	$65,390	$3,114	$0.00000
SCR Catalyst (m3)	w/equip.	0.10	8,938.80	$0	$268,713	$0.00005
Ammonia (19% NH3) (ton)	0.00	8.15	330.00	$0	$834,338	$0.00016
Subtotal Chemicals				**$1,727,326**	**$3,875,089**	**$0.00072**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$1,727,326**	**$15,298,727**	**$0.00285**
Fuel (MMBtu)	0	125,135	6.13	**$0**	**$237,986,582**	**$0.04433**

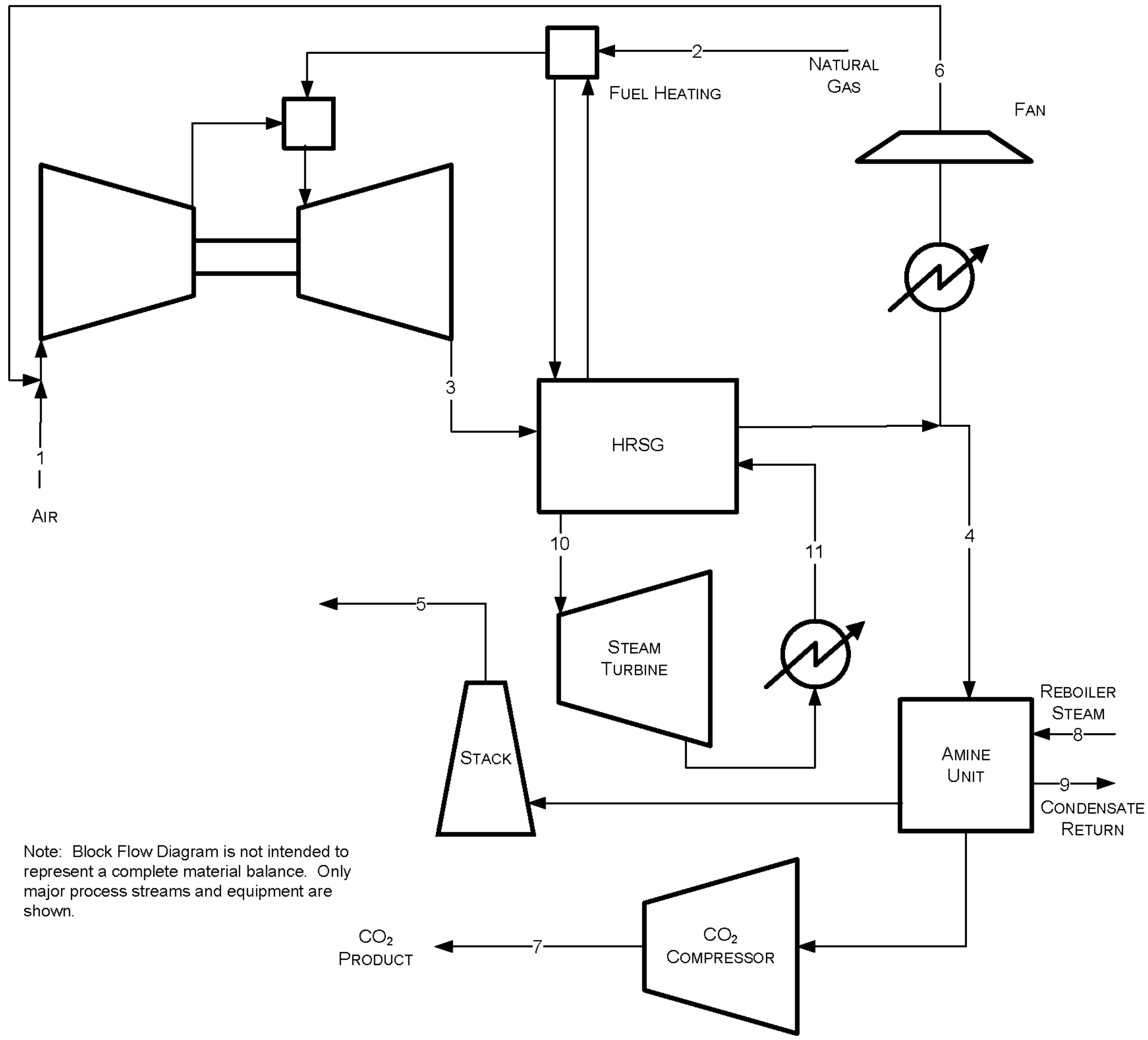
4.3 Case 2c – NGCC with CO_2 Capture and EGR Modeling Results

The block flow diagram of the combined cycle with CO_2 capture and EGR is shown in Exhibit 4-23. This case also uses the same H gas turbine model as that of Case 2a with the addition of EGR and CO_2 capture at the back end. Exhibit 4-23 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems. The heat required for the solvent (amine) system in the CO_2 capture system is supplied from the Rankine cycle (stream 4) similar to case 1b.

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,487°C (2,709°F). The flue gas exits the turbine at 619°C (1,146°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine as well as the steam required for the capture process (stream 8). Flue gas exits the HRSG (stream 4) at 106°C (223°F). A portion of the stream (stream 6) is recycled back to the air inlet and the remainder (stream 4) passes to the capture system where the CO_2 is captured and compressed (stream 7). Cooling is supplied to the steam turbine condenser via water from the cooling tower.

The gas turbine (Brayton cycle) performance and exhaust characteristics are impacted due to addition of the EGR. Of particular interest is that the CO_2 composition at the gas turbine exhaust increases from 4.2 percent in the capture only case (Case 2b) to 6.5 percent in this capture with EGR case. The O_2 composition concurrently decreases from 11.8 percent in the capture only case (Case 2b) to 7.5 percent in this capture with EGR. The higher concentration of the CO_2 in the exhaust gas stream reduces the energy consumption of the CO_2 capture system. Because of this, the EGR case provides a better output and efficiency compared to the capture case without EGR (Case 2b). However, the overall plant output and efficiency are reduced compared to the no CO_2 capture case (Case 2a) due to heat integration requirements and increased auxiliary loads for the EGR and CO_2 capture process

Exhibit 4-23 Case 2c – "H" frame turbine with CO_2 capture and EGR block flow diagram



Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Source: NETL

Exhibit 4-24 Case 2c – "H" frame turbine with CO_2 capture and EGR stream table

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0093	0.0000	0.0090	0.0090	0.0101	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0646	0.0646	0.0073	0.0685	1.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0101	0.0000	0.1026	0.1026	0.0555	0.0480	0.0000	1.0000	1.0000	1.0000	1.0000
N_2	0.7729	0.0160	0.7487	0.7487	0.8427	0.7943	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.2074	0.0000	0.0750	0.0750	0.0845	0.0796	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	0.9999	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	96,188	6,136	152,966	99,429	88,364	50,471	5,781	16,694	16,694	30,057	23,893
V-L Flowrate (kg/hr)	2,775,985	106,337	4,348,826	2,826,770	2,476,832	1,466,700	254,411	300,754	300,754	541,480	430,441
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	38	627	106	35	33	38	236	137	579	32
Pressure (MPa, abs)	0.10	4.14	0.10	0.10	0.10	0.10	15.17	0.33	0.33	16.65	0.00
Enthalpy (kJ/kg)[A]	0.90	47,245.71	309.82	402.63	40.26	108.41	362.39	2,938.67	577.55	3,513.89	2,389.27
Density (kg/m^3)	1.2	27.7	0.4	0.9	1.1	1.2	796.1	2.7	915.8	47.7	992.9
V-L Molecular Weight	28.860	17.330	28.430	28.430	28.030	29.060	44.010	18.015	18.015	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	212,058	13,528	337,233	219,204	194,808	111,270	12,744	36,805	36,805	66,264	52,675
V-L Flowrate (lb/hr)	6,120,000	234,432	9,587,520	6,231,960	5,460,480	3,233,520	560,880	663,048	663,048	1,193,760	948,960
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	100	1,160	223	95	92	101	457	279	1,075	90
Pressure (psia)	14.7	600.0	15.2	14.7	14.7	14.7	2,200.0	48.5	48.5	2,414.7	0.7
Enthalpy (Btu/lb)[A]	13.0	19.9	291.6	37.1	4.5	3.6	-97.1	1,263.4	248.3	1,510.7	1,027.2
Density (lb/ft^3)	0.076	1.731	0.025	0.057	0.069	0.072	49.700	0.169	57.172	2.977	61.982

Note: Total flow rates shown equal the sum for all process trains

4.3.1 Performance Results

The performance results are summarized in Exhibit 4-25 and when compared with Case 2b show that adding exhaust gas recycle increases the efficiency by approximately 0.6 percentage points. This is due to lowering the steam requirement for the reboiler slightly (to 2,790 kJ/kg CO_2 (1,200 Btu/lb CO_2) from the 2,960 kJ/kg CO_2 (1,272 Btu/lb CO_2) used in Case 2b) and based on the CO_2 concentration increasing and the oxygen concentration decreasing for the exhaust gas entering the solvent recovery section. An additional improvement would be expected if the exhaust gas recycle was increased from the 35 percent used to 50 percent. This was not explored in the current study since it was determined based on information from GE that 35 percent was a limit above which the gas turbine's combustor would need major redesign.

Additional tables below provide overall energy balance (Exhibit 4-26), water balance (Exhibit 4-27), carbon balance (Exhibit 4-28), and an emissions summary (Exhibit 4-29).

Exhibit 4-25 Case 2c – "H" frame turbine with CO_2 capture and EGR plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	553,926	kW_e
Steam Turbine Power	247,554	kW_e
Total	**801,480**	kW_e
Auxiliary Load		
Condensate Pumps	262	kW_e
Boiler Feedwater Pumps	6,400	kW_e
Exhaust Gas Recycle Fan	440	kW_e
Amine CO_2 Capture System Auxiliaries	15,104	kW_e
CO_2 Compression	23,575	kW_e
EGR Coolant Pump	374	kW_e
Circulating Water Pump	5,409	kW_e
Ground Water Pumps	450	kW_e
Cooling Tower Fans	3,491	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	1,097	kW_e
Steam Turbine Auxiliaries	656	kW_e
Miscellaneous Balance of Plant[2]	3,626	kW_e
Transformer Losses	3,000	kW_e
Total	**63,894**	**kW_e**
Plant Performance		
Net Plant Power	**737,586**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	47.7%	
Net Plant Efficiency (LHV)[1]	52.9%	
Net Plant Heat Rate (HHV)[1]	7,541 (7,148)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	6,807 (6,452)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	106,337 (234,432)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,545,122	kW_t
Thermal Input (LHV)[1]	1,394,650	kW_t
Condenser Duty	971 (920)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	18.7 (4,940)	m^3/min (gpm)
Raw Water Consumption	13.7 (3,626)	m^3/min (gpm)

[1] *HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)*
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] *Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads*

Exhibit 4-26 Case 2c – "H" frame turbine with CO_2 capture and EGR overall energy balance

	HHV	Sensible + Latent	Power	Total
		Energy In, GJ/hr (MMBtu/hr)		
Natural Gas	5,562 (5,272)	3.7 (3.5)	0 (0)	5,566 (5,276)
GT Air	0 (0)	83.9 (79.5)	0 (0)	84 (80)
Raw Water Withdrawal	0 (0)	70.3 (66.6)	0 (0)	70 (67)
Auxiliary Power	0 (0)	0.0 (0.0)	230 (218)	230 (218)
TOTAL	**5,562 (5,272)**	**157.9 (149.7)**	**230 (218)**	**5,950 (5,640)**
		Energy Out, GJ/hr (MMBtu/hr)		
Cooling Tower Blowdown	0 (0)	35.3 (33.5)	0 (0)	35 (33)
Stack Gas	0 (0)	26 (25)	0 (0)	26 (25)
Condenser	0 (0)	970 (920)	0 (0)	970 (920)
CO_2 Product	0 (0)	-57.4 (-54.4)	0 (0)	-57 (-54)
CO_2 Intercoolers	0 (0)	147.4 (139.7)	0 (0)	147 (140)
EGR Cooling	0 (0)	257.1 (243.7)	0 (0)	257 (244)
Amine System Losses	0 (0)	993.4 (941.6)	0 (0)	993 (942)
Process Losses*	*0 (0)*	*693 (657)*	*0 (0)*	*693 (657)*
Power	0 (0)	0.0 (0.0)	2,885 (2,735)	2,885 (2,735)
TOTAL	**0 (0)**	**3,065 (2,905)**	**2,885 (2,735)**	**5,950 (5,640)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 4-27 Case 2c – "H" frame turbine with CO_2 capture and EGR water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Amine Capture System	0.06 (17)	0.0 (0)	0.06 (17)	0.0 (0)	0.06 (17)
Condenser Makeup	**0.06 (16)**	**0.0 (0)**	**0.06 (16)**	**0.0 (0)**	**0.06 (16)**
BFW Makeup	0.06 (16)	0.0 (0)	0.06 (16)	0.0 (0)	0.0 (0)
Cooling Tower	**21.16 (5,589)**	**2.6 (681)**	**18.6 (4,907)**	**5.0 (1,314)**	**13.6 (3,593)**
BFW Blowdown	0.00 (0)	0.06 (16)	-0.06 (-16)	0.0 (0)	0.0 (0)
EGR Condensate	0.00 (0)	0.93 (245)	-0.93 (-245)	0.0 (0)	0.0 (0)
Flue Gas/CO_2 Condensate	0.00 (0)	1.59 (421)	-1.59 (-421)	0.0 (0)	0.0 (0)
Total	**21.3 (5,621)**	**2.58 (681)**	**18.7 (4,904)**	**5.0 (1,314)**	**13.6 (3,626)**

Exhibit 4-28 Case 2c – "H" frame turbine with CO_2 capture and EGR carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	76,795 (169,303)	Stack Gas	7,716 (17,011)
Air (CO_2)	347 (764)	CO_2 Product	69,433 (153,073)
		Convergence Tolerance*	-7 (-16)
Total	**77,141 (170,067)**	**Total**	**77,141 (170,067)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 4-29 Case 2c – "H" frame turbine with CO_2 capture and EGR air emissions

	Kg/GJ ($lb/10^6$ Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.002 (0.005)	83 (91)	0.014 (0.031)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	5.1 (11.8)	210,514 (232,052)	35 (78)
CO_2 [1]			*38 (85)*

[1] CO_2 emissions based on net power instead of gross power

4.3.2 Cost Estimate Results

The turbine costs for this case were estimated based on simulation results and vendor quotes/discussions on the Siemens "H" machine design. All other costs for this case were scaled from the costs in the previous cases based on simulation results using the methodology described in the initial NETL study of NGCC systems. [2] All costs are in June 2011 dollars. The cost estimation results for this case are summarized in Exhibit 4-30. The summary and detailed capital cost estimates are shown in Exhibit 4-31 and Exhibit 4-32, respectively. The annual operating cost estimates are shown in Exhibit 4-33.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 4-30 Case 2c – "H" frame turbine with CO_2 capture and EGR cost estimation summary

Case	2c
Total Plant Cost (2011$/kW)	**1,143**
Total Overnight Cost (2011$/kW)	**1,396**
Total As-spent Capital (2011$/kW)	**1,504**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	20.80
Fixed O&M	5.22
Variable O&M	2.87
Fuel	43.82
CO_2 T&S total	3.45
COE[1] Total	**76.16**
LCOE[1], total (including T&S)	96.54
Cost[1,2] of CO_2 avoided, $/tonne of CO_2 ($/ton of CO_2)	72.48 (65.75)
Cost[1,2] of CO_2 captured, $/tonne of CO_2 ($/ton of CO_2)	53.70 (48.71)

[1] Capacity factor assumed to be 85 percent
[2] Reference base case is 2a – "H" frame without capture

Exhibit 4-31 Case 2c – "H" frame turbine with CO_2 capture and EGR capital cost estimate summary

Client: USDOE/NETL **Report Date:** 2012-Apr-04
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2c - H-frame CCS EGR
Plant Size: 737.6 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$31,614	$7,372	$11,627	$0	$0	**$50,614**	$4,155	$0	$8,883	**$63,652**	**$86**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	$0	**$0**	**$0**	**$0**	$0	$0
5A	GAS CLEANUP & PIPING	$0	$9,734	$6,149	$0	$0	**$15,883**	$1,238	$0	$3,424	**$20,546**	$28
5B	CO2 REMOVAL & COMPRESSION	$141,292	$0	$45,180	$0	$0	**$186,472**	$15,568	$30,531	$46,514	**$279,085**	**$378**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$139,564	$0	$7,001	$0	$0	**$146,565**	$12,499	$0	$16,382	**$175,446**	$238
6.2-6.9	Combustion Turbine Other	$0	$1,011	$1,094	$0	$0	**$2,105**	$176	$0	$456	**$2,737**	$4
	SUBTOTAL 6	**$139,564**	**$1,011**	**$8,095**	**$0**	**$0**	**$148,670**	**$12,675**	**$0**	**$16,839**	**$178,183**	**$242**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$41,288	$0	$7,263	$0	$0	**$48,551**	$4,032	$0	$5,258	**$57,841**	$78
7.2-7.9	SCR System, Ductwork and Stack	$2,574	$1,676	$2,066	$0	$0	**$6,316**	$528	$0	$1,089	**$7,934**	$11
	SUBTOTAL 7	**$43,862**	**$1,676**	**$9,329**	**$0**	**$0**	**$54,867**	**$4,560**	**$0**	**$6,347**	**$65,774**	**$89**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$38,355	$0	$6,238	$0	$0	**$44,593**	$3,520	$0	$4,811	**$52,924**	$72
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$14,653	$1,059	$8,674	$0	$0	**$24,386**	$1,781	$0	$3,832	**$29,999**	$41
	SUBTOTAL 8	**$53,008**	**$1,059**	**$14,911**	**$0**	**$0**	**$68,978**	**$5,301**	**$0**	**$8,644**	**$82,923**	**$112**
9	COOLING WATER SYSTEM	$8,408	$8,858	$8,252	$0	$0	**$25,518**	$2,052	$0	$4,013	**$31,583**	$43
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$29,954	$9,427	$19,235	$0	$0	**$58,615**	$4,418	$0	$6,863	**$69,896**	$95
12	INSTRUMENTATION & CONTROL	$8,982	$1,016	$7,616	$0	$0	**$17,614**	$1,445	$881	$2,289	**$22,230**	$30
13	IMPROVEMENTS TO SITE	$2,421	$1,315	$6,854	$0	$0	**$10,591**	$938	$0	$2,306	**$13,835**	$19
14	BUILDINGS & STRUCTURES	$0	$5,962	$6,264	$0	$0	**$12,226**	$972	$0	$1,980	**$15,178**	$21
	TOTAL COST	**$459,104**	**$47,431**	**$143,512**	**$0**	**$0**	**$650,047**	**$53,323**	**$31,412**	**$108,102**	**$842,883**	**$1,143**

Exhibit 4-32 Case 2c – "H" frame turbine with CO_2 capture and EGR capital cost estimate detail

	Client:	USDOE/NETL							Report Date:	2012-Apr-04		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 2c - H-frame CCS EGR										
	Plant Size:	737.6 MW,net		Estimate Type:	Conceptual				Cost Base (Jun)	2011	($x1000)	
Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost	H.O.& Fee	Process	Project	$	$/kW
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,749	$3,882	$3,170	$0	$0	$10,801	$870	$0	$1,751	$13,422	$18
3.2	Water Makeup & Pretreating	$3,016	$312	$1,548	$0	$0	$4,876	$402	$0	$1,056	$6,334	$9
3.3	Other Feedwater Subsystems	$1,756	$580	$485	$0	$0	$2,822	$218	$0	$456	$3,496	$5
3.4	Service Water Systems	$364	$726	$2,340	$0	$0	$3,431	$292	$0	$745	$4,467	$6
3.5	Other Boiler Plant Systems	$2,454	$917	$2,109	$0	$0	$5,481	$446	$0	$889	$6,816	$9
3.6	Natural Gas, incl. pipeline	$17,767	$760	$658	$0	$0	$19,186	$1,582	$0	$3,115	$23,883	$32
3.7	Waste Treatment Equipment	$1,053	$0	$610	$0	$0	$1,663	$143	$0	$361	$2,168	$3
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,453	$194	$706	$0	$0	$2,353	$201	$0	$511	$3,065	$4
	SUBTOTAL 3.	**$31,614**	**$7,372**	**$11,627**	**$0**	**$0**	**$50,614**	**$4,155**	**$0**	**$8,883**	**$63,652**	**$86**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$9,734	$6,149	$0	$0	$15,883	$1,238	$0	$3,424	$20,546	$28
	SUBTOTAL 5.	**$0**	**$9,734**	**$6,149**	**$0**	**$0**	**$15,883**	**$1,238**	**$0**	**$3,424**	**$20,546**	**$28**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$117,306	$0	$35,349	$0	$0	$152,655	$12,737	$30,531	$39,185	$235,108	$319
5B.2	CO2 Compression & Drying	$23,985	$0	$9,831	$0	$0	$33,816	$2,831	$0	$7,330	$43,977	$60
	SUBTOTAL 5.	**$141,292**	**$0**	**$45,180**	**$0**	**$0**	**$186,472**	**$15,568**	**$30,531**	**$46,514**	**$279,085**	**$378**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	**$139,564**	**$0**	**$7,001**	$0	$0	$146,565	$12,499	$0	$16,382	$175,446	$238
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$1,011	$1,094	$0	$0	$2,105	$176	$0	$456	$2,737	$4
	SUBTOTAL 6.	**$139,564**	**$1,011**	**$8,095**	**$0**	**$0**	**$148,670**	**$12,675**	**$0**	**$16,839**	**$178,183**	**$242**

Exhibit 4-32 Case 2c – "H" frame turbine with CO_2 capture and EGR capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2012-Apr-04
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2c - H-frame CCS EGR
Plant Size: 737.6 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$41,288	$0	$7,263	$0	$0	$48,551	$4,032	$0	$5,258	$57,841	$78
7.2	HRSG Accessories	$2,574	$1,081	$1,508	$0	$0	$5,163	$432	$0	$839	$6,434	$9
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$595	$558	$0	$0	$1,153	$96	$0	$250	$1,499	$2
	SUBTOTAL 7.	**$43,862**	**$1,676**	**$9,329**	**$0**	**$0**	**$54,867**	**$4,560**	**$0**	**$6,347**	**$65,774**	**$89**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$38,355	$0	$6,238	$0	$0	$44,593	$3,520	$0	$4,811	$52,924	$72
8.2	Turbine Plant Auxiliaries	$247	$0	$550	$0	$0	$797	$68	$0	$87	$952	$1
8.3	Condenser & Auxiliaries	$2,267	$0	$1,455	$0	$0	$3,722	$313	$0	$404	$4,439	$6
8.4	Steam Piping	$12,138	$0	$4,920	$0	$0	$17,058	$1,162	$0	$2,733	$20,953	$28
8.9	TG Foundations	$0	$1,059	$1,749	$0	$0	$2,809	$237	$0	$609	$3,655	$5
	SUBTOTAL 8.	**$53,008**	**$1,059**	**$14,911**	**$0**	**$0**	**$68,978**	**$5,301**	**$0**	**$8,644**	**$82,923**	**$112**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$4,990	$0	$1,521	$0	$0	$6,510	$543	$0	$705	$7,759	$11
9.2	Circulating Water Pumps	$2,416	$0	$160	$0	$0	$2,576	$196	$0	$277	$3,049	$4
9.3	Circ.Water System Auxiliaries	$188	$0	$25	$0	$0	$212	$18	$0	$23	$253	$0
9.4	Circ.Water Piping	$0	$5,823	$1,318	$0	$0	$7,141	$535	$0	$1,151	$8,827	$12
9.5	Make-up Water System	$440	$0	$565	$0	$0	$1,005	$83	$0	$163	$1,251	$2
9.6	Component Cooling Water Sys	$374	$399	$287	$0	$0	$1,061	$85	$0	$172	$1,318	$2
9.9	Circ.Water System Foundations	$0	$2,636	$4,377	$0	$0	$7,012	$592	$0	$1,521	$9,125	$12
	SUBTOTAL 9.	**$8,408**	**$8,858**	**$8,252**	**$0**	**$0**	**$25,518**	**$2,052**	**$0**	**$4,013**	**$31,583**	**$43**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$8,497	$0	$5,026	$0	$0	$13,524	$1,111	$0	$1,098	$15,732	$21
11.2	Station Service Equipment	$3,069	$0	$264	$0	$0	$3,333	$274	$0	$271	$3,878	$5
11.3	Switchgear & Motor Control	$3,776	$0	$656	$0	$0	$4,432	$367	$0	$480	$5,279	$7
11.4	Conduit & Cable Tray	$0	$1,973	$5,685	$0	$0	$7,659	$638	$0	$1,245	$9,541	$13
11.5	Wire & Cable	$0	$6,342	$3,606	$0	$0	$9,948	$598	$0	$1,582	$12,128	$16
11.6	Protective Equipment	$0	$920	$3,192	$0	$0	$4,112	$354	$0	$447	$4,912	$7
11.7	Standby Equipment	$143	$0	$133	$0	$0	$276	$23	$0	$30	$329	$0
11.8	Main Power Transformers	$14,468	$0	$185	$0	$0	$14,653	$995	$0	$1,565	$17,213	$23
11.9	Electrical Foundations	$0	$192	$488	$0	$0	$680	$58	$0	$147	$885	$1
	SUBTOTAL 11.	**$29,954**	**$9,427**	**$19,235**	**$0**	**$0**	**$58,615**	**$4,418**	**$0**	**$6,863**	**$69,896**	**$95**

Exhibit 4-32 Case 2c – "H" frame turbine with CO_2 capture and EGR capital cost estimate detail (continued)

Client: USDOE/NETL — Report Date: 2012-Apr-04
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 2c - H-frame CCS EGR
Plant Size: 737.6 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,142	$0	$727	$0	$0	$1,869	$157	$93	$318	$2,438	$3
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$341	$0	$209	$0	$0	$550	$46	$27	$94	$717	$1
12.7	Computer & Accessories	$5,463	$0	$167	$0	$0	$5,629	$462	$281	$637	$7,010	$10
12.8	Instrument Wiring & Tubing	$0	$1,016	$1,798	$0	$0	$2,814	$202	$141	$474	$3,631	$5
12.9	Other I & C Equipment	$2,036	$0	$4,715	$0	$0	$6,751	$578	$338	$767	$8,433	$11
	SUBTOTAL 12.	**$8,982**	**$1,016**	**$7,616**	**$0**	**$0**	**$17,614**	**$1,445**	**$881**	**$2,289**	**$22,230**	**$30**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$129	$2,748	$0	$0	$2,877	$251	$0	$626	$3,754	$5
13.2	Site Improvements	$0	$1,186	$1,567	$0	$0	$2,752	$245	$0	$599	$3,597	$5
13.3	Site Facilities	$2,421	$0	$2,540	$0	$0	$4,961	$442	$0	$1,081	$6,484	$9
	SUBTOTAL 13.	**$2,421**	**$1,315**	**$6,854**	**$0**	**$0**	**$10,591**	**$938**	**$0**	**$2,306**	**$13,835**	**$19**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$352	$186	$0	$0	$539	$41	$0	$87	$667	$1
14.2	Steam Turbine Building	$0	$2,667	$3,548	$0	$0	$6,215	$500	$0	$1,007	$7,722	$10
14.3	Administration Building	$0	$645	$437	$0	$0	$1,082	$84	$0	$175	$1,342	$2
14.4	Circulation Water Pumphouse	$0	$210	$104	$0	$0	$314	$24	$0	$51	$388	$1
14.5	Water Treatment Buildings	$0	$634	$578	$0	$0	$1,212	$96	$0	$196	$1,504	$2
14.6	Machine Shop	$0	$560	$358	$0	$0	$918	$71	$0	$148	$1,137	$2
14.7	Warehouse	$0	$362	$218	$0	$0	$580	$45	$0	$94	$718	$1
14.8	Other Buildings & Structures	$0	$108	$79	$0	$0	$187	$15	$0	$30	$232	$0
14.9	Waste Treating Building & Str.	$0	$424	$756	$0	$0	$1,180	$96	$0	$191	$1,467	$2
	SUBTOTAL 14.	**$0**	**$5,962**	**$6,264**	**$0**	**$0**	**$12,226**	**$972**	**$0**	**$1,980**	**$15,178**	**$21**
	TOTAL COST	**$459,104**	**$47,431**	**$143,512**	**$0**	**$0**	**$650,047**	**$53,323**	**$31,412**	**$108,102**	**$842,883**	**$1,143**

Exhibit 4-32 Case 2c – "H" frame turbine with CO_2 capture and EGR capital cost estimate detail (continued)

	Client:	USDOE/NETL							**Report Date:**	2012-Apr-04		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 2c - H-frame CCS EGR										
	Plant Size:	737.6 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)	
Acct		**Equipment**	**Material**	**Labor**		**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**		
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Cost**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**	
	TOTAL COST	**$459,104**	**$47,431**	**$143,512**	**$0**	**$650,047**	**$53,323**	**$31,412**	**$108,102**	**$842,883**	**$1,143**	
	Owner's Costs											
	Preproduction Costs											
	6 Months All Labor									$5,907	$8	
	1 Month Maintenance Materials									$969	$1	
	1 Month Non-fuel Consumables									$574	$1	
	1 Month Waste Disposal									$0	$0	
	25% of 1 Months Fuel Cost at 100% CF									$5,898	$8	
	2% of TPC									$16,858	$23	
	Total									**$30,206**	**$41**	
	Inventory Capital											
	60 day supply of consumables at 100% CF									$785	$1	
	0.5% of TPC (spare parts)									$4,214	$6	
	Total									**$5,000**	**$7**	
	Initial Cost for Catalyst and Chemicals									$1,742	$2	
	Land									$300	$0	
	Other Owner's Costs									$126,433	$171	
	Financing Costs									$22,758	$31	
	Total Overnight Costs (TOC)									**$1,029,322**	**$1,396**	
	TASC Multiplier								(IOU, high-risk, 33 year)	1.078		
	Total As-Spent Cost (TASC)									**$1,109,609**	**$1,504**	

Exhibit 4-33 Case 2c – "H" frame turbine with CO_2 capture and EGR operating cost estimate

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun)	2011
Case 2c - H-frame CCS EGR					Heat Rate-net (Btu/kWh):	7,148
					MWe-net:	738
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	3.3		3.3			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	6.3		6.3			
					Annual Cost $	Annual Unit Cost $/kW-net
Annual Operating Labor Cost					$2,861,816	$3.880
Maintenance Labor Cost					$6,590,143	$8.935
Administrative & Support Labor					$2,362,990	$3.204
Property Taxes and Insurance					$16,857,668	$22.855
TOTAL FIXED OPERATING COSTS					**$28,672,617**	**$38.874**
VARIABLE OPERATING COSTS						
Maintenance Material Cost					$9,885,214	**$0.00180**
Consumables	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost		
Water (/1000 gallons)	0.00	3,556.70	1.67	**$0**	**$1,847,194**	**$0.00034**
Chemicals						
MU & WT Chem.(lbs)	0.00	21,189.76	0.27	$0	$1,760,807	$0.00032
MEA Solvent (ton)	481.32	0.68	3,481.91	$1,675,919	$730,188	$0.00013
Activated Carbon (lb)	0.00	807.44	1.63	$0	$407,134	$0.00007
Corrosion Inhibitor	0.00	0.00	0.00	$65,941	$3,140	$0.00000
SCR Catalyst (m3)	w/equip.	0.10	8,938.80	$0	$269,097	$0.00005
Ammonia (19% NH3) (ton)	0.00	8.16	330.00	$0	$835,530	$0.00015
Subtotal Chemicals				**$1,741,860**	**$4,005,897**	**$0.00073**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$1,741,860**	**$15,738,305**	**$0.00286**
Fuel (MMBtu)	0	126,534	6.13	**$0**	**$240,647,221**	**$0.04379**

5 Case 3 – Advanced Gas Turbine – ("J" frame)

These cases are based on the previous cases but use a more advanced turbine design based on a proposed "J" machine configuration. The current "J" frame is MHI's latest addition in their advanced frame design that has an ISO output of 312 MW and lower heating value (LHV) heat rate of 8,700 kJ/kWh (8,245 Btu/kWh) (Brayton cycle) on natural gas fuel. The output is approximately 48 percent more and the heat rate is approximately 7 percent better than the 7FA.05 model considered in Case 1a. This gas turbine model also has approximately 19 percent more exhaust flow and approximately 33°C (60°F) higher exhaust temperature than the 7FA.05 model. This model uses air cooling of blades but steam cooling for the combustors. The design also includes fast start capability.

This turbine in a NGCC has an estimated efficiency of 60 – 61 percent [12, 13] and was modified based on anticipated improvements to increase the efficiency to greater than 62 percent for this case. The current "J" turbine uses a small amount of steam cooling which was not included in the process level model developed for this case.

The performance summaries, block flow diagrams, stream tables, carbon balances, water balances, and overall energy balances for each of these three cases are presented in this section. Detailed process flow diagrams from the Thermoflow software are provided in the appendix.

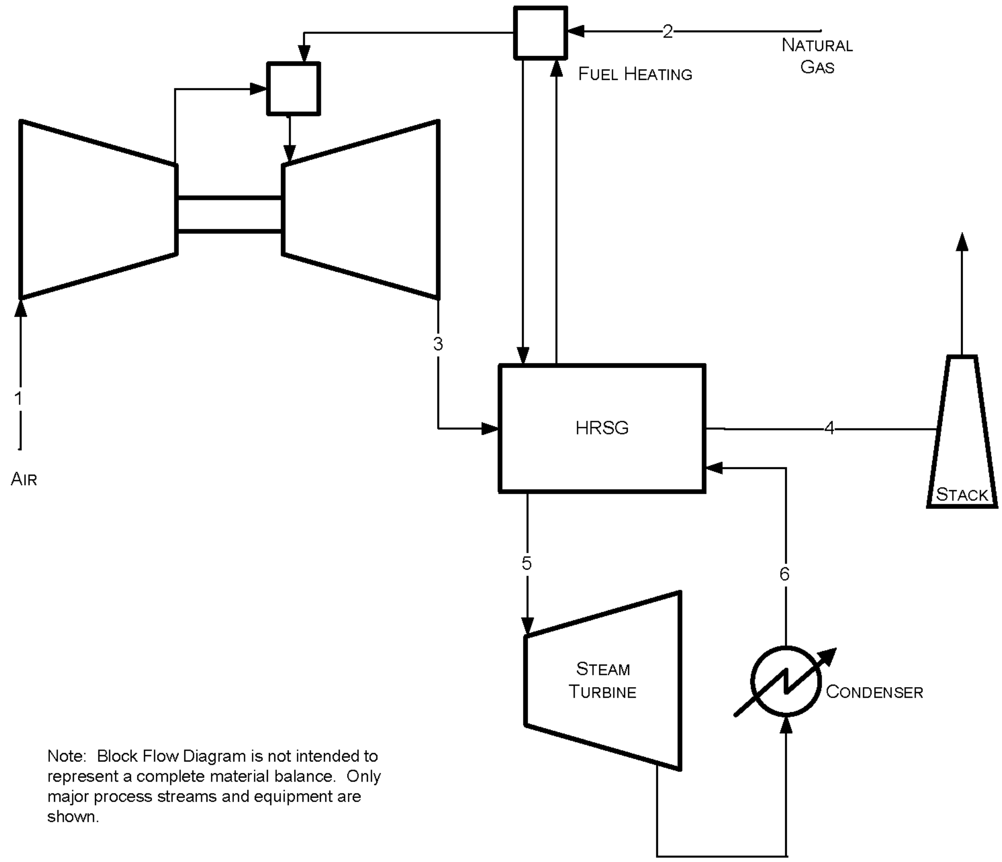
The turbine cost for each of the cases was estimated by WorleyParsons based on simulation results and vendor quotes/discussions. The remaining capital and operating cost estimation results were based on scaling from the previous Case 1 results and are included at the end of each case section. All costs are in June 2011 dollars.

5.1 Case 3a – NGCC without CO_2 Capture Modeling Results

The block flow diagram of the combined cycle is shown in Exhibit 5-1. This includes two MHI advanced "J" frame turbines, two triple pressure level single reheat type HRSGs, and one condensing steam turbine with evaporative cooling tower. Exhibit 5-2 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems. A fuel gas heating system is integrated in this design for the gas turbine and overall plant heat rate improvement.

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,620°C (2,949°F). The flue gas exits the turbine at 636°C (1,177°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine. Flue gas exits the HRSG (stream 4) at 88°C (190°F) and passes to the plant stack. Cooling is supplied to the condenser via water from the cooling tower.

Exhibit 5-1 Case 3a – "J" frame turbine without CO_2 capture block flow diagram



Source: NETL

Exhibit 5-2 Case 3a – "J" frame turbine without CO_2 capture stream table

	1	2	3	4	5	6
V-L Mole Fraction						
Ar	0.0092	0.0000	0.0089	0.0089	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0404	0.0462	0.0000	0.0000
H_2O	0.0099	0.0000	0.0867	0.0981	1.0000	1.0000
N_2	0.7732	0.0160	0.7432	0.7386	0.0000	0.0000
O_2	0.2074	0.0000	0.1209	0.1083	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0001	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	149,503	6,898	156,222	156,608	31,444	39,755
V-L Flowrate (kg/hr)	4,314,208	119,531	4,433,738	4,433,575	566,464	716,204
Solids Flowrate (kg/hr)	0	0	0	0	0	0
Temperature (°C)	15	38	636	88	593	32
Pressure (MPa, abs)	0.10	4.14	0.10	0.10	16.65	0.00
Enthalpy (kJ/kg)[A]	30.96	52,530.38	868.99	249.11	3,547.62	2,381.59
Density (kg/m^3)	1.2	22.2	0.4	0.9	47.7	992.9
V-L Molecular Weight	28.857	17.328	28.381	28.310	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	329,598	15,208	344,410	345,262	69,321	87,646
V-L Flowrate (lb/hr)	9,511,200	263,520	9,774,720	9,774,360	1,248,840	1,578,960
Solids Flowrate (lb/hr)	0	0	0	0	0	0
Temperature (°F)	59	100	1,177	190	1,100	90
Pressure (psia)	14.6	600.0	15.2	14.7	2,414.7	0.7
Enthalpy (Btu/lb)[A]	13.3	22,584.0	373.6	107.1	1,525.2	1,023.9
Density (lb/ft^3)	0.076	1.384	0.025	0.057	2.977	61.982

A - Reference conditions are 32.02 F & Liquid Water

Note: Total flow rates shown equal the sum for all process trains

5.1.1 Performance Results

The performance results are summarized in Exhibit 5-3 and represent both increases in power production and efficiency based on assumptions made when compared with the current commercial system based on the MHI "J" gas turbine. The overall efficiency of 62.6 percent represents an increase in the overall process efficiency of approximately 2.1 percentage points and approximately 10.5 percent gas turbine power increase when compared with the current commercial "J" system. Compared to Case 1a based on the 7FA.05 gas turbine, the overall efficiency increases by approximately 5.2 percentage points and the gas turbine power increases by approximately 64 percent. Additional tables below provide overall energy balance

(Exhibit 5-4), water balance (Exhibit 5-5), carbon balance (Exhibit 5-6), and an emissions summary (Exhibit 5-7).

Exhibit 5-3 Case 3a – "J" frame turbine without CO_2 capture plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	689,832	kW_e
Steam Turbine Power	314,517	kW_e
Total	**1,004,349**	kW_e
Auxiliary Load		
Condensate Pumps	0	kW_e
Boiler Feedwater Pumps	6,725	kW_e
Amine CO_2 Capture System Auxiliaries	0	kW_e
CO_2 Compression	0	kW_e
Circulating Water Pump	2,941	kW_e
Ground Water Pumps	300	kW_e
Cooling Tower Fans	2,180	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	1,097	kW_e
Steam Turbine Auxiliaries	672	kW_e
Miscellaneous Balance of Plant[2]	3,434	kW_e
Transformer Losses	5,022	kW_e
Total	**22,381**	**kW_e**
Plant Performance		
Net Plant Power	**981,968**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	56.5%	
Net Plant Efficiency (LHV)[1]	62.6%	
Net Plant Heat Rate (HHV)[1]	6,368 (6,036)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	5,748 (5,448)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	119,531 (263,520)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,736,982	kW_t
Thermal Input (LHV)[1]	1,567,848	kW_t
Condenser Duty	1,614 (1,530)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	12.5 (3,309)	m^3/min (gpm)
Raw Water Consumption	10.5 (2,744)	m^3/min (gpm)

[1] *HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)*
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] *Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads*

Exhibit 5-4 Case 3a – "J" frame turbine without CO_2 capture overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	6,253 (5,927)	4.2 (4.0)	0 (0)	6,257 (5,931)
GT Air	0 (0)	133.6 (126.6)	0 (0)	134 (127)
Raw Water Withdrawal	0 (0)	47.4 (45.0)	0 (0)	47 (45)
Auxiliary Power	0 (0)	0.0 (0.0)	81 (76)	81 (76)
TOTAL	**6,253 (5,927)**	**184.8 (175.2)**	**81 (76)**	**6,519 (6,178)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	20.9 (19.8)	0 (0)	21 (20)
Stack Gas	0 (0)	1,104 (1,047)	0 (0)	1,104 (1,047)
Condenser	0 (0)	1,609 (1,525)	0 (0)	1,609 (1,525)
Process Losses*	*0 (0)*	*169 (160)*	*0 (0)*	*169 (160)*
Power	0 (0)	0.0 (0.0)	3,616 (3,427)	3,616 (3,427)
TOTAL	**0 (0)**	**2,903 (2,751)**	**3,616 (3,427)**	**6,519 (6,178)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 5-5 Case 3a – "J" frame turbine without CO_2 capture water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Condenser Makeup	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**	**0.0 (0)**	**0.1 (15)**
BFW Makeup	0.06 (15)	0.0 (0)	0.06 (15)	0.00 (0)	0.00 (0)
Cooling Tower	**12.52 (3,309)**	**0.06 (15)**	**12.47 (3,294)**	**2.1 (565)**	**10.3 (2,729)**
BFW Blowdown	0.00 (0)	0.1 (15)	-0.06 (-15)	0.00 (0)	0.00 (0)
Flue Gas Condensate	0.00 (0)	0.0 (0)	0.00 (0)	0.00 (0)	0.00 (0)
Total	**12.6 (3,323)**	**0.06 (15)**	**12.5 (3,309)**	**2.1 (565)**	**10.4 (2,744)**

Exhibit 5-6 Case 3a – "J" frame turbine without CO_2 capture carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	86,336 (190,337)	Stack Gas	86,884 (191,547)
Air (CO_2)	587 (1,293)		
		Convergence Tolerance*	38 (84)
Total	**86,922 (191,631)**	**Total**	**86,922 (191,631)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 5-7 Case 3a – "J" frame turbine without CO_2 capture air emissions

	Kg/GJ (lb/10^6 Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.004 (0.009)	181 (200)	0.024 (0.053)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	50.9 (118.5)	2,370,471 (2,612,997)	317 (699)
CO_2[1]			324 (715)

[1] CO_2 emissions based on net power instead of gross power

5.1.2 Cost Estimate Results

The turbine costs for this case were estimated based on simulation results and vendor quotes/discussions on the Mitsubishi Heavy Industries (MHI) "J" machine design. All other costs for this case were scaled from the costs in the previous cases based on simulation results using the methodology described in the initial NETL study of NGCC systems. [2] All costs are in June 2011 dollars. The cost estimation results for this case are summarized in Exhibit 5-8. The summary and detailed capital cost estimates are shown in Exhibit 5-9 and Exhibit 5-10, respectively. The annual operating cost estimates are shown in Exhibit 5-11.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 5-8 Case 3a – "J" frame turbine without CO_2 capture cost estimation summary

Case	3a
Total Plant Cost (2011$/kW)	**558**
Total Overnight Cost (2011$/kW)	**684**
Total As-spent Capital (2011$/kW)	**735**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	9.64
Fixed O&M	2.67
Variable O&M	1.42
Fuel	37.00
CO_2 T&S total	0.00
COE[1] Total	**50.73**
LCOE[1], total (including T&S)	64.30

[1] Capacity factor assumed to be 85 percent

Exhibit 5-9 Case 3a – "J" frame turbine without CO_2 capture capital cost estimate summary

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 3a - J-frame
Plant Size: 982.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$30,078	$7,032	$10,143	$0	$0	**$47,254**	$3,875	$0	$8,211	**$59,340**	**$60**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
5B	CO2 REMOVAL & COMPRESSION	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	**$0**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$152,231	$0	$8,078	$0	$0	**$160,309**	$13,240	$0	$17,355	**$190,904**	$194
6.2-6.9	Combustion Turbine Other	$0	$1,126	$1,218	$0	$0	**$2,344**	$196	$0	$508	**$3,049**	$3
	SUBTOTAL 6	**$152,231**	**$1,126**	**$9,296**	**$0**	**$0**	**$162,653**	**$13,437**	**$0**	**$17,863**	**$193,952**	**$198**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$43,206	$0	$7,600	$0	$0	**$50,805**	$4,219	$0	$5,502	**$60,527**	$62
7.2-7.9	SCR System, Ductwork and Stack	$2,789	$1,785	$2,209	$0	$0	**$6,783**	$567	$0	$1,167	**$8,517**	$9
	SUBTOTAL 7	**$45,994**	**$1,785**	**$9,809**	**$0**	**$0**	**$57,588**	**$4,786**	**$0**	**$6,669**	**$69,044**	**$70**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$46,376	$0	$6,565	$0	$0	**$52,941**	$4,171	$0	$5,711	**$62,823**	$64
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$16,006	$1,261	$9,464	$0	$0	**$26,731**	$1,973	$0	$4,160	**$32,863**	$33
	SUBTOTAL 8	**$62,382**	**$1,261**	**$16,029**	**$0**	**$0**	**$79,672**	**$6,144**	**$0**	**$9,871**	**$95,686**	**$97**
9	COOLING WATER SYSTEM	$5,891	$6,466	$5,992	$0	$0	**$18,349**	$1,475	$0	$2,902	**$22,726**	$23
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$24,508	$7,107	$15,771	$0	$0	**$47,385**	$3,586	$0	$5,485	**$56,455**	$57
12	INSTRUMENTATION & CONTROL	$8,590	$972	$7,283	$0	$0	**$16,845**	$1,382	$0	$2,092	**$20,320**	$21
13	IMPROVEMENTS TO SITE	$2,515	$1,366	$7,120	$0	$0	**$11,001**	$975	$0	$2,395	**$14,370**	$15
14	BUILDINGS & STRUCTURES	$0	$6,305	$6,724	$0	$0	**$13,029**	$1,037	$0	$2,110	**$16,176**	$16
	TOTAL COST	**$332,189**	**$33,421**	**$88,165**	**$0**	**$0**	**$453,775**	**$36,697**	**$0**	**$57,598**	**$548,069**	**$558**

Exhibit 5-10 Case 3a – "J" frame turbine without CO_2 capture capital cost estimate detail

	Client:	USDOE/NETL							**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 3a - J-frame										
	Plant Size:	982.0 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)	
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Sales Tax**	**Bare Erected Cost**	**Eng'g CM H.O.& Fee**	**Contingencies Process**	**Contingencies Project**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,776	$3,910	$3,193	$0	$0	$10,880	$876	$0	$1,763	$13,519	$14
3.2	Water Makeup & Pretreating	$2,269	$234	$1,164	$0	$0	$3,668	$303	$0	$794	$4,764	$5
3.3	Other Feedwater Subsystems	$1,769	$585	$488	$0	$0	$2,842	$220	$0	$459	$3,521	$4
3.4	Service Water Systems	$274	$546	$1,760	$0	$0	$2,580	$219	$0	$560	$3,360	$3
3.5	Other Boiler Plant Systems	$1,846	$690	$1,586	$0	$0	$4,122	$336	$0	$669	$5,126	$5
3.6	Natural Gas, incl. pipeline	$17,819	$862	$746	$0	$0	$19,428	$1,602	$0	$3,155	$24,185	$25
3.7	Waste Treatment Equipment	$792	$0	$459	$0	$0	$1,251	$108	$0	$272	$1,631	$2
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,533	$205	$745	$0	$0	$2,483	$212	$0	$539	$3,234	$3
	SUBTOTAL 3.	**$30,078**	**$7,032**	**$10,143**	**$0**	**$0**	**$47,254**	**$3,875**	**$0**	**$8,211**	**$59,340**	**$60**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	**$152,231**	**$0**	**$8,078**	$0	$0	$160,309	$13,240	$0	$17,355	$190,904	$194
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$1,126	$1,218	$0	$0	$2,344	$196	$0	$508	$3,049	$3
	SUBTOTAL 6.	**$152,231**	**$1,126**	**$9,296**	**$0**	**$0**	**$162,653**	**$13,437**	**$0**	**$17,863**	**$193,952**	**$198**

Exhibit 5-10 Case 3a – "J" frame turbine without CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 3a - J-frame
Plant Size: 982.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost	H.O.& Fee	Process	Project	$	$/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$43,206	$0	$7,600	$0	$0	$50,805	$4,219	$0	$5,502	$60,527	$62
7.2	HRSG Accessories	$2,789	$1,171	$1,633	$0	$0	$5,593	$468	$0	$909	$6,971	$7
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$614	$576	$0	$0	$1,189	$99	$0	$258	$1,546	$2
	SUBTOTAL 7.	**$45,994**	**$1,785**	**$9,809**	**$0**	**$0**	**$57,588**	**$4,786**	**$0**	**$6,669**	**$69,044**	**$70**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$46,376	$0	$6,565	$0	$0	$52,941	$4,171	$0	$5,711	$62,823	$64
8.2	Turbine Plant Auxiliaries	$268	$0	$609	$0	$0	$877	$75	$0	$95	$1,047	$1
8.3	Condenser & Auxiliaries	$3,388	$0	$1,767	$0	$0	$5,155	$433	$0	$559	$6,146	$6
8.4	Steam Piping	$12,350	$0	$5,006	$0	$0	$17,356	$1,183	$0	$2,781	$21,319	$22
8.9	TG Foundations	$0	$1,261	$2,082	$0	$0	$3,343	$282	$0	$725	$4,350	$4
	SUBTOTAL 8.	**$62,382**	**$1,261**	**$16,029**	**$0**	**$0**	**$79,672**	**$6,144**	**$0**	**$9,871**	**$95,686**	**$97**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,455	$0	$1,055	$0	$0	$4,511	$376	$0	$489	$5,376	$5
9.2	Circulating Water Pumps	$1,676	$0	$105	$0	$0	$1,781	$136	$0	$192	$2,109	$2
9.3	Circ.Water System Auxiliaries	$137	$0	$18	$0	$0	$155	$13	$0	$17	$185	$0
9.4	Circ.Water Piping	$0	$4,256	$964	$0	$0	$5,220	$391	$0	$842	$6,452	$7
9.5	Make-up Water System	$348	$0	$448	$0	$0	$796	$66	$0	$129	$991	$1
9.6	Component Cooling Water Sys	$274	$288	$210	$0	$0	$772	$62	$0	$125	$958	$1
9.9	Circ.Water System Foundations	$0	$1,922	$3,192	$0	$0	$5,114	$432	$0	$1,109	$6,655	$7
	SUBTOTAL 9.	**$5,891**	**$6,466**	**$5,992**	**$0**	**$0**	**$18,349**	**$1,475**	**$0**	**$2,902**	**$22,726**	**$23**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$6,929	$0	$4,099	$0	$0	$11,028	$906	$0	$895	$12,829	$13
11.2	Station Service Equipment	$2,160	$0	$186	$0	$0	$2,346	$193	$0	$190	$2,729	$3
11.3	Switchgear & Motor Control	$2,658	$0	$462	$0	$0	$3,120	$258	$0	$338	$3,716	$4
11.4	Conduit & Cable Tray	$0	$1,389	$4,002	$0	$0	$5,391	$449	$0	$876	$6,716	$7
11.5	Wire & Cable	$0	$4,464	$2,538	$0	$0	$7,002	$421	$0	$1,113	$8,536	$9
11.6	Protective Equipment	$0	$1,029	$3,572	$0	$0	$4,601	$396	$0	$500	$5,497	$6
11.7	Standby Equipment	$159	$0	$148	$0	$0	$307	$26	$0	$33	$366	$0
11.8	Main Power Transformers	$12,601	$0	$192	$0	$0	$12,794	$869	$0	$1,366	$15,029	$15
11.9	Electrical Foundations	$0	$225	$572	$0	$0	$797	$67	$0	$173	$1,037	$1
	SUBTOTAL 11.	**$24,508**	**$7,107**	**$15,771**	**$0**	**$0**	**$47,385**	**$3,586**	**$0**	**$5,485**	**$56,455**	**$57**

Exhibit 5-10 Case 3a – "J" frame turbine without CO_2 capture capital cost estimate detail (continued)

	Client:	USDOE/NETL							**Report Date:**	2011-Dec-15			
	Project:	Costing Support for NGCC with CCS Analyses											
		TOTAL PLANT COST SUMMARY											
	Case:	Case 3a - J-frame											
	Plant Size:	982.0 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)		
Acct		**Equipment**	**Material**	**Labor**		**Sales**	**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**		
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Tax**	**Cost**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**	
12	INSTRUMENTATION & CONTROL												
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0	
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0	
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0	
12.4	Other Major Component Control	$1,092	$0	$696	$0	$0	$1,788	$150	$0	$291	$2,229	$2	
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0	
12.6	Control Boards,Panels & Racks	$326	$0	$200	$0	$0	$526	$44	$0	$86	$656	$1	
12.7	Computer & Accessories	$5,224	$0	$159	$0	$0	$5,384	$442	$0	$583	$6,408	$7	
12.8	Instrument Wiring & Tubing	$0	$972	$1,720	$0	$0	$2,692	$193	$0	$433	$3,318	$3	
12.9	Other I & C Equipment	$1,948	$0	$4,509	$0	$0	$6,457	$553	$0	$701	$7,710	$8	
	SUBTOTAL 12.	**$8,590**	**$972**	**$7,283**	**$0**	**$0**	**$16,845**	**$1,382**	**$0**	**$2,092**	**$20,320**	**$21**	
13	IMPROVEMENTS TO SITE												
13.1	Site Preparation	$0	$134	$2,854	$0	$0	$2,989	$261	$0	$650	$3,900	$4	
13.2	Site Improvements	$0	$1,232	$1,627	$0	$0	$2,859	$254	$0	$623	$3,736	$4	
13.3	Site Facilities	$2,515	$0	$2,638	$0	$0	$5,153	$459	$0	$1,123	$6,735	$7	
	SUBTOTAL 13.	**$2,515**	**$1,366**	**$7,120**	**$0**	**$0**	**$11,001**	**$975**	**$0**	**$2,395**	**$14,370**	**$15**	
14	BUILDINGS & STRUCTURES												
14.1	Combustion Turbine Area	$0	$396	$209	$0	$0	$605	$47	$0	$98	$749	$1	
14.2	Steam Turbine Building	$0	$3,077	$4,094	$0	$0	$7,172	$577	$0	$1,162	$8,911	$9	
14.3	Administration Building	$0	$653	$442	$0	$0	$1,095	$85	$0	$177	$1,357	$1	
14.4	Circulation Water Pumphouse	$0	$228	$113	$0	$0	$340	$26	$0	$55	$421	$0	
14.5	Water Treatment Buildings	$0	$481	$439	$0	$0	$920	$73	$0	$149	$1,142	$1	
14.6	Machine Shop	$0	$566	$362	$0	$0	$928	$72	$0	$150	$1,150	$1	
14.7	Warehouse	$0	$366	$221	$0	$0	$586	$45	$0	$95	$726	$1	
14.8	Other Buildings & Structures	$0	$110	$80	$0	$0	$189	$15	$0	$31	$235	$0	
14.9	Waste Treating Building & Str.	$0	$428	$765	$0	$0	$1,193	$97	$0	$194	$1,484	$2	
	SUBTOTAL 14.	**$0**	**$6,305**	**$6,724**	**$0**	**$0**	**$13,029**	**$1,037**	**$0**	**$2,110**	**$16,176**	**$16**	
	TOTAL COST	**$332,189**	**$33,421**	**$88,165**	**$0**	**$0**	**$453,775**	**$36,697**	**$0**	**$57,598**	**$548,069**	**$558**	

Exhibit 5-10 Case 3a – "J" frame turbine without CO_2 capture capital cost estimate detail (continued)

	Client:	USDOE/NETL							**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 3a - J-frame										
	Plant Size:	982.0 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)	
Acct		**Equipment**	**Material**	**Labor**		**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**		
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Cost**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**	
	TOTAL COST	**$332,189**	**$33,421**	**$88,165**	**$0**	**$453,775**	**$36,697**	**$0**	**$57,598**	**$548,069**	**$558**	
	Owner's Costs											
	Preproduction Costs											
	6 Months All Labor									$4,263	$4	
	1 Month Maintenance Materials									$671	$1	
	1 Month Non-fuel Consumables									$347	$0	
	1 Month Waste Disposal									$0	$0	
	25% of 1 Months Fuel Cost at 100% CF									$6,631	$7	
	2% of TPC									$10,961	$11	
	Total									**$22,873**	**$23**	
	Inventory Capital											
	60 day supply of consumables at 100% CF									$452	$0	
	0.5% of TPC (spare parts)									$2,740	$3	
	Total									**$3,192**	**$3**	
	Initial Cost for Catalyst and Chemicals									$0	$0	
	Land									$300	$0	
	Other Owner's Costs									$82,210	$84	
	Financing Costs									$14,798	$15	
	Total Overnight Costs (TOC)									**$671,444**	**$684**	
	TASC Multiplier							(IOU, low-risk, 33 year)		1.075		
	Total As-Spent Cost (TASC)									**$721,802**	**$735**	

Exhibit 5-11 Case 3a – "J" frame turbine without CO_2 capture operating cost estimate

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun)	2011
Case 3a - J-frame					Heat Rate-net (Btu/kWh):	6,036
					MWe-net:	982
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	2.0		2.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	5.0		5.0			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$2,260,518	$2.302
Maintenance Labor Cost					$4,560,499	$4.644
Administrative & Support Labor					$1,705,254	$1.737
Property Taxes and Insurance					$10,961,389	$11.163
TOTAL FIXED OPERATING COSTS					**$19,487,660**	**$19.846**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					**$6,840,748**	**$0.00094**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0.00	2,382.48	1.67	**$0**	**$1,237,357**	**$0.00017**
Chemicals						
MU & WT Chem.(lbs)	0.00	14,194.13	0.27	$0	$1,179,490	$0.00016
MEA Solvent (ton)	0.00	0.00	3,481.91	$0	$0	$0.00000
Activated Carbon (lb)	0.00	0.00	1.63	$0	$0	$0.00000
Corrosion Inhibitor	0.00	0.00	0.00	$0	$0	$0.00000
SCR Catalyst (m3)	w/equip.	0.10	8,938.80	$0	$274,351	$0.00004
Ammonia (19% NH3) (ton)	0.00	8.32	330.00	$0	$851,844	$0.00012
Subtotal Chemicals				**$0**	**$2,305,686**	**$0.00032**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$10,383,791**	**$0.00142**
Fuel (MMBtu)	0	142,252	6.13	**$0**	**$270,539,092**	**$0.03698**

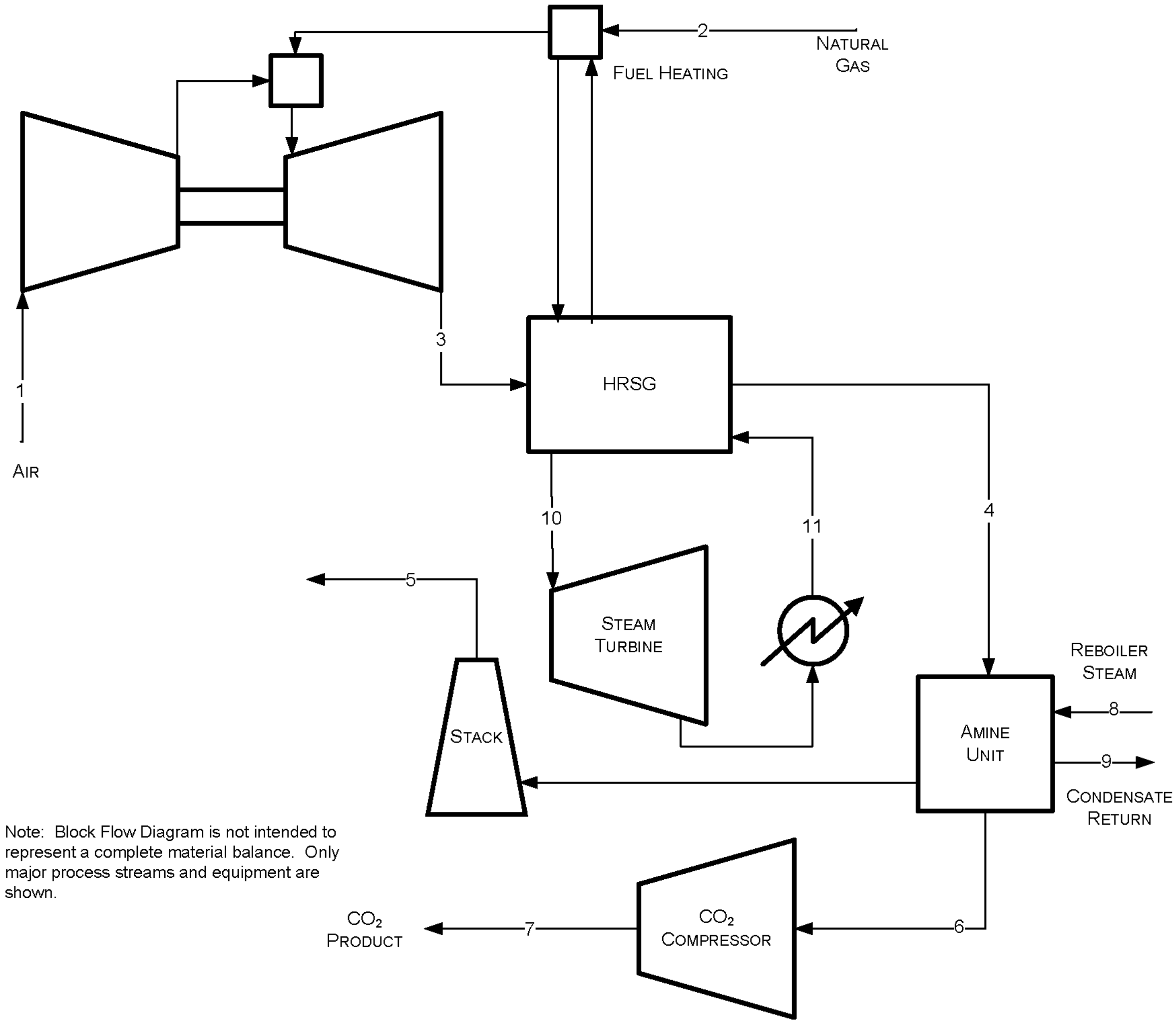
5.2 Case 3b – NGCC with CO_2 Capture Modeling Results

The block flow diagram of the combined cycle with CO_2 capture is shown in Exhibit 5-12. This case also uses the same "J" frame gas turbine model as that of Case 3a with the addition of CO_2 capture at the back end. Exhibit 5-13 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems. The heat required for the solvent (amine) system in the CO_2 capture system is supplied from the Rankine cycle (stream 4).

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,620°C (2,949°F). The flue gas exits the turbine at 636°C (1,177°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine as well as the steam required for the capture process (stream 8). Flue gas exits the HRSG (stream 4) at 110°C (231°F) and passes to the capture system where the CO_2 is captured and compressed (stream 7). Cooling is supplied to the steam turbine condenser via water from the cooling tower.

The gas turbine (Brayton cycle) performance is not impacted due to the CO_2 capture addition. However, the Rankine cycle performance and the overall plant output and efficiency are reduced due to heat integration requirements and increased auxiliary loads for the CO_2 capture process.

Exhibit 5-12 Case 3b – "J" frame turbine with CO_2 capture block flow diagram



Source: NETL

Exhibit 5-13 Case 3b – "J" frame turbine with CO_2 capture stream table

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0000	0.0089	0.0089	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0404	0.0462	0.0051	0.9674	1.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0099	0.0000	0.0867	0.0981	0.0555	0.0326	0.0000	1.0000	1.0000	1.0000	1.0000
N_2	0.7732	0.0160	0.7432	0.7386	0.8108	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.2074	0.0000	0.1209	0.1083	0.1189	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	1.0001	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	149,503	6,898	156,222	156,608	142,821	6,731	6,512	19,035	17,887	31,498	21,781
V-L Flowrate (kg/hr)	4,314,208	119,531	4,433,738	4,433,575	4,013,258	290,499	286,580	342,916	342,916	567,444	392,394
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	25	636	110	35	35	38	152	151	593	32
Pressure (MPa, abs)	0.10	4.14	0.10	0.10	0.10	0.17	15.27	0.51	0.49	16.65	0.00
Enthalpy (kJ/kg)[A]	30.96	52,504.80	868.99	273.31	112.50	91.58	-164.90	2,746.79	635.72	3,547.62	2,383.68
Density (kg/m^3)	1.2	22.2	0.4	0.8	0.9	2.9	653.5	2.7	915.8	47.7	992.9
V-L Molecular Weight	28.857	17.328	28.381	28.310	28.100	43.160	44.010	18.015	18.015	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	329,598	15,208	344,410	345,262	314,865	14,839	14,356	41,964	39,435	69,441	48,019
V-L Flowrate (lb/hr)	9,511,200	263,520	9,774,720	9,774,360	8,847,720	640,440	631,800	756,000	756,000	1,251,000	865,080
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	77	1,177	231	95	95	101	306	304	1,100	90
Pressure (psia)	14.6	600.0	15.2	14.7	14.7	25.0	2,214.7	73.5	71.0	2,414.7	0.7
Enthalpy (Btu/lb)[A]	13.3	22,573.0	373.6	117.5	48.4	39.4	-70.9	1,180.9	273.3	1,525.2	1,024.8
Density (lb/ft^3)	0.076	1.384	0.025	0.052	0.056	0.183	40.800	0.169	57.172	2.977	61.982

A - Reference conditions are 32.02 F & Liquid Water

Note: Total flow rates shown equal the sum for all process trains

5.2.1 Performance Results

The performance results are summarized in Exhibit 5-14 and when compared with Case 3a show that adding carbon capture reduces the efficiency by approximately 7 percentage points (similar results as determined for Case 1). This is based on using an assumed advanced solvent process that has a lower steam requirement for the reboiler of 2,960 kJ/kg CO_2 (1,272 Btu/lb CO_2) or 17 percent lower when compared with previous NETL/DOE system studies (i.e., 3,560 kJ/kg CO_2 (1,530 Btu/lb CO_2)). Additional tables below provide overall energy balance (Exhibit 5-15), water balance (Exhibit 5-16), carbon balance (Exhibit 5-17), and an emissions summary (Exhibit 5-18).

Exhibit 5-14 Case 3b – "J" frame turbine with CO_2 capture plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	689,832	kW_e
Steam Turbine Power	252,117	kW_e
Total	**941,949**	kW_e
Auxiliary Load		
Condensate Pumps	7	kW_e
Boiler Feedwater Pumps	6,790	kW_e
Amine CO_2 Capture System Auxiliaries	19,206	kW_e
CO_2 Compression	26,921	kW_e
Circulating Water Pump	5,290	kW_e
Ground Water Pumps	440	kW_e
Cooling Tower Fans	3,539	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	1,097	kW_e
Steam Turbine Auxiliaries	538	kW_e
Miscellaneous Balance of Plant[2]	3,106	kW_e
Transformer Losses	4,710	kW_e
Total	**71,654**	**kW_e**
Plant Performance		
Net Plant Power	**870,294**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	50.1%	
Net Plant Efficiency (LHV)[1]	55.5%	
Net Plant Heat Rate (HHV)[1]	7,185 (6,810)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	6,485 (6,417)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	119,531 (263,520)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,736,982	kW_t
Thermal Input (LHV)[1]	1,567,848	kW_t
Condenser Duty	886 (840)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	18.5 (4,876)	m^3/min (gpm)
Raw Water Consumption	15.0 (3,967)	m^3/min (gpm)

[1] HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 5-15 Case 3b – "J" frame turbine with CO_2 capture overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	6,253 (5,927)	4.2 (4.0)	0 (0)	6,257 (5,931)
GT Air	0 (0)	133.6 (126.6)	0 (0)	134 (127)
Raw Water Withdrawal	0 (0)	69.4 (65.8)	0 (0)	69 (66)
Auxiliary Power	0 (0)	0.0 (0.0)	258 (244)	258 (244)
TOTAL	**6,253 (5,927)**	**207.2 (196.3)**	**258 (244)**	**6,718 (6,368)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	34.5 (32.7)	0 (0)	34 (33)
Stack Gas	0 (0)	451 (428)	0 (0)	451 (428)
Condenser	0 (0)	883 (837)	0 (0)	883 (837)
CO_2 Product	0 (0)	-47.3 (-44.8)	0 (0)	-47 (-45)
CO_2 Intercoolers	0 (0)	133.2 (126.2)	0 (0)	133 (126)
Amine System Losses	0 (0)	1,111.3 (1,053.3)	0 (0)	1,111 (1,053)
Process Losses*	*0 (0)*	*761 (722)*	*0 (0)*	*761 (722)*
Power	0 (0)	0.0 (0.0)	3,391 (3,214)	3,391 (3,214)
TOTAL	**0 (0)**	**3,327 (3,154)**	**3,391 (3,214)**	**6,718 (6,368)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 5-16 Case 3b – "J" frame turbine with CO_2 capture water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Amine Capture System	0.07 (19)	0.00 (0)	0.07 (19)	0.0 (0)	0.07 (19)
Condenser Makeup	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**	**0.0 (0)**	**0.1 (15)**
BFW Makeup	0.06 (15)	0.0 (0)	0.06 (15)	0.0 (0)	0.0 (0)
Cooling Tower	**20.62 (5,447)**	**2.3 (605)**	**18.33 (4,842)**	**3.4 (909)**	**14.9 (3,934)**
BFW Blowdown	0.00 (0)	0.1 (15)	-0.06 (-15)	0.00 (0)	0.00 (0)
Flue Gas/CO_2 Condensate	0.00 (0)	2.2 (590)	-2.23 (-590)	0.00 (0)	0.00 (0)
Total	**20.7 (5,481)**	**2.29 (605)**	**18.5 (4,876)**	**3.4 (909)**	**15 (3,967)**

Exhibit 5-17 Case 3b – "J" frame turbine with CO_2 capture carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	86,336 (190,337)	Stack Gas	8,700 (19,180)
Air (CO_2)	587 (1,293)	CO_2 Product	78,212 (172,429)
		Convergence Tolerance*	10 (23)
Total	**86,922 (191,631)**	**Total**	**86,922 (191,631)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 5-18 Case 3b – "J" frame turbine with CO_2 capture air emissions

	Kg/GJ ($lb/10^6$ Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.003 (0.007)	134 (148)	0.019 (0.042)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	5.1 (11.9)	237,355 (261,639)	34 (75)
CO_2[1]			37 (81)

[1] CO_2 emissions based on net power instead of gross power

5.2.2 Cost Estimate Results

The turbine costs for this case were estimated based on simulation results and vendor quotes/discussions on the MHI "J" machine design. All other costs for this case were scaled from the costs in the previous cases based on simulation results using the methodology described in the initial NETL study of NGCC systems. [2] All costs are in June 2011 dollars. The cost estimation results for this case are summarized in Exhibit 5-19. The summary and detailed capital cost estimates are shown in Exhibit 5-20 and Exhibit 5-21, respectively. The annual operating cost estimates are shown in Exhibit 5-22.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 5-19 Case 3b – "J" frame turbine with CO_2 capture cost estimation summary

Case	3b
Total Plant Cost (2011$/kW)	**1,101**
Total Overnight Cost (2011$/kW)	**1,343**
Total As-spent Capital (2011$/kW)	**1,448**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	20.03
Fixed O&M	4.86
Variable O&M	2.54
Fuel	41.75
CO_2 T&S total	3.29
COE[1] Total	**72.47**
LCOE[1], total (including T&S)	91.86
Cost[1,2] of CO_2 avoided, $/tonne of CO_2 ($/ton of CO_2)	75.60 (68.58)
Cost[1,2] of CO_2 captured, $/tonne of CO_2 ($/ton of CO_2)	56.02 (50.82)

[1] *Capacity factor assumed to be 85 percent*
[2] *Reference base case is 3a – "J" frame without capture*

Exhibit 5-20 Case 3b – "J" frame turbine with CO_2 capture capital cost estimate summary

	Client:	USDOE/NETL								**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses											
		TOTAL PLANT COST SUMMARY											
	Case:	Case 3b - J-frame CCS											
	Plant Size:	870.3 MW,net		**Estimate Type:**	Conceptual					**Cost Base (Jun)**	2011	($x1000)	
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Sales Tax**	**Bare Erected Cost**	**Eng'g CM H.O.& Fee**	**Contingencies Process**	**Contingencies Project**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**	
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0	
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0	
3	FEEDWATER & MISC. BOP SYSTEMS	$31,795	$7,505	$11,741	$0	$0	**$51,041**	$4,190	$0	$8,959	**$64,191**	**$74**	
4	GASIFIER & ACCESSORIES												
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0	
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0	
5B	CO2 REMOVAL & COMPRESSION	$197,138	$0	$62,174	$0	$0	**$259,311**	$21,646	$44,417	$65,075	**$390,450**	**$449**	
6	COMBUSTION TURBINE/ACCESSORIES												
6.1	Combustion Turbine Generator	$152,231	$0	$8,078	$0	$0	**$160,309**	$13,240	$0	$17,355	**$190,904**	$219	
6.2-6.9	Combustion Turbine Other	$0	$1,126	$1,218	$0	$0	**$2,344**	$196	$0	$508	**$3,049**	$4	
	SUBTOTAL 6	**$152,231**	**$1,126**	**$9,296**	**$0**	**$0**	**$162,653**	**$13,437**	**$0**	**$17,863**	**$193,952**	**$223**	
7	HRSG, DUCTING & STACK												
7.1	Heat Recovery Steam Generator	$42,011	$0	$7,391	$0	$0	**$49,401**	$4,102	$0	$5,350	**$58,854**	$68	
7.2-7.9	SCR System, Ductwork and Stack	$2,803	$1,756	$2,185	$0	$0	**$6,744**	$564	$0	$1,157	**$8,465**	$10	
	SUBTOTAL 7	**$44,814**	**$1,756**	**$9,576**	**$0**	**$0**	**$56,146**	**$4,667**	**$0**	**$6,507**	**$67,319**	**$77**	
8	STEAM TURBINE GENERATOR												
8.1	Steam TG & Accessories	$38,879	$0	$6,326	$0	$0	**$45,205**	$3,568	$0	$4,877	**$53,651**	$62	
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$14,820	$1,073	$8,642	$0	$0	**$24,535**	$1,788	$0	$3,872	**$30,194**	$35	
	SUBTOTAL 8	**$53,699**	**$1,073**	**$14,968**	**$0**	**$0**	**$69,739**	**$5,356**	**$0**	**$8,749**	**$83,844**	**$96**	
9	COOLING WATER SYSTEM	$8,257	$8,693	$8,112	$0	$0	**$25,062**	$2,016	$0	$3,942	**$31,020**	$36	
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0	
11	ACCESSORY ELECTRIC PLANT	$30,828	$10,129	$20,861	$0	$0	**$61,818**	$4,675	$0	$7,241	**$73,734**	$85	
12	INSTRUMENTATION & CONTROL	$9,450	$1,069	$8,012	$0	$0	**$18,531**	$1,521	$927	$2,408	**$23,386**	$27	
13	IMPROVEMENTS TO SITE	$2,578	$1,400	$7,299	$0	$0	**$11,277**	$999	$0	$2,455	**$14,732**	$17	
14	BUILDINGS & STRUCTURES	$0	$6,132	$6,407	$0	$0	**$12,539**	$997	$0	$2,030	**$15,566**	$18	
	TOTAL COST	**$530,789**	**$38,884**	**$158,445**	**$0**	**$0**	**$728,117**	**$59,503**	**$45,344**	**$125,231**	**$958,195**	**$1,101**	

Exhibit 5-21 Case 3b – "J" frame turbine with CO_2 capture capital cost estimate detail

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 3b - J-frame CCS
Plant Size: 870.3 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,802	$3,937	$3,215	$0	$0	$10,954	$882	$0	$1,775	$13,611	$16
3.2	Water Makeup & Pretreating	$2,987	$309	$1,533	$0	$0	$4,829	$399	$0	$1,046	$6,274	$7
3.3	Other Feedwater Subsystems	$1,781	$589	$492	$0	$0	$2,862	$221	$0	$462	$3,545	$4
3.4	Service Water Systems	$361	$719	$2,318	$0	$0	$3,398	$289	$0	$737	$4,424	$5
3.5	Other Boiler Plant Systems	$2,431	$908	$2,089	$0	$0	$5,428	$442	$0	$880	$6,750	$8
3.6	Natural Gas, incl. pipeline	$17,803	$831	$719	$0	$0	$19,352	$1,596	$0	$3,142	$24,090	$28
3.7	Waste Treatment Equipment	$1,043	$0	$604	$0	$0	$1,647	$142	$0	$358	$2,147	$2
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,588	$212	$771	$0	$0	$2,571	$220	$0	$558	$3,349	$4
	SUBTOTAL 3.	**$31,795**	**$7,505**	**$11,741**	**$0**	**$0**	**$51,041**	**$4,190**	**$0**	**$8,959**	**$64,191**	**$74**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$170,660	$0	$51,427	$0	$0	$222,087	$18,530	$44,417	$57,007	$342,041	$393
5B.2	CO2 Compression & Drying	$26,477	$0	$10,747	$0	$0	$37,224	$3,116	$0	$8,068	$48,409	$56
	SUBTOTAL 5.	**$197,138**	**$0**	**$62,174**	**$0**	**$0**	**$259,311**	**$21,646**	**$44,417**	**$65,075**	**$390,450**	**$449**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	**$152,231**	**$0**	**$8,078**	$0	$0	$160,309	$13,240	$0	$17,355	$190,904	$219
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$1,126	$1,218	$0	$0	$2,344	$196	$0	$508	$3,049	$4
	SUBTOTAL 6.	**$152,231**	**$1,126**	**$9,296**	**$0**	**$0**	**$162,653**	**$13,437**	**$0**	**$17,863**	**$193,952**	**$223**

Exhibit 5-21 Case 3b – "J" frame turbine with CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 3b - J-frame CCS
Plant Size: 870.3 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$42,011	$0	$7,391	$0	$0	$49,401	$4,102	$0	$5,350	$58,854	$68
7.2	HRSG Accessories	$2,803	$1,177	$1,642	$0	$0	$5,623	$471	$0	$914	$7,008	$8
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$579	$543	$0	$0	$1,121	$94	$0	$243	$1,458	$2
	SUBTOTAL 7.	**$44,814**	**$1,756**	**$9,576**	**$0**	**$0**	**$56,146**	**$4,667**	**$0**	**$6,507**	**$67,319**	**$77**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$38,879	$0	$6,326	$0	$0	$45,205	$3,568	$0	$4,877	$53,651	$62
8.2	Turbine Plant Auxiliaries	$250	$0	$557	$0	$0	$808	$69	$0	$88	$964	$1
8.3	Condenser & Auxiliaries	$2,167	$0	$1,287	$0	$0	$3,454	$291	$0	$374	$4,119	$5
8.4	Steam Piping	$12,402	$0	$5,027	$0	$0	$17,429	$1,188	$0	$2,792	$21,409	$25
8.9	TG Foundations	$0	$1,073	$1,772	$0	$0	$2,845	$240	$0	$617	$3,702	$4
	SUBTOTAL 8.	**$53,699**	**$1,073**	**$14,968**	**$0**	**$0**	**$69,739**	**$5,356**	**$0**	**$8,749**	**$83,844**	**$96**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$4,897	$0	$1,487	$0	$0	$6,384	$533	$0	$692	$7,608	$9
9.2	Circulating Water Pumps	$2,370	$0	$155	$0	$0	$2,525	$192	$0	$272	$2,989	$3
9.3	Circ.Water System Auxiliaries	$184	$0	$24	$0	$0	$209	$17	$0	$23	$249	$0
9.4	Circ.Water Piping	$0	$5,727	$1,297	$0	$0	$7,023	$526	$0	$1,132	$8,682	$10
9.5	Make-up Water System	$437	$0	$562	$0	$0	$999	$83	$0	$162	$1,244	$1
9.6	Component Cooling Water Sys	$368	$375	$283	$0	$0	$1,026	$82	$0	$166	$1,274	$1
9.9	Circ.Water System Foundations	$0	$2,592	$4,304	$0	$0	$6,896	$582	$0	$1,496	$8,973	$10
	SUBTOTAL 9.	**$8,257**	**$8,693**	**$8,112**	**$0**	**$0**	**$25,062**	**$2,016**	**$0**	**$3,942**	**$31,020**	**$36**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$9,344	$0	$5,527	$0	$0	$14,871	$1,221	$0	$1,207	$17,299	$20
11.2	Station Service Equipment	$3,283	$0	$282	$0	$0	$3,565	$294	$0	$289	$4,148	$5
11.3	Switchgear & Motor Control	$4,040	$0	$702	$0	$0	$4,742	$393	$0	$513	$5,648	$6
11.4	Conduit & Cable Tray	$0	$2,111	$6,082	$0	$0	$8,193	$682	$0	$1,331	$10,207	$12
11.5	Wire & Cable	$0	$6,784	$3,858	$0	$0	$10,642	$640	$0	$1,692	$12,974	$15
11.6	Protective Equipment	$0	$1,019	$3,536	$0	$0	$4,555	$392	$0	$495	$5,442	$6
11.7	Standby Equipment	$154	$0	$144	$0	$0	$298	$25	$0	$32	$355	$0
11.8	Main Power Transformers	$14,007	$0	$183	$0	$0	$14,190	$963	$0	$1,515	$16,669	$19
11.9	Electrical Foundations	$0	$215	$547	$0	$0	$762	$65	$0	$165	$991	$1
	SUBTOTAL 11.	**$30,828**	**$10,129**	**$20,861**	**$0**	**$0**	**$61,818**	**$4,675**	**$0**	**$7,241**	**$73,734**	**$85**

Exhibit 5-21 Case 3b – "J" frame turbine with CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 3b - J-frame CCS
Plant Size: 870.3 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,202	$0	$765	$0	$0	$1,967	$165	$98	$335	$2,565	$3
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$359	$0	$220	$0	$0	$579	$49	$29	$98	$754	$1
12.7	Computer & Accessories	$5,747	$0	$175	$0	$0	$5,922	$486	$296	$670	$7,375	$8
12.8	Instrument Wiring & Tubing	$0	$1,069	$1,892	$0	$0	$2,961	$213	$148	$498	$3,820	$4
12.9	Other I & C Equipment	$2,142	$0	$4,960	$0	$0	$7,103	$608	$355	$807	$8,872	$10
	SUBTOTAL 12.	**$9,450**	**$1,069**	**$8,012**	**$0**	**$0**	**$18,531**	**$1,521**	**$927**	**$2,408**	**$23,386**	**$27**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$138	$2,926	$0	$0	$3,064	$268	$0	$666	$3,998	$5
13.2	Site Improvements	$0	$1,263	$1,668	$0	$0	$2,931	$261	$0	$638	$3,830	$4
13.3	Site Facilities	$2,578	$0	$2,705	$0	$0	$5,283	$471	$0	$1,151	$6,904	$8
	SUBTOTAL 13.	**$2,578**	**$1,400**	**$7,299**	**$0**	**$0**	**$11,277**	**$999**	**$0**	**$2,455**	**$14,732**	**$17**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$396	$209	$0	$0	$605	$47	$0	$98	$749	$1
14.2	Steam Turbine Building	$0	$2,695	$3,586	$0	$0	$6,281	$505	$0	$1,018	$7,804	$9
14.3	Administration Building	$0	$674	$457	$0	$0	$1,131	$88	$0	$183	$1,402	$2
14.4	Circulation Water Pumphouse	$0	$219	$108	$0	$0	$327	$25	$0	$53	$405	$0
14.5	Water Treatment Buildings	$0	$630	$574	$0	$0	$1,204	$95	$0	$195	$1,494	$2
14.6	Machine Shop	$0	$585	$374	$0	$0	$959	$74	$0	$155	$1,188	$1
14.7	Warehouse	$0	$378	$228	$0	$0	$605	$47	$0	$98	$750	$1
14.8	Other Buildings & Structures	$0	$113	$82	$0	$0	$195	$15	$0	$32	$242	$0
14.9	Waste Treating Building & Str.	$0	$442	$790	$0	$0	$1,232	$100	$0	$200	$1,533	$2
	SUBTOTAL 14.	**$0**	**$6,132**	**$6,407**	**$0**	**$0**	**$12,539**	**$997**	**$0**	**$2,030**	**$15,566**	**$18**
	TOTAL COST	**$530,789**	**$38,884**	**$158,445**	**$0**	**$0**	**$728,117**	**$59,503**	**$45,344**	**$125,231**	**$958,195**	**$1,101**

Exhibit 5-21 Case 3b – "J" frame turbine with CO_2 capture capital cost estimate detail (continued)

	Client:	USDOE/NETL							**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 3b - J-frame CCS										
	Plant Size:	870.3 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)	
Acct		**Equipment**	**Material**	**Labor**		**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**		
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Cost**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**	
	TOTAL COST	**$530,789**	**$38,884**	**$158,445**	**$0**	**$728,117**	**$59,503**	**$45,344**	**$125,231**	**$958,195**	**$1,101**	
	Owner's Costs											
	Preproduction Costs											
	6 Months All Labor									$6,164	$7	
	1 Month Maintenance Materials									$1,029	$1	
	1 Month Non-fuel Consumables									$585	$1	
	1 Month Waste Disposal									$0	$0	
	25% of 1 Months Fuel Cost at 100% CF									$6,630	$8	
	2% of TPC									$19,164	$22	
	Total									**$33,573**	**$39**	
	Inventory Capital											
	60 day supply of consumables at 100% CF									$813	$1	
	0.5% of TPC (spare parts)									$4,791	$6	
	Total									**$5,604**	**$6**	
	Initial Cost for Catalyst and Chemicals									$1,962	$2	
	Land									$300	$0	
	Other Owner's Costs									$143,729	$165	
	Financing Costs									$25,871	$30	
	Total Overnight Costs (TOC)									**$1,169,235**	**$1,343**	
	TASC Multiplier								(IOU, high-risk, 33 year)	1.078		
	Total As-Spent Cost (TASC)									**$1,260,435**	**$1,448**	

Exhibit 5-22 Case 3b – "J" frame turbine with CO_2 capture operating cost estimate

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun)	2011
Case 3b - J-frame CCS					Heat Rate-net (Btu/kWh):	6,810
					MWe-net:	870
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	3.3		3.3			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	6.3		6.3			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$2,861,816	$3.288
Maintenance Labor Cost					$7,000,304	$8.044
Administrative & Support Labor					$2,465,530	$2.833
Property Taxes and Insurance					$19,163,900	$22.020
TOTAL FIXED OPERATING COSTS					**$31,491,551**	**$36.185**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					$10,500,457	**$0.00162**
Consumables	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost		
Water (/1000 gallons)	0.00	3,510.43	1.67	**$0**	**$1,823,167**	**$0.00028**
Chemicals						
MU & WT Chem.(lbs)	0.00	20,914.14	0.27	$0	$1,737,904	$0.00027
MEA Solvent (ton)	542.18	0.76	3,481.91	$1,887,829	$822,516	$0.00013
Activated Carbon (lb)	0.00	909.53	1.63	$0	$458,613	$0.00007
Corrosion Inhibitor	0.00	0.00	0.00	$74,278	$3,537	$0.00000
SCR Catalyst (m3)	w/equip.	0.10	8,938.80	$0	$274,351	$0.00004
Ammonia (19% NH3) (ton)	0.00	8.32	330.00	$0	$851,844	$0.00013
Subtotal Chemicals				**$1,962,108**	**$4,148,766**	**$0.00064**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$1,962,108**	**$16,472,389**	**$0.00254**
Fuel (MMBtu)	0	142,241	6.13	**$0**	**$270,518,341**	**$0.04172**

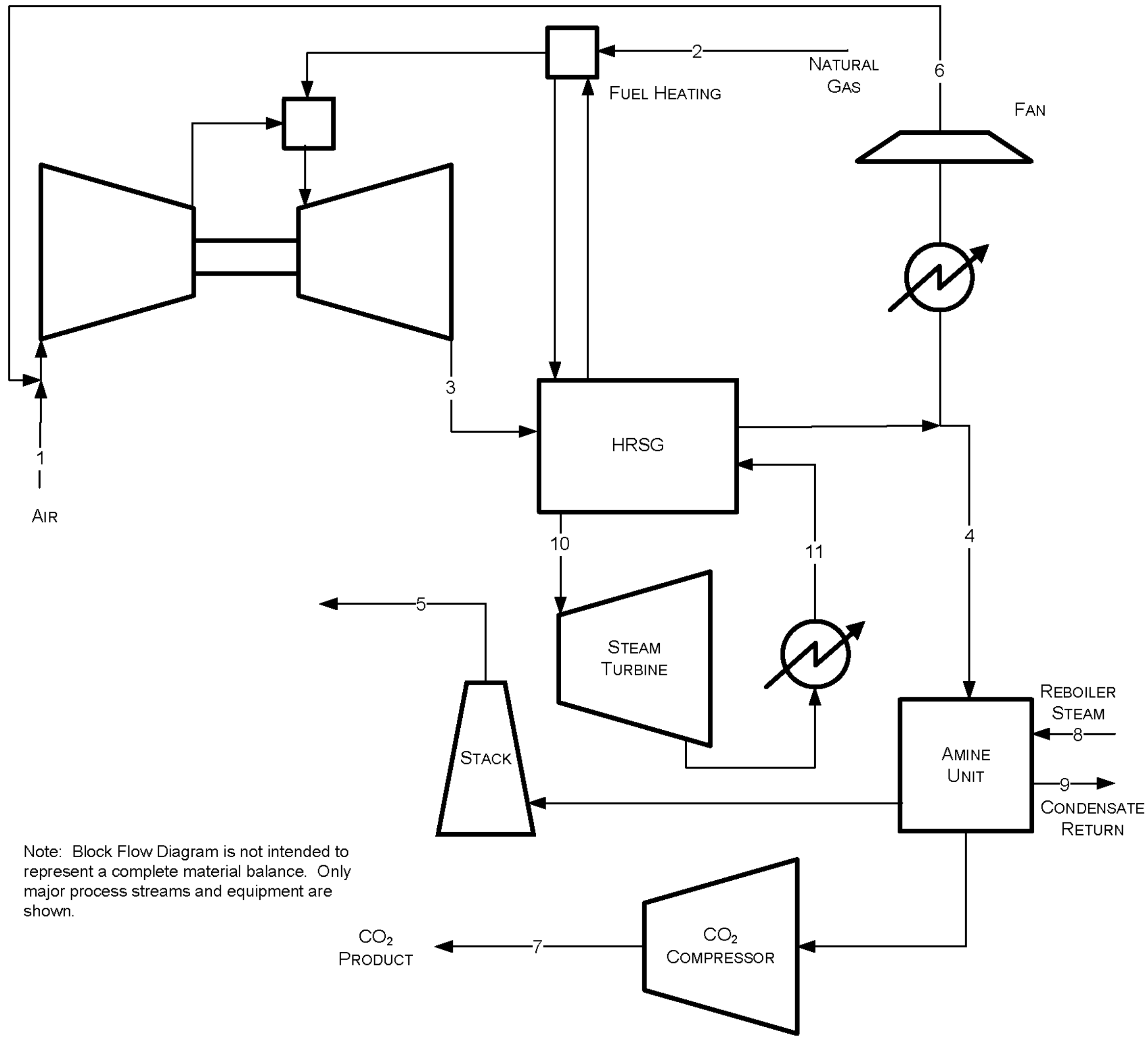
5.3 Case 3c – NGCC with CO_2 Capture and EGR Modeling Results

The block flow diagram of the combined cycle with CO_2 capture and EGR is shown in Exhibit 5-23. This case also uses the same "J" frame gas turbine model as that of Case 3a with the addition of EGR and CO_2 capture at the back end. Exhibit 5-24 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems. The heat required for the solvent (amine) system in the CO_2 capture system is supplied from the Rankine cycle (stream 4) similar to Case 3b.

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,617°C (2,944°F). The flue gas exits the turbine at 644°C (1,191°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine as well as the steam required for the capture process (stream 8). Flue gas exits the HRSG (stream 4) at 107°C (224°F). A portion of the stream (stream 6) is recycled back to the air inlet and the remainder (stream 4) passes to the capture system where the CO_2 is captured and compressed (stream 7). Cooling is supplied to the steam turbine condenser via water from the cooling tower.

The gas turbine (Brayton cycle) performance and exhaust characteristics are impacted due to addition of the EGR. Of particular interest is that the CO_2 composition at gas turbine exhaust increases from 4.6 percent in the capture only case (Case 3b) to 7.2 percent in this capture with EGR case. The O_2 composition concurrently decreases from 10.8 percent in the capture only case (Case 3b) to 6.0 percent in this capture with EGR. The higher concentration of the CO_2 in the exhaust gas stream reduces the energy consumption of the CO_2 capture system. Because of this, the EGR case provides a better output and efficiency compared to the capture case without EGR (Case 3b). However, the overall plant output and efficiency are reduced compared to the no CO_2 capture case (Case 3a) due to heat integration requirements and increased auxiliary loads for the EGR and CO_2 capture process

Exhibit 5-23 Case 3c – "J" frame turbine with CO_2 capture and EGR block flow diagram



Source: NETL

Exhibit 5-24 Case 3c – "J" frame turbine with CO_2 capture and EGR stream table

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0093	0.0000	0.0090	0.0090	0.0103	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0719	0.0719	0.0082	0.0770	1.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0101	0.0000	0.1116	0.1116	0.0555	0.0480	0.0000	1.0000	1.0000	1.0000	1.0000
N_2	0.7729	0.0160	0.7472	0.7472	0.8568	0.8007	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.2074	0.0000	0.0604	0.0604	0.0692	0.0647	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)	97,931	6,971	156,072	101,449	88,484	50,983	6,564	18,068	18,068	32,839	23,766
V-L Flowrate (kg/hr)	2,826,280	120,804	4,432,432	2,881,146	2,476,669	1,485,642	288,866	325,509	325,509	591,611	428,155
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	38	644	107	35	33	38	292	137	593	32
Pressure (MPa, abs)	0.10	4.14	0.10	0.10	0.10	0.10	15.17	0.33	0.33	16.65	0.00
Enthalpy (kJ/kg)^A	0.92	47,245.71	351.69	457.29	45.73	123.12	411.47	3,052.18	574.75	3,547.62	2,393.22
Density (kg/m^3)	1.2	27.7	0.4	0.9	1.1	1.2	796.4	2.7	915.8	47.7	992.9
V-L Molecular Weight	28.860	17.330	28.400	28.400	27.990	29.140	44.010	18.015	18.015	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	215,900	15,368	344,079	223,656	195,074	112,398	14,470	39,834	39,834	72,399	52,396
V-L Flowrate (lb/hr)	6,230,880	266,328	9,771,840	6,351,840	5,460,120	3,275,280	636,840	717,624	717,624	1,304,280	943,920
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	100	1,191	224	95	92	101	557	278	1,100	90
Pressure (psia)	14.7	600.0	15.2	14.7	14.7	14.7	2,200.0	47.6	47.6	2,414.7	0.7
Enthalpy (Btu/lb)^A	13.0	19.9	302.2	37.6	4.5	3.6	-97.1	1,312.2	247.1	1,525.2	1,028.9
Density (lb/ft^3)	0.076	1.731	0.024	0.057	0.069	0.072	49.720	0.169	57.172	2.977	61.982

Note: Total flow rates shown equal the sum for all process trains

5.3.1 Performance Results

The performance results are summarized in Exhibit 5-25 and when compared with Case 3b show that adding exhaust gas recycle increases the efficiency by approximately 0.6 percentage points. This is due to lowering the steam requirement for the reboiler slightly (to 2,790 kJ/kg CO_2 (1,200 Btu/lb CO_2) from the 2,960 kJ/kg CO_2 (1,272 Btu/lb CO_2) used in Case 3b), based on the CO_2 concentration increasing and the oxygen concentration decreasing for the exhaust gas entering the solvent recovery section. An additional improvement would be expected if the exhaust gas recycle was increased from the 35 percent used to 50 percent. This was not explored in the current study since it was determined based on information from GE that 35 percent was a limit above which the gas turbine's combustor would need major redesign. Additional tables below provide overall energy balance (Exhibit 5-26), water balance (Exhibit 5-27), carbon balance (Exhibit 5-28), and an emissions summary (Exhibit 5-29).

Exhibit 5-25 Case 3c – "J" frame turbine with CO_2 capture and EGR plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	694,394	kW_e
Steam Turbine Power	263,964	kW_e
Total	**958,358**	kW_e
Auxiliary Load		
Condensate Pumps	255	kW_e
Boiler Feedwater Pumps	6,872	kW_e
Exhaust Gas Recycle Fan	444	kW_e
Amine CO_2 Capture System Auxiliaries	15,684	kW_e
CO_2 Compression	26,766	kW_e
EGR Coolant Pump	414	kW_e
Circulating Water Pump	5,857	kW_e
Ground Water Pumps	480	kW_e
Cooling Tower Fans	3,751	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	1,097	kW_e
Steam Turbine Auxiliaries	669	kW_e
Miscellaneous Balance of Plant[2]	4,523	kW_e
Transformer Losses	3,000	kW_e
Total	**69,822**	**kW_e**
Plant Performance		
Net Plant Power	**888,536**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	50.6%	
Net Plant Efficiency (LHV)[1]	56.1%	
Net Plant Heat Rate (HHV)[1]	7,112 (6,741)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	6,420 (6,085)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	120,804 (266,328)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,755,410	kW_t
Thermal Input (LHV)[1]	1,584,459	kW_t
Condenser Duty	971 (920)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	19.9 (5,268)	m^3/min (gpm)
Raw Water Consumption	14.7 (3,889)	m^3/min (gpm)

[1] HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 5-26 Case 3c – "J" frame turbine with CO_2 capture and EGR overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	6,319 (5,990)	4.2 (4.0)	0 (0)	6,324 (5,994)
GT Air	0 (0)	85.4 (81.0)	0 (0)	85 (81)
Raw Water Withdrawal	0 (0)	75.0 (71.1)	0 (0)	75 (71)
Auxiliary Power	0 (0)	0.0 (0.0)	251 (238)	251 (238)
TOTAL	**6,319 (5,990)**	**164.6 (156.1)**	**251 (238)**	**6,735 (6,384)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	38.2 (36.2)	0 (0)	38 (36)
Stack Gas	0 (0)	26 (25)	0 (0)	26 (25)
Condenser	0 (0)	967 (916)	0 (0)	967 (916)
CO_2 Product	0 (0)	-65.2 (-61.8)	0 (0)	65 (62)
CO_2 Intercoolers	0 (0)	420.5 (398.6)	0 (0)	421 (399)
EGR Cooling	0 (0)	34.6 (32.8)	0 (0)	35 (33)
Amine System Losses	0 (0)	1,146.3 (1,086.5)	0 (0)	1,146 (1,086)
Process Losses*	*0 (0)*	*718 (681)*	*0 (0)*	*718 (681)*
Power	0 (0)	0.0 (0.0)	3,450 (3,270)	3,450 (3,270)
TOTAL	**0 (0)**	**3,285 (3,114)**	**3,450 (3,270)**	**6,735 (6,384)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 5-27 Case 3c – "J" frame turbine with CO_2 capture and EGR water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Amine Capture System	0.07 (19)	0.00 (0)	0.07 (19)	0.0 (0)	0.07 (19)
Condenser Makeup	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**
BFW Makeup	0.06 (15)	0.0 (0)	0.06 (15)	0.0 (0)	0.0 (0)
Cooling Tower	**22.9 (6,046)**	**3.1 (812)**	**19.8 (5,234)**	**5.2 (1,380)**	**14.6 (3,855)**
BFW Blowdown	0.00 (0)	0.06 (15)	-0.06 (-15)	0.0 (0)	0.0 (0)
EGR Condensate	0.00 (0)	1.1 (288)	-1.1 (-288)	0.0 (0)	0.0 (0)
Flue Gas/CO_2 Condensate	0.00 (0)	1.9 (509)	-1.9 (-509)	0.0 (0)	0.0 (0)
Total	**23.0 (6,079)**	**3.1 (812)**	**32.87 (5,268)**	**5.2 (1,380)**	**14.7 (3,889)**

Exhibit 5-28 Case 3c – "J" frame turbine with CO_2 capture and EGR carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	87,243 (192,338)	Stack Gas	8,762 (19,316)
Air (CO_2)	353 (778)	CO_2 Product	78,836 (173,803)
		Convergence Tolerance*	-2 (-3)
Total	**87,596 (193,116)**	**Total**	**87,596 (193,116)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 5-29 Case 3c – "J" frame turbine with CO_2 capture and EGR air emissions

	Kg/GJ ($lb/10^6$ Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.002 (0.004)	83 (92)	0.012 (0.026)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	5.1 (11.8)	239,043 (263,499)	33 (74)
CO_2[1]			36 (80)

[1] CO_2 emissions based on net power instead of gross power

5.3.2 Cost Estimate Results

The turbine costs for this case were estimated based on simulation results and vendor quotes/discussions on the MHI "J" machine design. All other costs for this case were scaled from the costs in the previous cases based on simulation results using the methodology described in the initial NETL study of NGCC systems. [2] All costs are in June 2011 dollars. The cost estimation results for this case are summarized in Exhibit 5-30. The summary and detailed capital cost estimates are shown in Exhibit 5-31 and Exhibit 5-32, respectively. The annual operating cost estimates are shown in Exhibit 5-33.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 5-30 Case 3c – "J" frame turbine with CO_2 capture and EGR cost estimation summary

Case	3c
Total Plant Cost (2011$/kW)	**1,024**
Total Overnight Cost (2011$/kW)	**1,251**
Total As-spent Capital (2011$/kW)	**1,349**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	18.65
Fixed O&M	4.64
Variable O&M	2.56
Fuel	41.32
CO_2 T&S total	3.25
COE[1] Total	**70.42**
LCOE[1], total (including T&S)	89.26
Cost[1,2] of CO_2 avoided, $/tonne of CO_2 ($/ton of CO_2)	68.35 (62.01)
Cost[1,2] of CO_2 captured, $/tonne of CO_2 ($/ton of CO_2)	50.56 (45.87)

[1] Capacity factor assumed to be 85 percent
[2] Reference base case is 3a – "J" frame without capture

Exhibit 5-31 Case 3c – "J" frame turbine with CO_2 capture and EGR capital cost estimate summary

	Client:	USDOE/NETL								**Report Date:**	2012-Apr-04	
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 3c - J-frame CCS EGR										
	Plant Size:	888.5 MW,net		**Estimate Type:**	Conceptual					**Cost Base (Jun)** 2011	($x1000)	
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Sales Tax**	**Bare Erected Cost**	**Eng'g CM H.O.& Fee**	**Contingencies Process**	**Contingencies Project**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$32,371	$7,762	$12,239	$0	$0	**$52,372**	$4,299	$0	$9,207	**$65,878**	**$74**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0
5A	GAS CLEANUP & PIPING	$0	$9,774	$6,175	$0	$0	**$15,949**	$1,244	$0	$3,439	**$20,631**	$23
5B	CO2 REMOVAL & COMPRESSION	$153,130	$0	$48,979	$0	$0	**$202,108**	$16,874	$32,962	$50,389	**$302,333**	**$340**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$159,842	$0	$8,018	$0	$0	**$167,861**	$14,315	$0	$18,763	**$200,938**	$226
6.2-6.9	Combustion Turbine Other	$0	$1,131	$1,223	$0	$0	**$2,353**	$197	$0	$510	**$3,060**	$3
	SUBTOTAL 6	**$159,842**	**$1,131**	**$9,241**	**$0**	**$0**	**$170,214**	**$14,511**	**$0**	**$19,273**	**$203,998**	**$230**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$42,975	$0	$7,560	$0	$0	**$50,536**	$4,196	$0	$5,473	**$60,205**	$68
7.2-7.9	SCR System, Ductwork and Stack	$2,792	$1,768	$2,194	$0	$0	**$6,754**	$565	$0	$1,160	**$8,480**	$10
	SUBTOTAL 7	**$45,767**	**$1,768**	**$9,754**	**$0**	**$0**	**$57,290**	**$4,762**	**$0**	**$6,634**	**$68,685**	**$77**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$40,339	$0	$6,563	$0	$0	**$46,902**	$3,702	$0	$5,060	**$55,664**	$63
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$15,286	$1,110	$9,113	$0	$0	**$25,509**	$1,863	$0	$4,010	**$31,382**	$35
	SUBTOTAL 8	**$55,625**	**$1,110**	**$15,676**	**$0**	**$0**	**$72,411**	**$5,565**	**$0**	**$9,071**	**$87,046**	**$98**
9	COOLING WATER SYSTEM	$8,866	$9,262	$8,660	$0	$0	**$26,788**	$2,155	$0	$4,209	**$33,152**	$37
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$31,306	$10,034	$20,798	$0	$0	**$62,137**	$4,697	$0	$7,262	**$74,096**	$83
12	INSTRUMENTATION & CONTROL	$9,486	$1,073	$8,042	$0	$0	**$18,601**	$1,526	$930	$2,417	**$23,475**	$26
13	IMPROVEMENTS TO SITE	$2,589	$1,406	$7,329	$0	$0	**$11,325**	$1,003	$0	$2,466	**$14,794**	$17
14	BUILDINGS & STRUCTURES	$0	$6,252	$6,548	$0	$0	**$12,800**	$1,018	$0	$2,073	**$15,890**	$18
	TOTAL COST	**$498,982**	**$49,572**	**$153,441**	**$0**	**$0**	**$701,995**	**$57,653**	**$33,892**	**$116,438**	**$909,979**	**$1,024**

Exhibit 5-32 Case 3c – "J" frame turbine with CO_2 capture and EGR capital cost estimate detail

	Client:	USDOE/NETL							**Report Date:**	2012-Apr-04		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 3c - J-frame CCS EGR										
	Plant Size:	888.5 MW,net		**Estimate Type:**	Conceptual				**Cost Base (Jun)**	2011	($x1000)	
Acct		**Equipment**	**Material**	**Labor**		**Sales**	**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**	
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Tax**	**Cost**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,918	$4,057	$3,313	$0	$0	$11,288	$909	$0	$1,829	$14,026	$16
3.2	Water Makeup & Pretreating	$3,157	$326	$1,620	$0	$0	$5,103	$421	$0	$1,105	$6,629	$7
3.3	Other Feedwater Subsystems	$1,835	$607	$507	$0	$0	$2,949	$228	$0	$476	$3,653	$4
3.4	Service Water Systems	$381	$760	$2,449	$0	$0	$3,590	$305	$0	$779	$4,675	$5
3.5	Other Boiler Plant Systems	$2,568	$960	$2,207	$0	$0	$5,735	$467	$0	$930	$7,133	$8
3.6	Natural Gas, incl. pipeline	$17,807	$839	$726	$0	$0	$19,371	$1,597	$0	$3,145	$24,114	$27
3.7	Waste Treatment Equipment	$1,102	$0	$638	$0	$0	$1,741	$150	$0	$378	$2,269	$3
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,603	$214	$779	$0	$0	$2,595	$222	$0	$563	$3,380	$4
	SUBTOTAL 3.	**$32,371**	**$7,762**	**$12,239**	**$0**	**$0**	**$52,372**	**$4,299**	**$0**	**$9,207**	**$65,878**	**$74**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$9,774	$6,175	$0	$0	$15,949	$1,244	$0	$3,439	$20,631	$23
	SUBTOTAL 5.	**$0**	**$9,774**	**$6,175**	**$0**	**$0**	**$15,949**	**$1,244**	**$0**	**$3,439**	**$20,631**	**$23**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$126,647	$0	$38,164	$0	$0	$164,810	$13,751	$32,962	$42,305	$253,828	$286
5B.2	CO2 Compression & Drying	$26,483	$0	$10,815	$0	$0	$37,298	$3,123	$0	$8,084	$48,505	$55
	SUBTOTAL 5.	**$153,130**	**$0**	**$48,979**	**$0**	**$0**	**$202,108**	**$16,874**	**$32,962**	**$50,389**	**$302,333**	**$340**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	**$159,842**	**$0**	**$8,018**	$0	$0	$167,861	$14,315	$0	$18,763	$200,938	$226
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$1,131	$1,223	$0	$0	$2,353	$197	$0	$510	$3,060	$3
	SUBTOTAL 6.	**$159,842**	**$1,131**	**$9,241**	**$0**	**$0**	**$170,214**	**$14,511**	**$0**	**$19,273**	**$203,998**	**$230**

Exhibit 5-32 Case 3c – "J" frame turbine with CO_2 capture and EGR capital cost estimate detail (continued)

	Client:	USDOE/NETL								**Report Date:**	2012-Apr-04		
	Project:	Costing Support for NGCC with CCS Analyses											
		TOTAL PLANT COST SUMMARY											
	Case:	Case 3c - J-frame CCS EGR											
	Plant Size:	888.5 MW,net		**Estimate Type:**	Conceptual					**Cost Base (Jun)**	2011	($x1000)	
Acct No.	**Item/Description**	**Equipment Cost**	**Material Cost**	**Labor Direct**	**Labor Indirect**	**Sales Tax**	**Bare Erected Cost**	**Eng'g CM H.O.& Fee**	**Contingencies Process**	**Contingencies Project**	**TOTAL PLANT COST $**	**TOTAL PLANT COST $/kW**	
7	HRSG, DUCTING & STACK												
7.1	Heat Recovery Steam Generator	$42,975	$0	$7,560	$0	$0	$50,536	$4,196	$0	$5,473	$60,205	$68	
7.2	HRSG Accessories	$2,792	$1,173	$1,635	$0	$0	$5,600	$469	$0	$910	$6,979	$8	
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	
7.9	HRSG,Duct & Stack Foundations	$0	$596	$559	$0	$0	$1,155	$96	$0	$250	$1,501	$2	
	SUBTOTAL 7.	**$45,767**	**$1,768**	**$9,754**	**$0**	**$0**	**$57,290**	**$4,762**	**$0**	**$6,634**	**$68,685**	**$77**	
8	STEAM TURBINE GENERATOR												
8.1	Steam TG & Accessories	$40,339	$0	$6,563	$0	$0	$46,902	$3,702	$0	$5,060	$55,664	$63	
8.2	Turbine Plant Auxiliaries	$259	$0	$576	$0	$0	$835	$72	$0	$91	$997	$1	
8.3	Condenser & Auxiliaries	$2,312	$0	$1,552	$0	$0	$3,864	$325	$0	$419	$4,608	$5	
8.4	Steam Piping	$12,715	$0	$5,153	$0	$0	$17,868	$1,218	$0	$2,863	$21,949	$25	
8.9	TG Foundations	$0	$1,110	$1,832	$0	$0	$2,942	$248	$0	$638	$3,828	$4	
	SUBTOTAL 8.	**$55,625**	**$1,110**	**$15,676**	**$0**	**$0**	**$72,411**	**$5,565**	**$0**	**$9,071**	**$87,046**	**$98**	
9	COOLING WATER SYSTEM												
9.1	Cooling Towers	$5,267	$0	$1,606	$0	$0	$6,873	$574	$0	$745	$8,191	$9	
9.2	Circulating Water Pumps	$2,552	$0	$172	$0	$0	$2,724	$208	$0	$293	$3,225	$4	
9.3	Circ.Water System Auxiliaries	$197	$0	$26	$0	$0	$223	$18	$0	$24	$265	$0	
9.4	Circ.Water Piping	$0	$6,102	$1,381	$0	$0	$7,483	$561	$0	$1,207	$9,251	$10	
9.5	Make-up Water System	$458	$0	$589	$0	$0	$1,047	$87	$0	$170	$1,304	$1	
9.6	Component Cooling Water Sys	$392	$399	$301	$0	$0	$1,093	$87	$0	$177	$1,357	$2	
9.9	Circ.Water System Foundations	$0	$2,761	$4,584	$0	$0	$7,345	$620	$0	$1,593	$9,558	$11	
	SUBTOTAL 9.	**$8,866**	**$9,262**	**$8,660**	**$0**	**$0**	**$26,788**	**$2,155**	**$0**	**$4,209**	**$33,152**	**$37**	
10	ASH/SPENT SORBENT HANDLING SYS												
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	
11	ACCESSORY ELECTRIC PLANT												
11.1	Generator Equipment	$9,437	$0	$5,582	$0	$0	$15,019	$1,233	$0	$1,219	$17,471	$20	
11.2	Station Service Equipment	$3,248	$0	$279	$0	$0	$3,527	$290	$0	$286	$4,104	$5	
11.3	Switchgear & Motor Control	$3,997	$0	$694	$0	$0	$4,691	$389	$0	$508	$5,588	$6	
11.4	Conduit & Cable Tray	$0	$2,089	$6,017	$0	$0	$8,106	$675	$0	$1,317	$10,099	$11	
11.5	Wire & Cable	$0	$6,712	$3,816	$0	$0	$10,528	$633	$0	$1,674	$12,836	$14	
11.6	Protective Equipment	$0	$1,016	$3,525	$0	$0	$4,541	$390	$0	$493	$5,425	$6	
11.7	Standby Equipment	$155	$0	$145	$0	$0	$300	$25	$0	$33	$358	$0	
11.8	Main Power Transformers	$14,468	$0	$185	$0	$0	$14,653	$995	$0	$1,565	$17,213	$19	
11.9	Electrical Foundations	$0	$217	$553	$0	$0	$771	$65	$0	$167	$1,003	$1	
	SUBTOTAL 11.	**$31,306**	**$10,034**	**$20,798**	**$0**	**$0**	**$62,137**	**$4,697**	**$0**	**$7,262**	**$74,096**	**$83**	

Exhibit 5-32 Case 3c – "J" frame turbine with CO_2 capture and EGR capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2012-Apr-04
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 3c - J-frame CCS EGR
Plant Size: 888.5 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,206	$0	$768	$0	$0	$1,974	$166	$99	$336	$2,575	$3
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$360	$0	$220	$0	$0	$581	$49	$29	$99	$757	$1
12.7	Computer & Accessories	$5,769	$0	$176	$0	$0	$5,945	$488	$297	$673	$7,403	$8
12.8	Instrument Wiring & Tubing	$0	$1,073	$1,899	$0	$0	$2,972	$214	$149	$500	$3,834	$4
12.9	Other I & C Equipment	$2,151	$0	$4,979	$0	$0	$7,130	$610	$356	$810	$8,906	$10
	SUBTOTAL 12.	**$9,486**	**$1,073**	**$8,042**	**$0**	**$0**	**$18,601**	**$1,526**	**$930**	**$2,417**	**$23,475**	**$26**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$138	$2,938	$0	$0	$3,077	$269	$0	$669	$4,014	$5
13.2	Site Improvements	$0	$1,268	$1,675	$0	$0	$2,943	$262	$0	$641	$3,846	$4
13.3	Site Facilities	$2,589	$0	$2,716	$0	$0	$5,305	$473	$0	$1,156	$6,933	$8
	SUBTOTAL 13.	**$2,589**	**$1,406**	**$7,329**	**$0**	**$0**	**$11,325**	**$1,003**	**$0**	**$2,466**	**$14,794**	**$17**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$397	$210	$0	$0	$607	$47	$0	$98	$752	$1
14.2	Steam Turbine Building	$0	$2,770	$3,686	$0	$0	$6,456	$519	$0	$1,046	$8,022	$9
14.3	Administration Building	$0	$676	$458	$0	$0	$1,134	$88	$0	$183	$1,406	$2
14.4	Circulation Water Pumphouse	$0	$220	$109	$0	$0	$329	$25	$0	$53	$407	$0
14.5	Water Treatment Buildings	$0	$666	$607	$0	$0	$1,273	$101	$0	$206	$1,580	$2
14.6	Machine Shop	$0	$587	$375	$0	$0	$961	$75	$0	$155	$1,191	$1
14.7	Warehouse	$0	$379	$228	$0	$0	$607	$47	$0	$98	$752	$1
14.8	Other Buildings & Structures	$0	$113	$82	$0	$0	$196	$15	$0	$32	$243	$0
14.9	Waste Treating Building & Str.	$0	$444	$792	$0	$0	$1,236	$101	$0	$200	$1,537	$2
	SUBTOTAL 14.	**$0**	**$6,252**	**$6,548**	**$0**	**$0**	**$12,800**	**$1,018**	**$0**	**$2,073**	**$15,890**	**$18**
	TOTAL COST	**$498,982**	**$49,572**	**$153,441**	**$0**	**$0**	**$701,995**	**$57,653**	**$33,892**	**$116,438**	**$909,979**	**$1,024**

Exhibit 5-32 Case 3c – "J" frame turbine with CO_2 capture and EGR capital cost estimate detail (continued)

Client:	USDOE/NETL
Report Date:	2012-Apr-04
Project:	Costing Support for NGCC with CCS Analyses
	TOTAL PLANT COST SUMMARY
Case:	Case 3c - J-frame CCS EGR
Plant Size:	888.5 MW,net
Estimate Type:	Conceptual
Cost Base (Jun)	2011 ($x1000)

Acct 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 $	TOTAL PLANT COST $/kW
	TOTAL COST	**$498,982**	**$49,572**	**$153,441**	**$0**	**$701,995**	**$57,653**	**$33,892**	**$116,438**	**$909,979**	**$1,024**
	Owner's Costs										
	Preproduction Costs										
	6 Months All Labor									$6,235	$7
	1 Month Maintenance Materials									$1,046	$1
	1 Month Non-fuel Consumables									$615	$1
	1 Month Waste Disposal									$0	$0
	25% of 1 Months Fuel Cost at 100% CF									$6,701	$8
	2% of TPC									$18,200	$20
	Total									**$32,797**	**$37**
	Inventory Capital										
	60 day supply of consumables at 100% CF									$843	$1
	0.5% of TPC (spare parts)									$4,550	$5
	Total									**$5,393**	**$6**
	Initial Cost for Catalyst and Chemicals									$1,978	$2
	Land									$300	$0
	Other Owner's Costs									$136,497	$154
	Financing Costs									$24,569	$28
	Total Overnight Costs (TOC)									**$1,111,512**	**$1,251**
	TASC Multiplier								(IOU, high-risk, 33 year)	1.078	
	Total As-Spent Cost (TASC)									**$1,198,210**	**$1,349**

Exhibit 5-33 Case 3c – "J" frame turbine with CO_2 capture and EGR operating cost estimate

INITIAL & ANNUAL O&M EXPENSES						
Case 3c - J-frame CCS EGR					Cost Base (Jun)	2011
					Heat Rate-net (Btu/kWh):	6,741
					MWe-net:	889
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	3.3		3.3			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	6.3		6.3			
					Annual Cost $	Annual Unit Cost $/kW-net
Annual Operating Labor Cost					$2,861,816	$3.221
Maintenance Labor Cost					$7,114,734	$8.007
Administrative & Support Labor					$2,494,138	$2.807
Property Taxes and Insurance					$18,199,580	$20.483
TOTAL FIXED OPERATING COSTS					**$30,670,268**	**$34.518**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					$10,672,102	**$0.00161**
Consumables	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost		
Water (/1000 gallons)	0.00	3,793.08	1.67	**$0**	**$1,969,960**	**$0.00030**
Chemicals						
MU & WT Chem.(lbs)	0.00	22,598.05	0.27	$0	$1,877,832	$0.00028
MEA Solvent (ton)	546.51	0.77	3,481.91	$1,902,889	$829,078	$0.00013
Activated Carbon (lb)	0.00	916.79	1.63	$0	$462,272	$0.00007
Corrosion Inhibitor	0.00	0.00	0.00	$74,871	$3,565	$0.00000
SCR Catalyst (m3)	w/equip.	0.10	8,938.80	$0	$274,270	$0.00004
Ammonia (19% NH3) (ton)	0.00	8.32	330.00	$0	$851,593	$0.00013
Subtotal Chemicals				**$1,977,760**	**$4,298,611**	**$0.00065**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$1,977,760**	**$16,940,672**	**$0.00256**
Fuel (MMBtu)	0	143,751	6.13	**$0**	**$273,390,109**	**$0.04130**

6 Case 4 – Future Gas Turbine – (“X” frame)

These cases are based on the previous cases but use an advanced/future turbine design based on a conceptual advanced future turbine, designated as an “X” machine configuration.

The generic design has an ISO output of 405 MW and LHV heat rate of approximately 8,124 kJ/kWh (7,700 Btu/kWh) (Brayton cycle) on natural gas fuel. The output is approximately 90 percent more and the heat rate is approximately 13 percent better than the 7FA.05 model considered in Case 1a. This gas turbine model also has approximately 20 percent more exhaust flow and approximately 36°C (65°F) higher exhaust temperature than the 7FA.05 model.

The turbine uses a high turbine inlet temperature and a high pressure ratio (turbine inlet temperature [TIT] of 1,704°C (3,100°F), PR of 30), which are higher when compared with current commercial designs (see Case 2). This turbine would require both improvements in materials and cooling technologies to become feasible. The net power for a 2 x 2 x 1 system is 1000 MWe which can be compared with current planned nuclear reactors and with recent orders for NGCC system based on “H” turbines (3 x 3 x 1). [14, 15]

The performance summaries, block flow diagrams, stream tables, carbon balances, water balances, and overall energy balances for each of these three cases are presented in this section. Detailed process flow diagrams from the Thermoflow software are provided in the appendix.

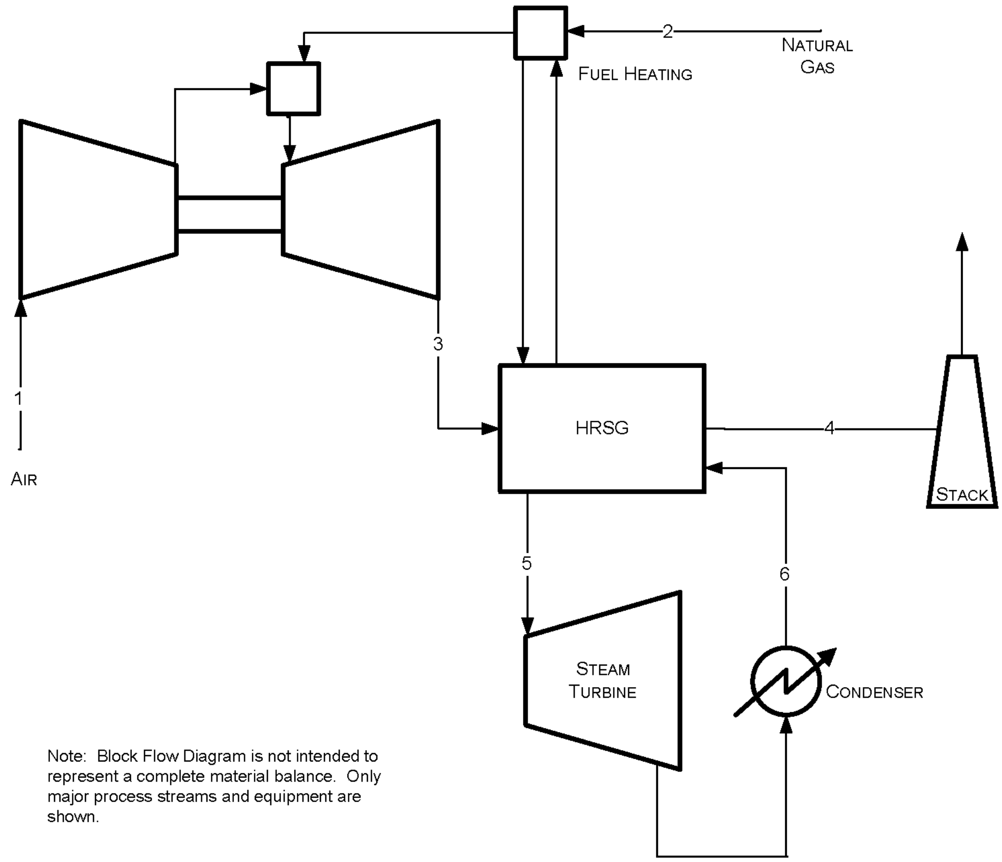
Capital and operating costs for these cases were estimated by WorleyParsons based on simulation results, costing software, and vendor quotes/discussions on the projections of advanced machine designs from multiple vendors. All costs are in June 2011 dollars.

6.1 Case 4a – NGCC without CO_2 Capture Modeling Results

The block flow diagram of the combined cycle is shown in Exhibit 6-1. This includes two generic advanced future frame gas turbines, two triple pressure level single reheat type HRSGs, and one condensing steam turbine with evaporative cooling tower. Exhibit 6-2 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems. A fuel gas heating system is integrated in this design for the gas turbine and overall plant heat rate improvement.

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,708°C (3,107°F). The flue gas exits the turbine at 638°C (1,182°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine. Flue gas exits the HRSG (stream 4) at 88°C (190°F) and passes to the plant stack. Cooling is supplied to the condenser via water from the cooling tower.

Exhibit 6-1 Case 4a – Advanced/Future turbine without CO_2 capture block flow diagram



Source: NETL

Exhibit 6-2 Case 4a – Advanced/Future turbine without CO_2 capture stream table

	1	2	3	4	5	6
V-L Mole Fraction						
Ar	0.0092	0.0000	0.0089	0.0089	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0404	0.0499	0.0000	0.0000
H_2O	0.0099	0.0000	0.0867	0.1052	1.0000	1.0000
N_2	0.7732	0.0160	0.7432	0.7358	0.0000	0.0000
O_2	0.2074	0.0000	0.1209	0.1004	0.0000	0.0000
SO_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0000	1.0000	1.0001	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	149,503	7,483	156,578	157,188	32,015	40,118
V-L Flowrate (kg/hr)	4,314,208	129,655	4,443,863	4,443,699	576,752	722,736
Solids Flowrate (kg/hr)	0	0	0	0	0	0
Temperature (°C)	15	38	639	88	593	32
Pressure (MPa, abs)	0.10	4.14	0.10	0.10	16.65	0.00
Enthalpy (kJ/kg)^A	30.96	52,530.38	886.90	260.98	3,547.62	2,374.85
Density (kg/m^3)	1.2	22.2	0.4	0.9	47.7	992.9
V-L Molecular Weight	28.857	17.328	28.381	28.270	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	329,598	16,496	345,196	346,540	70,580	88,445
V-L Flowrate (lb/hr)	9,511,200	285,840	9,797,040	9,796,680	1,271,520	1,593,360
Solids Flowrate (lb/hr)	0	0	0	0	0	0
Temperature (°F)	59	100	1,182	190	1,100	90
Pressure (psia)	14.6	600.0	15.2	14.7	2,414.7	0.7
Enthalpy (Btu/lb)^A	13.3	22,584.0	381.3	112.2	1,525.2	1,021.0
Density (lb/ft^3)	0.076	1.384	0.025	0.057	2.977	61.982

A - Reference conditions are 32.02 F & Liquid Water

Note: Total flow rates shown equal the sum for all process trains

6.1.1 Performance Results

The performance results are summarized in Exhibit 6-3 and represent both increases in power production and efficiency based on assumptions made when compared with the current NGCC commercial systems (see Cases 1a, 2a). The overall efficiency of 65.2 percent represents an increase in the overall process efficiency of approximately 5.2 percentage points and approximately 30 percent gas turbine power increase when compared with the current commercial "J" system. Compared to Case 1a based on the 7FA.05 gas turbine, the overall efficiency increases by approximately 7.8 percentage points and the gas turbine power increases by approximately 93 percent. Additional tables below provide overall energy balance

(Exhibit 6-4), water balance (Exhibit 6-5), carbon balance (Exhibit 6-6), and an emissions summary (Exhibit 6-7).

Exhibit 6-3 Case 4a – Advanced/Future turbine without CO_2 capture plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	810,862	kW_e
Steam Turbine Power	320,546	kW_e
Total	**1,131,408**	kW_e
Auxiliary Load		
Condensate Pumps	0	kW_e
Boiler Feedwater Pumps	6,848	kW_e
Amine CO_2 Capture System Auxiliaries	0	kW_e
CO_2 Compression	0	kW_e
Circulating Water Pump	2,964	kW_e
Ground Water Pumps	300	kW_e
Cooling Tower Fans	2,193	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	1,098	kW_e
Steam Turbine Auxiliaries	684	kW_e
Miscellaneous Balance of Plant[2]	3,508	kW_e
Transformer Losses	5,657	kW_e
Total	**23,262**	**kW_e**
Plant Performance		
Net Plant Power	**1,108,147**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	58.8%	
Net Plant Efficiency (LHV)[1]	65.2%	
Net Plant Heat Rate (HHV)[1]	6,121 (5,801)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	5,525 (5,237)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	129,655 (285,840)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,884,103	kW_t
Thermal Input (LHV)[1]	1,700,644	kW_t
Condenser Duty	1,614 (1,530)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	12.6 (3,329)	m^3/min (gpm)
Raw Water Consumption	10.4 (2,760)	m^3/min (gpm)

[1] HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads

Exhibit 6-4 Case 4a – Advanced/Future turbine without CO_2 capture overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	6,783 (6,429)	4.5 (4.3)	0 (0)	6,787 (6,433)
GT Air	0 (0)	133.6 (126.6)	0 (0)	134 (127)
Raw Water Withdrawal	0 (0)	47.4 (44.9)	0 (0)	48 (45)
Auxiliary Power	0 (0)	0.0 (0.0)	84 (79)	84 (79)
TOTAL	**6,783 (6,429)**	**185.5 (175.8)**	**84 (79)**	**7,052 (6,684)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	21.1 (20.0)	0 (0)	21 (20)
Stack Gas	0 (0)	1,160 (1,099)	0 (0)	1,160 (1,099)
Condenser	0 (0)	1,619 (1,535)	0 (0)	1,619 (1,535)
Process Losses*	*0 (0)*	*179 (170)*	*0 (0)*	*179 (170)*
Power	0 (0)	0.0 (0.0)	4,073 (3,861)	4,073 (3,861)
TOTAL	**0 (0)**	**2,979 (2,823)**	**4,073 (3,861)**	**7,052 (6,684)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 6-5 Case 4a – Advanced/Future turbine without CO_2 capture water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Condenser Makeup	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**
BFW Makeup	0.06 (15)	0.0 (0)	0.06 (15)	0.0 (0)	0.0 (0)
Cooling Tower	**12.60 (3,329)**	**0.06 (15)**	**12.54 (3,314)**	**2.2 (568)**	**10.4 (2,746)**
BFW Blowdown	0.00 (0)	0.06 (15)	-0.06 (-15)	0.00 (0)	0.00 (0)
Flue Gas Condensate	0.00 (0)	0.0 (0)	0.00 (0)	0.00 (0)	0.00 (0)
Total	**12.7 (3,343)**	**0.06 (15)**	**12.6 (3,329)**	**2.2 (568)**	**10.4 (2,760)**

Exhibit 6-6 Case 4a – Advanced/Future turbine without CO_2 capture carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	93,648 (206,459)	Stack Gas	94,173 (207,615)
Air (CO_2)	587 (1,293)		
		Convergence Tolerance*	62 (137)
Total	**94,235 (207,752)**	**Total**	**94,235 (207,752)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 6-7 Case 4a – Advanced/Future turbine without CO_2 capture air emissions

	Kg/GJ (lb/10^6 Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.004 (0.009)	196 (216)	0.023 (0.051)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	50.9 (118.3)	2,569,317 (2,832,187)	305 (672)
CO_2[1]			311 (686)

[1] CO_2 emissions based on net power instead of gross power

6.1.2 Major Equipment List

This section contains the equipment list corresponding to the advanced/future turbine design without CO_2 capture plant configuration for case 4a. This list, along with the heat and material balance and supporting performance data, was used to generate plant costs. The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as N/A.

Account 1 – Coal and Sorbent Handling

N/A

Account 2 – Coal and Sorbent Preparation and Feed

N/A

Account 3 - Feedwater and Miscellaneous Systems and Equipment

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	437,105 liters (115,470 gal)	2 (0)
2	Condensate Pumps	Vertical canned	6,662 lpm @ 3 m H_2O (1,760 gpm @ 10 ft H_2O)	2 (1)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
3	Boiler Feedwater Pump	Horizontal, split case, multi-stage, centrifugal, with interstage bleed for IP and LP feedwater	HP water: 5,337lpm @ 1,887m H_2O (1,410gpm @ 6,190ft H_2O) IP water: 6,965 lpm @ 546m H_2O (1,840gpm @ 1,790ft H_2O) LP water: 416 lpm @ 0.0 m H_2O (110 gpm @ 00 ft H_2O)	2 (1)
4	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg /hr, 2.8 MPa, 343°C (40,000 lb /hr, 400 psig, 650°F)	1 (0)
5	Service Air Compressors	Flooded Screw	13 m^3/min @ 0.7 MPa (450 scfm @ 100 psig)	2 (1)
6	Instrument Air Dryers	Duplex, regenerative	13 m^3/min (450 scfm)	2 (1)
7	Closed Cycle Cooling Heat Exchangers	Plate and frame	13 GJ/hr (13 MMBtu/hr)	2 (0)
8	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	5,300 lpm @ 21 m H_2O (1,400 gpm @ 70 ft H_2O)	2 (1)
9	Engine-driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1 (1)
10	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1 (1)
11	Raw Water Pumps	Stainless steel, single suction	7,192 lpm @ 18 m H_2O (1,900 gpm @ 60 ft H_2O)	2 (1)
12	Filtered Water Pumps	Stainless steel, single suction	231 lpm @ 49 m H_2O (61 gpm @ 160 ft H_2O)	2 (1)
13	Filtered Water Tank	Vertical, cylindrical	219,556 liter (58,000 gal)	1 (0)
14	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly and electro-deionization unit	492 lpm (130 gpm)	1 (0)
15	Liquid Waste Treatment System	--	10 years, 24-hour storm	1 (0)
16	Gas Pipeline	Underground, coated carbon steel, wrapped cathodic protection	107 m^3/min @ 4.1 MPa (3,785 acfm @ 600 psia) 41 cm (16 in) standard wall pipe	16 km 10 mile
17	Gas Metering Station	--	107 m^3/min (3,785 acfm)	1 (0)

Account 4 – Gasifier, Boiler, and Accessories

N/A

Account 5 – Flue Gas Cleanup

N/A

Account 6 – Combustion Turbine Generators and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Gas Turbine	Advanced Future w/ dry low-NOx burner	400 MW	2 (0)
2	Gas Turbine Generator	TEWAC	440 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2 (0)

Account 7 – Waste Heat Boiler, Ducting, and Stack

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Stack	CS plate, type 409SS liner	46 m (150 ft) high x 8.0 m (26 ft) diameter	2 (0)
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 317,214 kg/h, 16.5 MPa/593°C (699,336 lb/h, 2,400 psig/1,100°F) Reheat steam - 366,610 kg/h, 2.4 MPa/593°C (808,236 lb/h, 345 psig/1,100°F)	2 (0)
3	SCR Reactor	Space for spare layer	2,444,866 kg/h (5,390,000 lb/h)	2 (0)
4	SCR Catalyst	--	Space available for an additional catalyst layer	1 layer (0)
5	Dilution Air Blowers	Centrifugal	15 m^3/min @ 107 cm WG (530 scfm @ 42 in WG)	2 (1)
6	Ammonia Feed Pump	Centrifugal	3.8 lpm @ 91 m H_2O (1 gpm @ 300 ft H_2O)	2 (1)
7	Ammonia Storage Tank	Horizontal tank	90,851 liter (24,000 gal)	1 (0)

Account 8 – Steam Turbine Generator and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Steam Turbine	Tandem compound, HP, IP, and two-flow LP turbines	337 MW 16.5 MPa/593°C/593°C (2,400 psig/ 1100°F/1100°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	370 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)
3	Steam Bypass	One per HRSG	50% steam flow @ design steam conditions	2 (0)
4	Surface Condenser	Single pass, divided waterbox including vacuum pumps	1,782 MMkJ/hr, (1,690 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

Account 9 – Cooling Water System

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	325,548 lpm @ 30.5 m (86,000 gpm @ 100 ft)	2 (1)
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT 1,808 MMkJ/hr (1,716 MMBtu/hr) heat load	1 (0)

Account 10 – Ash Spent Sorbent Recovery and Handling

N/A

Account 11 – Accessory Electric Plant

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	CTG Transformer	Oil-filled	24 kV/345 kV, 440 MVA, 3-ph, 60 Hz	2 (0)
2	STG Transformer	Oil-filled	24 kV/345 kV, 350 MVA, 3-ph, 60 Hz	1 (0)
3	Auxiliary Transformer	Oil-filled	24 kV/4.16 kV, 20 MVA, 3-ph, 60 Hz	1 (1)
4	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 3 MVA, 3-ph, 60 Hz	1 (1)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
5	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2 (0)
6	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1 (0)
7	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1 (1)
8	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1 (1)
9	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

Account 12 – Instrumentation and Control

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	DCS - Main Control	Monitor/keyboard; Operator printer; Engineering printer	Operator stations/printers and engineering stations/printers	1 (0)
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1 (0)
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1 (0)

6.1.3 Cost Estimate Results

Capital and operating costs for Cases 4a using the advanced future turbine design were estimated by WorleyParsons based on simulation results, costing software, and vendor quotes/discussions on the projections of advanced machine designs from multiple vendors. All costs are in June 2011 dollars. The cost estimation results for this case are summarized in Exhibit 6-8. The summary and detailed capital cost estimates are shown in Exhibit 6-9 and Exhibit 6-10, respectively. The annual operating cost estimates are shown in Exhibit 6-11.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 6-8 Case 4a - Advanced/Future turbine without CO_2 capture cost estimation summary

Case	4a
Total Plant Cost (2011$/kW)	**539**
Total Overnight Cost (2011$/kW)	**661**
Total As-spent Capital (2011$/kW)	**711**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	9.32
Fixed O&M	2.73
Variable O&M	1.56
Fuel	35.56
CO_2 T&S total	0.00
COE[1] Total	**49.17**
LCOE[1], total (including T&S)	62.32

[1] *Capacity factor assumed to be 85 percent*

Exhibit 6-9 Case 4a - Advanced/Future turbine without CO_2 capture capital cost estimate summary

Client:	USDOE/NETL	**Report Date:**	2011-Dec-15
Project:	Costing Support for NGCC with CCS Analyses		
	TOTAL PLANT COST SUMMARY		
Case:	Case 4a - AdvFuture		
Plant Size:	1108.1 MW,net	**Estimate Type:** Conceptual	**Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$30,296	$7,165	$10,307	$0	$0	**$47,767**	$3,919	$0	$8,304	**$59,991**	**$54**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
5B	CO2 REMOVAL & COMPRESSION	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	**$0**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$180,000	$0	$10,386	$0	$0	**$190,386**	$15,722	$0	$20,611	**$226,719**	$205
6.2-6.9	Combustion Turbine Other	$0	$1,221	$1,320	$0	$0	**$2,541**	$213	$0	$551	**$3,304**	$3
	SUBTOTAL 6	**$180,000**	**$1,221**	**$11,706**	**$0**	**$0**	**$192,927**	**$15,934**	**$0**	**$21,161**	**$230,023**	**$208**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$43,570	$0	$7,664	$0	$0	**$51,234**	$4,254	$0	$5,549	**$61,037**	$55
7.2-7.9	SCR System, Ductwork and Stack	$2,835	$1,805	$2,237	$0	$0	**$6,878**	$575	$0	$1,182	**$8,636**	$8
	SUBTOTAL 7	**$46,405**	**$1,805**	**$9,901**	**$0**	**$0**	**$58,111**	**$4,830**	**$0**	**$6,731**	**$69,673**	**$63**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$47,080	$0	$6,666	$0	$0	**$53,746**	$4,234	$0	$5,798	**$63,778**	$58
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$16,236	$1,279	$9,635	$0	$0	**$27,149**	$2,005	$0	$4,219	**$33,373**	$30
	SUBTOTAL 8	**$63,316**	**$1,279**	**$16,300**	**$0**	**$0**	**$80,894**	**$6,240**	**$0**	**$10,017**	**$97,151**	**$88**
9	COOLING WATER SYSTEM	$5,915	$6,529	$6,014	$0	$0	**$18,458**	$1,484	$0	$2,920	**$22,862**	$21
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$30,710	$7,327	$16,565	$0	$0	**$54,601**	$4,095	$0	$6,259	**$64,956**	$59
12	INSTRUMENTATION & CONTROL	$8,794	$995	$7,456	$0	$0	**$17,244**	$1,415	$0	$2,142	**$20,801**	$19
13	IMPROVEMENTS TO SITE	$2,695	$1,464	$7,631	$0	$0	**$11,790**	$1,045	$0	$2,567	**$15,402**	$14
14	BUILDINGS & STRUCTURES	$0	$6,484	$6,884	$0	$0	**$13,368**	$1,064	$0	$2,165	**$16,596**	$15
	TOTAL COST	**$368,131**	**$34,268**	**$92,764**	**$0**	**$0**	**$495,163**	**$40,026**	**$0**	**$62,267**	**$597,455**	**$539**

Exhibit 6-10 Case 4a - Advanced/Future turbine without CO_2 capture capital cost estimate detail

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 4a - AdvFuture
Plant Size: 1108.1 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost	H.O.& Fee	Process	Project	$	$/kW
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,825	$3,961	$3,235	$0	$0	$11,022	$887	$0	$1,786	$13,696	$12
3.2	Water Makeup & Pretreating	$2,278	$235	$1,169	$0	$0	$3,683	$304	$0	$797	$4,785	$4
3.3	Other Feedwater Subsystems	$1,792	$592	$495	$0	$0	$2,879	$222	$0	$465	$3,567	$3
3.4	Service Water Systems	$275	$549	$1,768	$0	$0	$2,591	$220	$0	$562	$3,374	$3
3.5	Other Boiler Plant Systems	$1,854	$693	$1,593	$0	$0	$4,140	$337	$0	$672	$5,148	$5
3.6	Natural Gas, incl. pipeline	$17,845	$917	$794	$0	$0	$19,556	$1,614	$0	$3,175	$24,345	$22
3.7	Waste Treatment Equipment	$796	$0	$461	$0	$0	$1,256	$108	$0	$273	$1,638	$1
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,630	$218	$792	$0	$0	$2,640	$226	$0	$573	$3,439	$3
	SUBTOTAL 3.	**$30,296**	**$7,165**	**$10,307**	**$0**	**$0**	**$47,767**	**$3,919**	**$0**	**$8,304**	**$59,991**	**$54**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$180,000	$0	$10,386	$0	$0	$190,386	$15,722	$0	$20,611	$226,719	$205
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$1,221	$1,320	$0	$0	$2,541	$213	$0	$551	$3,304	$3
	SUBTOTAL 6.	**$180,000**	**$1,221**	**$11,706**	**$0**	**$0**	**$192,927**	**$15,934**	**$0**	**$21,161**	**$230,023**	**$208**

Exhibit 6-10 Case 4a - Advanced/Future turbine without CO_2 capture capital cost estimate detail (continued)

Client:	USDOE/NETL
Project:	Costing Support for NGCC with CCS Analyses
Report Date:	2011-Dec-15

TOTAL PLANT COST SUMMARY

Case:	Case 4a - AdvFuture
Plant Size:	1108.1 MW,net
Estimate Type:	Conceptual
Cost Base (Jun)	2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$43,570	$0	$7,664	$0	$0	$51,234	$4,254	$0	$5,549	$61,037	$55
7.2	HRSG Accessories	$2,835	$1,191	$1,661	$0	$0	$5,686	$476	$0	$924	$7,087	$6
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$615	$577	$0	$0	$1,191	$99	$0	$258	$1,549	$1
	SUBTOTAL 7.	**$46,405**	**$1,805**	**$9,901**	**$0**	**$0**	**$58,111**	**$4,830**	**$0**	**$6,731**	**$69,673**	**$63**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$47,080	$0	$6,666	$0	$0	$53,746	$4,234	$0	$5,798	$63,778	$58
8.2	Turbine Plant Auxiliaries	$271	$0	$618	$0	$0	$889	$76	$0	$97	$1,062	$1
8.3	Condenser & Auxiliaries	$3,490	$0	$1,850	$0	$0	$5,340	$449	$0	$579	$6,368	$6
8.4	Steam Piping	$12,474	$0	$5,056	$0	$0	$17,530	$1,195	$0	$2,809	$21,533	$19
8.9	TG Foundations	$0	$1,279	$2,111	$0	$0	$3,390	$286	$0	$735	$4,411	$4
	SUBTOTAL 8.	**$63,316**	**$1,279**	**$16,300**	**$0**	**$0**	**$80,894**	**$6,240**	**$0**	**$10,017**	**$97,151**	**$88**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$3,470	$0	$1,060	$0	$0	$4,530	$378	$0	$491	$5,399	$5
9.2	Circulating Water Pumps	$1,683	$0	$106	$0	$0	$1,789	$136	$0	$193	$2,118	$2
9.3	Circ.Water System Auxiliaries	$138	$0	$18	$0	$0	$156	$13	$0	$17	$186	$0
9.4	Circ.Water Piping	$0	$4,271	$967	$0	$0	$5,238	$393	$0	$845	$6,475	$6
9.5	Make-up Water System	$350	$0	$449	$0	$0	$799	$66	$0	$130	$995	$1
9.6	Component Cooling Water Sys	$275	$329	$211	$0	$0	$814	$65	$0	$132	$1,011	$1
9.9	Circ.Water System Foundations	$0	$1,929	$3,203	$0	$0	$5,132	$433	$0	$1,113	$6,679	$6
	SUBTOTAL 9.	**$5,915**	**$6,529**	**$6,014**	**$0**	**$0**	**$18,458**	**$1,484**	**$0**	**$2,920**	**$22,862**	**$21**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$7,429	$0	$4,395	$0	$0	$11,824	$971	$0	$960	$13,755	$12
11.2	Station Service Equipment	$2,217	$0	$191	$0	$0	$2,408	$198	$0	$195	$2,801	$3
11.3	Switchgear & Motor Control	$2,728	$0	$474	$0	$0	$3,202	$265	$0	$347	$3,814	$3
11.4	Conduit & Cable Tray	$0	$1,426	$4,107	$0	$0	$5,533	$461	$0	$899	$6,893	$6
11.5	Wire & Cable	$0	$4,581	$2,605	$0	$0	$7,186	$432	$0	$1,143	$8,761	$8
11.6	Protective Equipment	$0	$1,075	$3,732	$0	$0	$4,807	$413	$0	$522	$5,743	$5
11.7	Standby Equipment	$168	$0	$157	$0	$0	$325	$27	$0	$35	$388	$0
11.8	Main Power Transformers	$18,167	$0	$284	$0	$0	$18,451	$1,253	$0	$1,970	$21,675	$20
11.9	Electrical Foundations	$0	$244	$622	$0	$0	$866	$73	$0	$188	$1,127	$1
	SUBTOTAL 11.	**$30,710**	**$7,327**	**$16,565**	**$0**	**$0**	**$54,601**	**$4,095**	**$0**	**$6,259**	**$64,956**	**$59**

Exhibit 6-10 Case 4a - Advanced/Future turbine without CO_2 capture capital cost estimate detail (continued)

	Client:	USDOE/NETL								**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses											
		TOTAL PLANT COST SUMMARY											
	Case:	Case 4a - AdvFuture											
	Plant Size:	1108.1 MW,net		**Estimate Type:**	Conceptual					**Cost Base (Jun)**	2011	($x1000)	
Acct		**Equipment**	**Material**	**Labor**		**Sales**	**Bare Erected**	**Eng'g CM**	**Contingencies**		**TOTAL PLANT COST**		
No.	**Item/Description**	**Cost**	**Cost**	**Direct**	**Indirect**	**Tax**	**Cost**	**H.O.& Fee**	**Process**	**Project**	**$**	**$/kW**	
12	INSTRUMENTATION & CONTROL												
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0	
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0	
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0	
12.4	Other Major Component Control	$1,118	$0	$712	$0	$0	$1,830	$154	$0	$298	$2,281	$2	
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0	
12.6	Control Boards,Panels & Racks	$334	$0	$204	$0	$0	$538	$45	$0	$88	$671	$1	
12.7	Computer & Accessories	$5,348	$0	$163	$0	$0	$5,511	$452	$0	$596	$6,560	$6	
12.8	Instrument Wiring & Tubing	$0	$995	$1,760	$0	$0	$2,755	$198	$0	$443	$3,396	$3	
12.9	Other I & C Equipment	$1,994	$0	$4,616	$0	$0	$6,609	$566	$0	$718	$7,893	$7	
	SUBTOTAL 12.	**$8,794**	**$995**	**$7,456**	**$0**	**$0**	**$17,244**	**$1,415**	**$0**	**$2,142**	**$20,801**	**$19**	
13	IMPROVEMENTS TO SITE												
13.1	Site Preparation	$0	$144	$3,059	$0	$0	$3,203	$280	$0	$697	$4,179	$4	
13.2	Site Improvements	$0	$1,320	$1,744	$0	$0	$3,064	$272	$0	$667	$4,004	$4	
13.3	Site Facilities	$2,695	$0	$2,828	$0	$0	$5,523	$492	$0	$1,203	$7,218	$7	
	SUBTOTAL 13.	**$2,695**	**$1,464**	**$7,631**	**$0**	**$0**	**$11,790**	**$1,045**	**$0**	**$2,567**	**$15,402**	**$14**	
14	BUILDINGS & STRUCTURES												
14.1	Combustion Turbine Area	$0	$431	$228	$0	$0	$659	$51	$0	$106	$816	$1	
14.2	Steam Turbine Building	$0	$3,113	$4,141	$0	$0	$7,254	$583	$0	$1,176	$9,013	$8	
14.3	Administration Building	$0	$685	$464	$0	$0	$1,149	$89	$0	$186	$1,424	$1	
14.4	Circulation Water Pumphouse	$0	$229	$113	$0	$0	$342	$26	$0	$55	$423	$0	
14.5	Water Treatment Buildings	$0	$484	$441	$0	$0	$924	$73	$0	$150	$1,147	$1	
14.6	Machine Shop	$0	$594	$380	$0	$0	$974	$76	$0	$157	$1,207	$1	
14.7	Warehouse	$0	$384	$231	$0	$0	$615	$48	$0	$99	$762	$1	
14.8	Other Buildings & Structures	$0	$115	$84	$0	$0	$199	$16	$0	$32	$246	$0	
14.9	Waste Treating Building & Str.	$0	$450	$803	$0	$0	$1,252	$102	$0	$203	$1,557	$1	
	SUBTOTAL 14.	**$0**	**$6,484**	**$6,884**	**$0**	**$0**	**$13,368**	**$1,064**	**$0**	**$2,165**	**$16,596**	**$15**	
	TOTAL COST	**$368,131**	**$34,268**	**$92,764**	**$0**	**$0**	**$495,163**	**$40,026**	**$0**	**$62,267**	**$597,455**	**$539**	

Exhibit 6-10 Case 4a - Advanced/Future turbine without CO_2 capture capital cost estimate detail (continued)

Client:	USDOE/NETL			**Report Date:**	2011-Dec-15
Project:	Costing Support for NGCC with CCS Analyses				

TOTAL PLANT COST SUMMARY

Case:	Case 4a - AdvFuture						
Plant Size:	1108.1 MW,net	**Estimate Type:**	Conceptual	**Cost Base (Jun)**	2011	($x1000)	

Acct 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 $	TOTAL PLANT COST $/kW
	TOTAL COST	**$368,131**	**$34,268**	**$92,764**	**$0**	**$495,163**	**$40,026**	**$0**	**$62,267**	**$597,455**	**$539**
	Owner's Costs										
	Preproduction Costs										
	6 Months All Labor									$5,277	$5
	1 Month Maintenance Materials									$909	$1
	1 Month Non-fuel Consumables									$349	$0
	1 Month Waste Disposal									$0	$0
	25% of 1 Months Fuel Cost at 100% CF									$7,192	$6
	2% of TPC									$11,949	$11
	Total									**$25,676**	**$23**
	Inventory Capital										
	60 day supply of consumables at 100% CF									$454	$0
	0.5% of TPC (spare parts)									$2,987	$3
	Total									**$3,441**	**$3**
	Initial Cost for Catalyst and Chemicals									$0	$0
	Land									$300	$0
	Other Owner's Costs									$89,618	$81
	Financing Costs									$16,131	$15
	Total Overnight Costs (TOC)									**$732,622**	**$661**
	TASC Multiplier								(IOU, low-risk, 33 year)	1.075	
	Total As-Spent Cost (TASC)									**$787,568**	**$711**

Exhibit 6-11 Case 4a - Advanced/Future turbine without CO_2 capture operating cost estimate

INITIAL & ANNUAL O&M EXPENSES					Cost Base (Jun)	2011
Case 4a - AdvFuture					Heat Rate-net (Btu/kWh):	5,801
					MWe-net:	1108
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	2.0		2.0			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	5.0		5.0			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$2,260,518	$2.040
Maintenance Labor Cost					$6,182,298	$5.579
Administrative & Support Labor					$2,110,704	$1.905
Property Taxes and Insurance					$11,949,102	$10.783
TOTAL FIXED OPERATING COSTS					**$22,502,622**	**$20.307**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					**$9,273,447**	**$0.00112**
Consumables	Consumption		Unit	Initial Fill		
	Initial Fill	/Day	Cost	Cost		
Water (/1000 gallons)	0.00	2,396.88	1.67	**$0**	**$1,244,836**	**$0.00015**
Chemicals						
MU & WT Chem.(lbs)	0.00	14,279.92	0.27	$0	$1,186,619	$0.00014
MEA Solvent (ton)	0.00	0.00	3,481.91	$0	$0	$0.00000
Activated Carbon (lb)	0.00	0.00	1.63	$0	$0	$0.00000
Corrosion Inhibitor	0.00	0.00	0.00	$0	$0	$0.00000
SCR Catalyst (m3)	w/equip.	0.10	8,938.80	$0	$274,977	$0.00003
Ammonia (19% NH3) (ton)	0.00	8.34	330.00	$0	$853,789	$0.00010
Subtotal Chemicals				**$0**	**$2,315,386**	**$0.00028**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$0**	**$12,833,669**	**$0.00155**
Fuel (MMBtu)	0	154,281	6.13	**$0**	**$293,415,837**	**$0.03554**

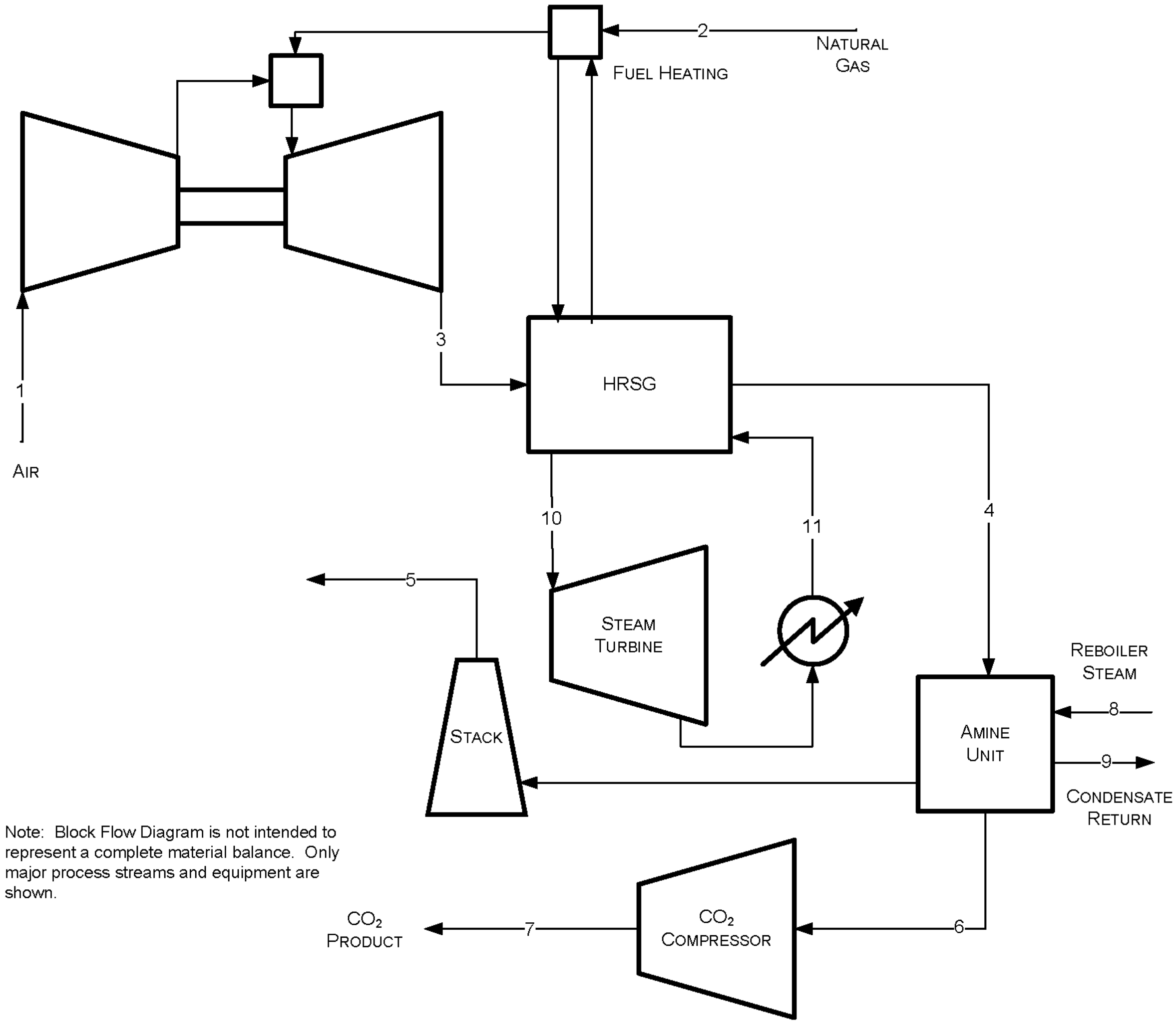
6.2 Case 4b – NGCC with CO_2 Capture Modeling Results

The block flow diagram of the combined cycle with CO_2 capture is shown in Exhibit 6-12. This case also uses the same generic "X" frame gas turbine model as that of Case 4a with the addition of CO_2 capture at the back end. Exhibit 6-13 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems. The heat required for the solvent (amine) system in the CO_2 capture system is supplied from the Rankine cycle (stream 4)

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,708°C (3,107°F). The flue gas exits the turbine at 638°C (1,182°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine as well as the steam required for the capture process (stream 8). Flue gas exits the HRSG (stream 4) at 113°C (235°F) and passes to the capture system where the CO_2 is captured and compressed (stream 7). Cooling is supplied to the steam turbine condenser via water from the cooling tower.

The gas turbine (Brayton cycle) performance is not impacted due to the CO_2 capture addition. However, the Rankine cycle performance and the overall plant output and efficiency are reduced due to heat integration requirements and increased auxiliary loads for the CO_2 capture process.

Exhibit 6-12 Case 4b – Advanced/Future turbine with CO_2 capture block flow diagram



Source: NETL

Exhibit 6-13 Case 4b – Advanced/Future turbine with CO_2 capture stream table

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0092	0.0000	0.0089	0.0089	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0404	0.0499	0.0055	0.9674	1.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0099	0.0000	0.0867	0.1052	0.0555	0.0326	0.0000	1.0000	1.0000	1.0000	1.0000
N_2	0.7732	0.0160	0.7432	0.7358	0.8176	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.2074	0.0000	0.1209	0.1004	0.1115	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	1.0001	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	149,503	7,483	156,578	157,188	141,480	7,294	7,057	20,639	17,887	32,069	20,639
V-L Flowrate (kg/hr)	4,314,208	129,655	4,443,863	4,443,699	3,977,007	314,829	310,584	371,819	371,819	577,732	371,819
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	38	639	113	35	35	38	152	151	593	32
Pressure (MPa, abs)	0.10	4.14	0.10	0.10	0.10	0.17	15.27	0.51	0.49	16.65	0.00
Enthalpy (kJ/kg)[A]	30.96	52,530.38	886.90	287.73	116.31	91.58	-164.90	2,746.79	635.72	3,547.62	2,375.54
Density (kg/m^3)	1.2	22.2	0.4	0.8	0.9	2.9	653.5	2.7	915.8	47.7	992.9
V-L Molecular Weight	28.857	17.328	28.381	28.270	28.110	43.160	44.010	18.015	18.015	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	329,598	16,496	345,196	346,540	311,910	16,082	15,558	45,501	39,435	70,700	45,501
V-L Flowrate (lb/hr)	9,511,200	285,840	9,797,040	9,796,680	8,767,800	694,080	684,720	819,720	819,720	1,273,680	819,720
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	100	1,182	235	95	95	101	306	304	1,100	90
Pressure (psia)	14.6	600.0	15.2	14.7	14.7	25.0	2,214.7	73.5	71.0	2,414.7	0.7
Enthalpy (Btu/lb)[A]	13.3	22,584.0	381.3	123.7	50.0	39.4	-70.9	1,180.9	273.3	1,525.2	1,021.3
Density (lb/ft^3)	0.076	1.384	0.025	0.052	0.056	0.183	40.800	0.169	57.172	2.977	61.982

A - Reference conditions are 32.02 F & Liquid Water

Note: Total flow rates shown equal the sum for all process trains

6.2.1 Performance Results

The performance results are summarized in Exhibit 6-14 and when compared with Case 4a show that adding carbon capture reduces the efficiency by approximately 7 percentage points (similar results as determined for Case 1). This is based on using an assumed advanced solvent process that has a lower steam requirement for the reboiler of 2,960 kJ/kg CO_2 (1,272 Btu/lb CO_2) or 17 percent lower when compared with earlier NETL/DOE system studies (i.e., 3,560 kJ/kg CO_2 (1,530 Btu/lb CO_2)). Additional tables below provide overall energy balance (Exhibit 6-15), water balance (Exhibit 6-16), carbon balance (Exhibit 6-17), and an emissions summary (Exhibit 6-18).

Exhibit 6-14 Case 4b – Advanced/Future turbine with CO_2 capture plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	810,862	kW_e
Steam Turbine Power	252,770	kW_e
Total	**1,063,632**	kW_e
Auxiliary Load		
Condensate Pumps	13	kW_e
Boiler Feedwater Pumps	6,902	kW_e
Amine CO_2 Capture System Auxiliaries	19,249	kW_e
CO_2 Compression	29,183	kW_e
Circulating Water Pump	5,520	kW_e
Ground Water Pumps	450	kW_e
Cooling Tower Fans	3,675	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	1,097	kW_e
Steam Turbine Auxiliaries	540	kW_e
Miscellaneous Balance of Plant[2]	3,157	kW_e
Transformer Losses	5,318	kW_e
Total	**75,114**	**kW_e**
Plant Performance		
Net Plant Power	**988,518**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	52.5%	
Net Plant Efficiency (LHV)[1]	58.1%	
Net Plant Heat Rate (HHV)[1]	6,862 (6,503)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	6,193 (5,870)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	129,655 (285,840)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,884,103	kW_t
Thermal Input (LHV)[1]	1,700,644	kW_t
Condenser Duty	833 (790)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	18.9 (5.006)	m^3/min (gpm)
Raw Water Consumption	15.4 (4,063)	m^3/min (gpm)

[1] *HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)*
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] *Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads*

Exhibit 6-15 Case 4b – Advanced/Future turbine with CO_2 capture overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	6,783 (6,429)	4.5 (4.3)	0 (0)	6,787 (6,433)
GT Air	0 (0)	133.6 (126.6)	0 (0)	134 (127)
Raw Water Withdrawal	0 (0)	71.3 (67.5)	0 (0)	71 (68)
Auxiliary Power	0 (0)	0.0 (0.0)	270 (256)	270 (256)
TOTAL	**6,783 (6,429)**	**209.4 (198.4)**	**270 (256)**	**7,263 (6,884)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	35.9 (34.0)	0 (0)	36 (34)
Stack Gas	0 (0)	463 (438)	0 (0)	463 (438)
Condenser	0 (0)	833 (790)	0 (0)	833 (790)
CO_2 Product	0 (0)	-51.2 (-48.5)	0 (0)	-51 (-49)
CO_2 Intercoolers	0 (0)	144.4 (136.8)	0 (0)	144 (137)
Amine System Losses	0 (0)	1,233.8 (1,169.4)	0 (0)	1,234 (1,169)
Process Losses*	*0 (0)*	*775 (734)*	*0 (0)*	*775 (734)*
Power	0 (0)	0.0 (0.0)	3,829 (3,629)	3,829 (3,629)
TOTAL	**0 (0)**	**3,433 (3,254)**	**3,829 (3,629)**	**7,263 (6,884)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 6-16 Case 4b – Advanced/Future turbine with CO_2 capture water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Amine Capture System	0.08 (20)	0.00 (0)	0.08 (20)	0.0 (0)	0.08 (20)
Condenser Makeup	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**	**0.0 (0)**	**0.1 (15)**
BFW Makeup	0.06 (15)	0.0 (0)	0.06 (15)	0.0 (0)	0.0 (0)
Cooling Tower	**21.5 (5,674)**	**2.7 (703)**	**18.82 (4,971)**	**3.6 (943)**	**15.2 (4,027)**
BFW Blowdown	0.00 (0)	0.06 (15)	-0.06 (-15)	0.00 (0)	0.00 (0)
Flue Gas/CO_2 Condensate	0.00 (0)	2.6 (688)	-2.61 (-688)	0.00 (0)	0.00 (0)
Total	**21.6 (5,709)**	**2.66 (703)**	**18.9 (5,006)**	**3.6 (943)**	**15.4 (4,063)**

Exhibit 6-17 Case 4b – Advanced/Future turbine with CO_2 capture carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	93,648 (206,459)	Stack Gas	9,419 (20,766)
Air (CO_2)	587 (1,293)	CO_2 Product	84,763 (186,871)
		Convergence Tolerance*	52 (115)
Total	**94,235 (207,752)**	**Total**	**94,235 (207,752)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 6-18 Case 4b – Advanced/Future turbine with CO_2 capture air emissions

	Kg/GJ ($lb/10^6$ Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.003 (0.006)	133 (146)	0.017 (0.037)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	5.1 (11.8)	256,988 (283,281)	32 (72)
CO_2[1]			35 (77)

[1] CO_2 emissions based on net power instead of gross power

6.2.2 Major Equipment List

This section contains the equipment list corresponding to the advanced/future turbine design with CO_2 capture plant configuration for case 4b. This list, along with the heat and material balance and supporting performance data, was used to generate plant costs. The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as N/A.

Account 1 – Coal and Sorbent Handling

N/A

Account 2 – Coal and Sorbent Preparation and Feed

N/A

Account 3 - Feedwater and Miscellaneous Systems and Equipment

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	446,682 liters (118,000 gal)	2 (0)
2	Condensate Pumps	Vertical canned	6,852 lpm @ 6 m H_2O (1,810 gpm @ 20 ft H_2O)	2 (1)
3	Boiler Feedwater Pump	Horizontal, split case, multi-stage, centrifugal, with interstage bleed for IP and LP feedwater	HP water: 5,375 lpm @ 1,887 m H_2O (1,420 gpm @ 6,190 ft H_2O) IP water: 7,003 lpm @ 543 m H_2O (1,850 gpm @ 1,780 ft H_2O) LP water: 606 lpm @ 0.0 m H_2O (160 gpm @ 00 ft H_2O)	2 (1)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
4	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg /hr, 2.8 MPa, 343°C (40,000 lb /hr, 400 psig, 650°F)	1 (0)
5	Service Air Compressors	Flooded Screw	13 m^3/min @ 0.7 MPa (450 scfm @ 100 psig)	2 (1)
6	Instrument Air Dryers	Duplex, regenerative	13 m^3/min (450 scfm)	2 (1)
7	Closed Cycle Cooling Heat Exchangers	Plate and frame	13 GJ/hr (13 MMBtu/hr)	2 (0)
8	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	5,300 lpm @ 21 m H_2O (1,400 gpm @ 70 ft H_2O)	2 (1)
9	Engine-driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1 (1)
10	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1 (1)
11	Raw Water Pumps	Stainless steel, single suction	10,560 lpm @ 18 m H_2O (2,800 gpm @ 60 ft H_2O)	2 (1)
12	Filtered Water Pumps	Stainless steel, single suction	235 lpm @ 49 m H_2O (62 gpm @ 160 ft H_2O)	2 (1)
13	Filtered Water Tank	Vertical, cylindrical	223,341 liter (59,000 gal)	1 (0)
14	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly and electro-deionization unit	530 lpm (140 gpm)	1 (0)
15	Liquid Waste Treatment System	--	10 years, 24-hour storm	1 (0)
16	Gas Pipeline	Underground, coated carbon steel, wrapped cathodic protection	107 m^3/min @ 4.1 MPa (3,785 acfm @ 600 psia) 41 cm (16 in) standard wall pipe	16 km 10 mile
17	Gas Metering Station	--	107 m^3/min (3,785 acfm)	1 (0)

Account 4 – Gasifier, Boiler, and Accessories

N/A

Account 5 – Flue Gas Cleanup

N/A

Account 5B – CO_2 Capture and Compression

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Amine CO_2 Capture System	Amine-based CO_2 capture technology	2,443,960 kg/hr (5,388,000 lb/hr) 7.8 wt % CO_2 concentration	2 (0)
2	CO_2 Compressor	Integrally geared, multi-stage centrifugal	171,005 kg/hr @ 15.3 MPa (377,000 lb/hr @ 2,215 psia)	2 (0)

Account 6 – Combustion Turbine Generators and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Gas Turbine	Advanced Future w/ dry low-NOx burner	400 MW	2 (0)
2	Gas Turbine Generator	TEWAC	440 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2 (0)

Account 7 – Waste Heat Boiler, Ducting, and Stack

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Stack	CS plate, type 409SS liner	46 m (150 ft) high x 8.0 m (26 ft) diameter	2 (0)
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 317,753 kg/h, 16.5 MPa/593°C (700,524 lb/h, 2,400 psig/1,100°F) Reheat steam - 364,814 kg/h, 2.4 MPa/593°C (804,276 lb/h, 345 psig/1,100°F)	2 (0)
3	SCR Reactor	Space for spare layer	2,186,316 kg/h (4,820,000 lb/h)	2 (0)
4	SCR Catalyst	--	Space available for an additional catalyst layer	1 layer (0)
5	Dilution Air Blowers	Centrifugal	15 m^3/min @ 107 cm WG (530 scfm @ 42 in WG)	2 (1)
6	Ammonia Feed Pump	Centrifugal	3.8 lpm @ 91 m H_2O (1 gpm @ 300 ft H_2O)	2 (1)
7	Ammonia Storage Tank	Horizontal tank	90,851 liter (24,000 gal)	1 (0)

Account 8 – Steam Turbine Generator and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Steam Turbine	Tandem compound, HP, IP, and two-flow LP turbines	266 MW 16.5 MPa/596°C/596°C (2,400 psig/ 1,100°F/1,100°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	300 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)
3	Steam Bypass	One per HRSG	50% steam flow @ design steam conditions	2 (0)
4	Surface Condenser	Single pass, divided waterbox including vacuum pumps	917 GJ/hr, (870 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

Account 9 – Cooling Water System

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	552,674 lpm @ 30.5 m (146,000 gpm @ 100 ft)	2 (1)
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT 3,083 MMkJ/hr (2,924 MMBtu/hr) heat load	1 (0)

Account 10 – Ash Spent Sorbent Recovery and Handling

N/A

Account 11 – Accessory Electric Plant

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	CTG Transformer	Oil-filled	24 kV/345 kV, 440 MVA, 3-ph, 60 Hz	2 (0)
2	STG Transformer	Oil-filled	24 kV/345 kV, 250 MVA, 3-ph, 60 Hz	1 (0)
3	High Voltage Auxiliary Transformer	Oil-filled	345 kV/13.8 kV, 16 MVA, 3-ph, 60 Hz	2 (0)
4	Medium Voltage Transformer	Oil-filled	24 kV/4.16 kV, 45 MVA, 3-ph, 60 Hz	1 (1)
5	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 7 MVA, 3-ph, 60 Hz	1 (1)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
6	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2 (0)
7	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1 (0)
8	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1 (1)
9	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1 (1)
10	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

Account 12 – Instrumentation and Control

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	DCS - Main Control	Monitor/keyboard; Operator printer; Engineering printer	Operator stations/printers and engineering stations/printers	1 (0)
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1 (0)
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1 (0)

6.2.3 Cost Estimate Results

Capital and operating costs for Cases 4b using the advanced future turbine design were estimated by WorleyParsons based on simulation results, costing software, and vendor quotes/discussions on the projections of advanced machine designs from multiple vendors. All costs are in June 2011 dollars. The cost estimation results for this case are summarized in Exhibit 6-19. The summary and detailed capital cost estimates are shown in Exhibit 6-20 and Exhibit 6-21, respectively. The annual operating cost estimates are shown in Exhibit 6-22.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 6-19 Case 4b – Advanced/Future turbine with CO_2 capture cost estimation summary

Case	4b
Total Plant Cost (2011$/kW)	**1,041**
Total Overnight Cost (2011$/kW)	**1,271**
Total As-spent Capital (2011$/kW)	**1,370**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	18.95
Fixed O&M	4.77
Variable O&M	2.63
Fuel	39.86
CO_2 T&S total	3.14
COE[1] Total	**69.35**
LCOE[1], total (including T&S)	87.91
Cost[1,2] of CO_2 avoided, $/tonne of CO_2 ($/ton of CO_2)	73.00 (66.22)
Cost[1,2] of CO_2 captured, $/tonne of CO_2 ($/ton of CO_2)	54.23 (49.20)

[1] *Capacity factor assumed to be 85 percent*
[2] *Reference base case is 4a – Advanced/Future without capture*

Exhibit 6-20 Case 4b – Advanced/Future turbine with CO_2 capture capital cost estimate summary

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 4b - AdvFuture CCS
Plant Size: 988.5 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$32,122	$7,666	$12,008	$0	$0	**$51,797**	$4,253	$0	$9,101	**$65,151**	**$66**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0
5A	GAS CLEANUP & PIPING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
5B	CO2 REMOVAL & COMPRESSION	$207,455	$0	$65,446	$0	$0	**$272,901**	$22,781	$46,655	$68,467	**$410,805**	**$416**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$180,000	$0	$10,386	$0	$0	**$190,386**	$15,722	$0	$20,611	**$226,719**	$229
6.2-6.9	Combustion Turbine Other	$0	$1,221	$1,320	$0	$0	**$2,541**	$213	$0	$551	**$3,304**	$3
	SUBTOTAL 6	**$180,000**	**$1,221**	**$11,706**	**$0**	**$0**	**$192,927**	**$15,934**	**$0**	**$21,161**	**$230,023**	**$233**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$42,250	$0	$7,433	$0	$0	**$49,683**	$4,126	$0	$5,381	**$59,189**	$60
7.2-7.9	SCR System, Ductwork and Stack	$2,835	$1,769	$2,203	$0	$0	**$6,806**	$569	$0	$1,167	**$8,543**	$9
	SUBTOTAL 7	**$45,085**	**$1,769**	**$9,636**	**$0**	**$0**	**$56,489**	**$4,695**	**$0**	**$6,548**	**$67,732**	**$69**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$38,960	$0	$6,339	$0	$0	**$45,299**	$3,576	$0	$4,887	**$53,762**	$54
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$14,928	$1,075	$8,692	$0	$0	**$24,695**	$1,799	$0	$3,896	**$30,390**	$31
	SUBTOTAL 8	**$53,888**	**$1,075**	**$15,031**	**$0**	**$0**	**$69,994**	**$5,375**	**$0**	**$8,783**	**$84,152**	**$85**
9	COOLING WATER SYSTEM	$8,491	$8,975	$8,319	$0	$0	**$25,785**	$2,074	$0	$4,055	**$31,914**	$32
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$37,577	$10,465	$21,929	$0	$0	**$69,971**	$5,255	$0	$8,119	**$83,345**	$84
12	INSTRUMENTATION & CONTROL	$9,734	$1,101	$8,253	$0	$0	**$19,089**	$1,566	$954	$2,481	**$24,090**	$24
13	IMPROVEMENTS TO SITE	$2,748	$1,493	$7,781	$0	$0	**$12,022**	$1,065	$0	$2,617	**$15,704**	$16
14	BUILDINGS & STRUCTURES	$0	$6,292	$6,536	$0	$0	**$12,829**	$1,020	$0	$2,077	**$15,926**	$16
	TOTAL COST	**$577,102**	**$40,057**	**$166,644**	**$0**	**$0**	**$783,803**	**$64,019**	**$47,610**	**$133,410**	**$1,028,841**	**$1,041**

Exhibit 6-21 Case 4b – Advanced/Future turbine with CO_2 capture capital cost estimate detail

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 4b - AdvFuture CCS
Plant Size: 988.5 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,850	$3,987	$3,256	$0	$0	$11,093	$893	$0	$1,798	$13,785	$14
3.2	Water Makeup & Pretreating	$3,044	$315	$1,562	$0	$0	$4,921	$406	$0	$1,065	$6,392	$6
3.3	Other Feedwater Subsystems	$1,804	$596	$498	$0	$0	$2,898	$224	$0	$468	$3,590	$4
3.4	Service Water Systems	$368	$733	$2,361	$0	$0	$3,462	$294	$0	$751	$4,508	$5
3.5	Other Boiler Plant Systems	$2,477	$925	$2,129	$0	$0	$5,530	$450	$0	$897	$6,878	$7
3.6	Natural Gas, incl. pipeline	$17,827	$884	$765	$0	$0	$19,477	$1,607	$0	$3,163	$24,247	$25
3.7	Waste Treatment Equipment	$1,063	$0	$615	$0	$0	$1,679	$145	$0	$365	$2,188	$2
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,690	$226	$821	$0	$0	$2,736	$234	$0	$594	$3,564	$4
	SUBTOTAL 3.	**$32,122**	**$7,666**	**$12,008**	**$0**	**$0**	**$51,797**	**$4,253**	**$0**	**$9,101**	**$65,151**	**$66**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$179,258	$0	$54,018	$0	$0	$233,276	$19,464	$46,655	$59,879	$359,273	$363
5B.2	CO2 Compression & Drying	$28,198	$0	$11,428	$0	$0	$39,626	$3,317	$0	$8,589	$51,531	$52
	SUBTOTAL 5.	**$207,455**	**$0**	**$65,446**	**$0**	**$0**	**$272,901**	**$22,781**	**$46,655**	**$68,467**	**$410,805**	**$416**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$180,000	$0	$10,386	$0	$0	$190,386	$15,722	$0	$20,611	$226,719	$229
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$1,221	$1,320	$0	$0	$2,541	$213	$0	$551	$3,304	$3
	SUBTOTAL 6.	**$180,000**	**$1,221**	**$11,706**	**$0**	**$0**	**$192,927**	**$15,934**	**$0**	**$21,161**	**$230,023**	**$233**

Exhibit 6-21 Case 4b – Advanced/Future turbine with CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 4b - AdvFuture CCS
Plant Size: 988.5 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct		Equipment	Material	Labor		Sales	Bare Erected	Eng'g CM	Contingencies		TOTAL PLANT COST	
No.	Item/Description	Cost	Cost	Direct	Indirect	Tax	Cost	H.O.& Fee	Process	Project	$	$/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$42,250	$0	$7,433	$0	$0	$49,683	$4,126	$0	$5,381	$59,189	$60
7.2	HRSG Accessories	$2,835	$1,191	$1,661	$0	$0	$5,686	$476	$0	$924	$7,087	$7
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$578	$542	$0	$0	$1,120	$93	$0	$243	$1,456	$1
	SUBTOTAL 7.	**$45,085**	**$1,769**	**$9,636**	**$0**	**$0**	**$56,489**	**$4,695**	**$0**	**$6,548**	**$67,732**	**$69**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$38,960	$0	$6,339	$0	$0	$45,299	$3,576	$0	$4,887	$53,762	$54
8.2	Turbine Plant Auxiliaries	$251	$0	$558	$0	$0	$809	$69	$0	$88	$966	$1
8.3	Condenser & Auxiliaries	$2,190	$0	$1,298	$0	$0	$3,488	$293	$0	$378	$4,159	$4
8.4	Steam Piping	$12,487	$0	$5,061	$0	$0	$17,548	$1,196	$0	$2,812	$21,555	$22
8.9	TG Foundations	$0	$1,075	$1,775	$0	$0	$2,850	$241	$0	$618	$3,709	$4
	SUBTOTAL 8.	**$53,888**	**$1,075**	**$15,031**	**$0**	**$0**	**$69,994**	**$5,375**	**$0**	**$8,783**	**$84,152**	**$85**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$5,040	$0	$1,530	$0	$0	$6,570	$548	$0	$712	$7,830	$8
9.2	Circulating Water Pumps	$2,438	$0	$162	$0	$0	$2,600	$198	$0	$280	$3,078	$3
9.3	Circ.Water System Auxiliaries	$189	$0	$25	$0	$0	$214	$18	$0	$23	$255	$0
9.4	Circ.Water Piping	$0	$5,868	$1,328	$0	$0	$7,196	$539	$0	$1,160	$8,896	$9
9.5	Make-up Water System	$447	$0	$574	$0	$0	$1,021	$84	$0	$166	$1,271	$1
9.6	Component Cooling Water Sys	$377	$451	$290	$0	$0	$1,118	$89	$0	$181	$1,389	$1
9.9	Circ.Water System Foundations	$0	$2,656	$4,410	$0	$0	$7,066	$596	$0	$1,533	$9,195	$9
	SUBTOTAL 9.	**$8,491**	**$8,975**	**$8,319**	**$0**	**$0**	**$25,785**	**$2,074**	**$0**	**$4,055**	**$31,914**	**$32**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$10,032	$0	$5,934	$0	$0	$15,966	$1,311	$0	$1,296	$18,573	$19
11.2	Station Service Equipment	$3,379	$0	$290	$0	$0	$3,670	$302	$0	$298	$4,270	$4
11.3	Switchgear & Motor Control	$4,158	$0	$722	$0	$0	$4,880	$404	$0	$528	$5,813	$6
11.4	Conduit & Cable Tray	$0	$2,173	$6,260	$0	$0	$8,433	$702	$0	$1,370	$10,506	$11
11.5	Wire & Cable	$0	$6,983	$3,971	$0	$0	$10,954	$659	$0	$1,742	$13,354	$14
11.6	Protective Equipment	$0	$1,075	$3,732	$0	$0	$4,807	$413	$0	$522	$5,743	$6
11.7	Standby Equipment	$163	$0	$152	$0	$0	$316	$27	$0	$34	$376	$0
11.8	Main Power Transformers	$19,844	$0	$272	$0	$0	$20,116	$1,366	$0	$2,148	$23,630	$24
11.9	Electrical Foundations	$0	$234	$595	$0	$0	$829	$70	$0	$180	$1,079	$1
	SUBTOTAL 11.	**$37,577**	**$10,465**	**$21,929**	**$0**	**$0**	**$69,971**	**$5,255**	**$0**	**$8,119**	**$83,345**	**$84**

Exhibit 6-21 Case 4b – Advanced/Future turbine with CO_2 capture capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2011-Dec-15
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 4b - AdvFuture CCS
Plant Size: 988.5 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,238	$0	$788	$0	$0	$2,026	$170	$101	$345	$2,642	$3
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$370	$0	$226	$0	$0	$596	$50	$30	$101	$777	$1
12.7	Computer & Accessories	$5,920	$0	$181	$0	$0	$6,101	$501	$305	$691	$7,597	$8
12.8	Instrument Wiring & Tubing	$0	$1,101	$1,949	$0	$0	$3,050	$219	$152	$513	$3,935	$4
12.9	Other I & C Equipment	$2,207	$0	$5,109	$0	$0	$7,316	$626	$366	$831	$9,139	$9
	SUBTOTAL 12.	**$9,734**	**$1,101**	**$8,253**	**$0**	**$0**	**$19,089**	**$1,566**	**$954**	**$2,481**	**$24,090**	**$24**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$147	$3,119	$0	$0	$3,266	$285	$0	$710	$4,261	$4
13.2	Site Improvements	$0	$1,346	$1,778	$0	$0	$3,124	$278	$0	$680	$4,083	$4
13.3	Site Facilities	$2,748	$0	$2,883	$0	$0	$5,631	$502	$0	$1,227	$7,360	$7
	SUBTOTAL 13.	**$2,748**	**$1,493**	**$7,781**	**$0**	**$0**	**$12,022**	**$1,065**	**$0**	**$2,617**	**$15,704**	**$16**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$431	$228	$0	$0	$659	$51	$0	$106	$816	$1
14.2	Steam Turbine Building	$0	$2,699	$3,591	$0	$0	$6,290	$506	$0	$1,019	$7,816	$8
14.3	Administration Building	$0	$705	$477	$0	$0	$1,182	$92	$0	$191	$1,465	$1
14.4	Circulation Water Pumphouse	$0	$224	$111	$0	$0	$335	$26	$0	$54	$415	$0
14.5	Water Treatment Buildings	$0	$646	$589	$0	$0	$1,235	$97	$0	$200	$1,532	$2
14.6	Machine Shop	$0	$611	$391	$0	$0	$1,002	$78	$0	$162	$1,242	$1
14.7	Warehouse	$0	$395	$238	$0	$0	$633	$49	$0	$102	$784	$1
14.8	Other Buildings & Structures	$0	$118	$86	$0	$0	$204	$16	$0	$33	$253	$0
14.9	Waste Treating Building & Str.	$0	$463	$826	$0	$0	$1,288	$105	$0	$209	$1,602	$2
	SUBTOTAL 14.	**$0**	**$6,292**	**$6,536**	**$0**	**$0**	**$12,829**	**$1,020**	**$0**	**$2,077**	**$15,926**	**$16**
	TOTAL COST	**$577,102**	**$40,057**	**$166,644**	**$0**	**$0**	**$783,803**	**$64,019**	**$47,610**	**$133,410**	**$1,028,841**	**$1,041**

Exhibit 6-21 Case 4b – Advanced/Future turbine with CO_2 capture capital cost estimate detail (continued)

	Client:	USDOE/NETL							**Report Date:**	2011-Dec-15		
	Project:	Costing Support for NGCC with CCS Analyses										
		TOTAL PLANT COST SUMMARY										
	Case:	Case 4b - AdvFuture CCS										
	Plant Size:	988.5 MW,net		**Estimate Type:**		Conceptual			**Cost Base (Jun)**	2011	($x1000)	
Acct 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 $**	**TOTAL PLANT COST $/kW**	
	TOTAL COST	**$577,102**	**$40,057**	**$166,644**	**$0**	**$783,803**	**$64,019**	**$47,610**	**$133,410**	**$1,028,841**	**$1,041**	
	Owner's Costs											
	Preproduction Costs											
	6 Months All Labor									$7,268	$7	
	1 Month Maintenance Materials									$1,289	$1	
	1 Month Non-fuel Consumables									$606	$1	
	1 Month Waste Disposal									$0	$0	
	25% of 1 Months Fuel Cost at 100% CF									$7,192	$7	
	2% of TPC									$20,577	$21	
	Total									**$36,931**	**$37**	
	Inventory Capital											
	60 day supply of consumables at 100% CF									$844	$1	
	0.5% of TPC (spare parts)									$5,144	$5	
	Total									**$5,988**	**$6**	
	Initial Cost for Catalyst and Chemicals									$2,126	$2	
	Land									$300	$0	
	Other Owner's Costs									$154,326	$156	
	Financing Costs									$27,779	$28	
	Total Overnight Costs (TOC)									**$1,256,292**	**$1,271**	
	TASC Multiplier							(IOU, high-risk, 33 year)		1.078		
	Total As-Spent Cost (TASC)									**$1,354,283**	**$1,370**	

Exhibit 6-22 Case 4b – Advanced/Future turbine with CO_2 capture operating cost estimate

INITIAL & ANNUAL O&M EXPENSES						
					Cost Base (Jun)	2011
Case 4b - AdvFuture CCS					Heat Rate-net (Btu/kWh):	6,503
					MWe-net:	989
					Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR						
Operating Labor						
Operating Labor Rate(base):	39.70	$/hour				
Operating Labor Burden:	30.00	% of base				
Labor O-H Charge Rate:	25.00	% of labor				
			Total			
Skilled Operator	1.0		1.0			
Operator	3.3		3.3			
Foreman	1.0		1.0			
Lab Tech's, etc.	1.0		1.0			
TOTAL-O.J.'s	6.3		6.3			
					Annual Cost	Annual Unit Cost
					$	$/kW-net
Annual Operating Labor Cost					$2,861,816	$2.895
Maintenance Labor Cost					$8,766,960	$8.869
Administrative & Support Labor					$2,907,194	$2.941
Property Taxes and Insurance					$20,576,829	$20.816
TOTAL FIXED OPERATING COSTS					**$35,112,799**	**$35.521**
VARIABLE OPERATING COSTS						
						$/kWh-net
Maintenance Material Cost					**$13,150,441**	**$0.00179**
Consumables	Consumption Initial Fill	Consumption /Day	Unit Cost	Initial Fill Cost		
Water (/1000 gallons)	0.00	3,604.32	1.67	**$0**	**$1,871,928**	**$0.00025**
Chemicals						
MU & WT Chem.(lbs)	0.00	21,473.49	0.27	$0	$1,784,385	$0.00024
MEA Solvent (ton)	587.60	0.83	3,481.91	$2,045,955	$891,411	$0.00012
Activated Carbon (lb)	0.00	985.72	1.63	$0	$497,027	$0.00007
Corrosion Inhibitor	0.00	0.00	0.00	$80,500	$3,833	$0.00000
SCR Catalyst (m3)	w/equip.	0.10	8,938.80	$0	$274,977	$0.00004
Ammonia (19% NH3) (ton)	0.00	8.34	330.00	$0	$853,789	$0.00012
Subtotal Chemicals				**$2,126,455**	**$4,305,423**	**$0.00058**
Other						
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0	$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0	$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$0**	**$0.00000**
Waste Disposal						
Flyash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal Waste Disposal				**$0**	**$0**	**$0.00000**
By-products						
Sulfur (tons)	0.00	0.00	0.00	$0	$0	$0.00000
Subtotal By-products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$2,126,455**	**$19,327,791**	**$0.00262**
Fuel (MMBtu)	0	154,280	6.13	**$0**	**$293,414,792**	**$0.03984**

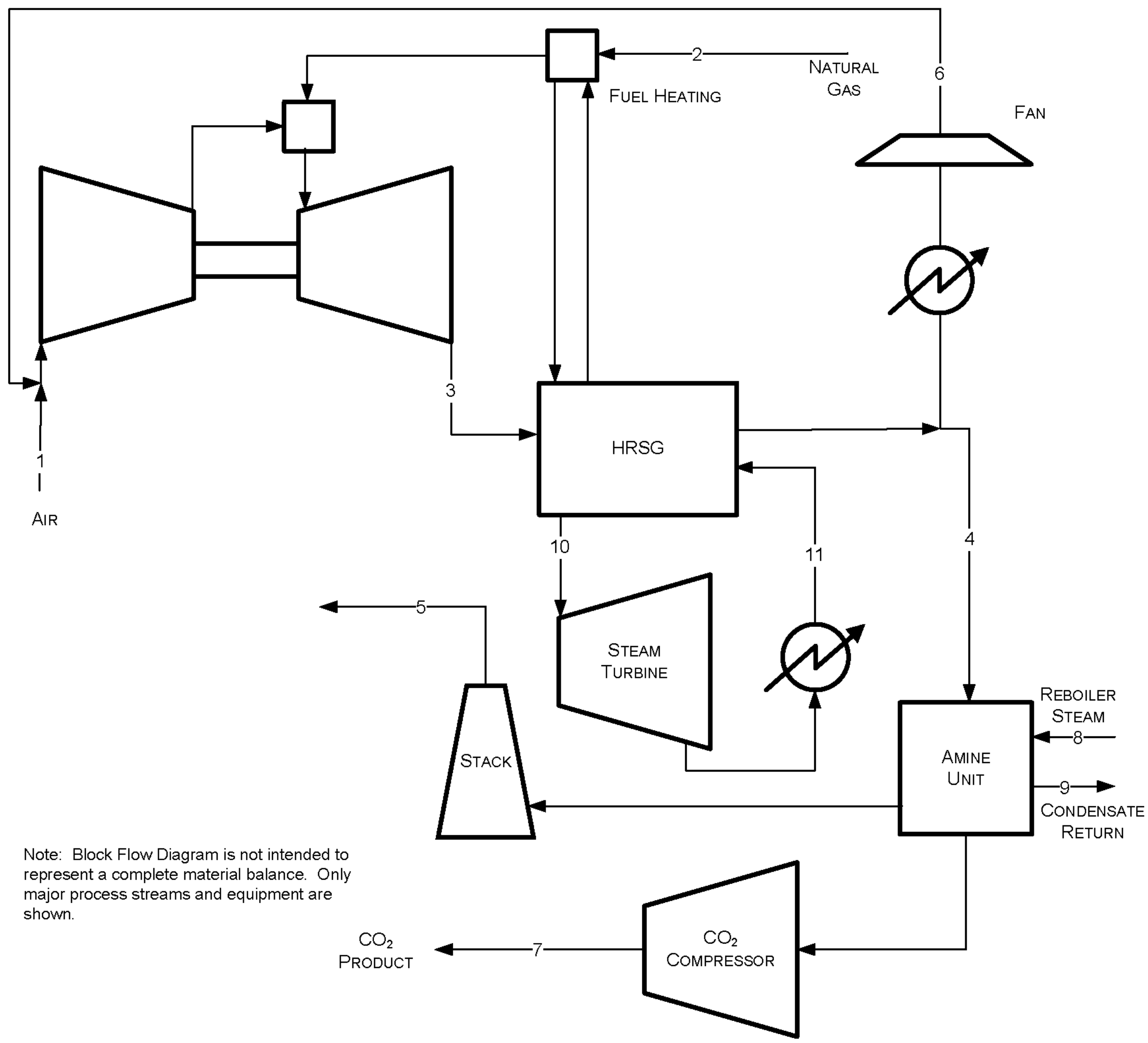
6.3 Case 4c – NGCC with CO_2 Capture and EGR Modeling Results

The block flow diagram of the combined cycle with CO_2 capture and EGR is shown in Exhibit 6-23. This case also uses the same generic "X" frame gas turbine model as that of Case 4a with the addition of EGR and CO_2 capture at the back end. Exhibit 6-24 provides process data for the numbered streams in the BFD. The BFD shows only one of the two GT/HRSG combinations, but the flow rates in the stream table are the total for two systems. The heat required for the solvent (amine) system in the CO_2 capture system is supplied from the Rankine cycle (stream 4) similar to case 4b.

Ambient air (stream 1) and natural gas (stream 2) are combined in the dry LNB, which is operated to control the rotor inlet temperature at 1,706°C (3,104°F). The flue gas exits the turbine at 647°C (1,197°F) (stream 3) and passes into the HRSG. The HRSG generates both the main steam and reheat steam for the steam turbine as well as the steam required for the capture process (stream 8). Flue gas exits the HRSG (stream 4) at 108°C (227°F). A portion of the stream (stream 6) is recycled back to the air inlet and the remainder (stream 4) passes to the capture system where the CO_2 is captured and compressed (stream 7). Cooling is supplied to the steam turbine condenser via water from the cooling tower.

The gas turbine (Brayton cycle) performance and exhaust characteristics are impacted due to addition of the EGR. Of particular interest is that the CO_2 composition at gas turbine exhaust increases from 5.0 percent in the capture only case (Case 4b) to 7.8 percent in this capture with EGR case. The O_2 composition concurrently decreases from 10.0 percent in the capture only case (Case 4b) to 4.9 percent in this capture with EGR. The higher concentration of the CO_2 in the exhaust gas stream reduces the energy consumption of the CO_2 capture system. Because of this, the EGR case provides a better output and efficiency compared to the capture case without EGR (Case 4b). However, the overall plant output and efficiency are reduced compared to the no CO_2 capture case (Case 4a) due to heat integration requirements and increased auxiliary loads for the EGR and CO_2 capture process.

Exhibit 6-23 Case 4c – Advanced/Future turbine with CO_2 capture and EGR block flow diagram



Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Source: NETL

Exhibit 6-24 Case 4c – Advanced/Future turbine with CO_2 capture and EGR stream table

	1	2	3	4	5	6	7	8	9	10	11
V-L Mole Fraction											
Ar	0.0093	0.0000	0.0090	0.0090	0.0104	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000
CH_4	0.0000	0.9310	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_2H_6	0.0000	0.0320	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3H_8	0.0000	0.0070	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	0.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO_2	0.0003	0.0100	0.0775	0.0775	0.0090	0.0837	1.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0101	0.0000	0.1185	0.1185	0.0555	0.0480	0.0000	1.0000	1.0000	1.0000	1.0000
N_2	0.7729	0.0160	0.7460	0.7460	0.8680	0.8057	0.0000	0.0000	0.0000	0.0000	0.0000
O_2	0.2074	0.0000	0.0491	0.0491	0.0571	0.0530	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	1.0001	1.0000	1.0000	1.0000	1.0000	1.0000
V-L Flowrate (kg_{mol}/hr)	98,134	7,544	156,709	101,861	87,528	50,777	7,102	19,542	19,542	33,565	22,805
V-L Flowrate (kg/hr)	2,832,158	130,733	4,445,822	2,889,801	2,447,276	1,482,703	312,543	352,060	352,060	604,675	410,846
Solids Flowrate (kg/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°C)	15	38	647	108	35	33	38	292	137	593	32
Pressure (MPa, abs)	0.10	4.14	0.10	0.10	0.10	0.10	15.17	0.33	0.33	16.65	0.00
Enthalpy (kJ/kg)^A	0.92	47,245.71	380.53	494.74	49.47	133.21	445.20	3,052.18	574.75	3,547.62	2,384.85
Density (kg/m^3)	1.2	27.7	0.4	0.9	1.1	1.2	796.4	2.7	915.8	47.7	992.9
V-L Molecular Weight	28.860	17.330	28.370	28.370	27.960	29.200	44.010	18.015	18.015	18.015	18.015
V-L Flowrate (lb_{mol}/hr)	216,349	16,631	345,483	224,565	192,966	111,945	15,656	43,083	43,083	73,997	50,277
V-L Flowrate (lb/hr)	6,243,840	288,216	9,801,360	6,370,920	5,395,320	3,268,800	689,040	776,160	776,160	1,333,080	905,760
Solids Flowrate (lb/hr)	0	0	0	0	0	0	0	0	0	0	0
Temperature (°F)	59	100	1,197	227	95	92	101	557	278	1,100	90
Pressure (psia)	14.7	600.0	15.2	14.7	14.7	14.7	2,200.0	47.6	47.6	2,414.7	0.7
Enthalpy (Btu/lb)^A	13.0	19.9	305.3	38.5	4.5	3.6	-97.1	1,312.2	247.1	1,525.2	1,025.3
Density (lb/ft^3)	0.076	1.731	0.024	0.057	0.069	0.072	49.720	0.169	57.172	2.977	61.982

Note: Total flow rates shown equal the sum for all process trains

6.3.1 Performance Results

The performance results are summarized in Exhibit 6-25 and when compared with Case 4b show that adding exhaust gas recycle increases the efficiency only by approximately 0.4 percentage points. This is due to lowering the steam requirement for the reboiler slightly (to 2,790 kJ/kg CO_2 (1,200 Btu/lb CO_2) from the 2,960 kJ/kg CO_2 (1,272 Btu/lb CO_2) used in Case 4b), based on the CO_2 concentration increasing and the oxygen concentration decreasing for the exhaust gas entering the solvent recovery section. An additional improvement would be expected if the exhaust gas recycle was increased from the 35 percent used to 50 percent. This was not explored in the current study since it was determined based on information from GE that 35 percent was a limit above which the gas turbine's combustor would need major redesign. Additional tables below provide overall energy balance (Exhibit 6-26), water balance (Exhibit 6-27), carbon balance (Exhibit 6-28), and an emissions summary (Exhibit 6-29).

Exhibit 6-25 Case 4c – Advanced/Future turbine with CO_2 capture and EGR plant performance summary
(Values shown are for total 2x2x1 system)

Plant Output		
Gas Turbine Power	811,186	kW_e
Steam Turbine Power	266,140	kW_e
Total	**1,077,326**	kW_e
Auxiliary Load		
Condensate Pumps	245	kW_e
Boiler Feedwater Pumps	7,023	kW_e
Exhaust Gas Recycle Fan	443	kW_e
Amine CO_2 Capture System Auxiliaries	15,923	kW_e
CO_2 Compression	28,961	kW_e
EGR Coolant Pump	448	kW_e
Circulating Water Pump	6,110	kW_e
Ground Water Pumps	490	kW_e
Cooling Tower Fans	3,890	kW_e
SCR	10	kW_e
Gas Turbine Auxiliaries	1,097	kW_e
Steam Turbine Auxiliaries	671	kW_e
Miscellaneous Balance of Plant[2]	5,155	kW_e
Transformer Losses	3,000	kW_e
Total	**73,466**	**kW_e**
Plant Performance		
Net Plant Power	**1,003,860**	**kW_e**
Plant Capacity Factor	85.0	
Net Plant Efficiency (HHV)[1]	52.8%	
Net Plant Efficiency (LHV)[1]	58.5%	
Net Plant Heat Rate (HHV)[1]	6,813 (6,458)	kJ/kWh (Btu/kWh)
Net Plant Heat Rate (LHV)[1]	6,150 (5,829)	kJ/kWh (Btu/kWh)
Natural Gas Feed Flow	130,733 (288,216)	kg/hr (lb/hr)
Thermal Input (HHV)[1]	1,899,942	kW_t
Thermal Input (LHV)[1]	1,714,916	kW_t
Condenser Duty	928 (880)	GJ/hr (MMBtu/hr)
Raw Water Withdrawal	20.5 (5,411)	m^3/min (gpm)
Raw Water Consumption	14.5 (3,844)	m^3/min (gpm)

[1] *HHV of Natural Gas 52,314 kJ/kg (22,491 Btu/lb)*
LHV of Natural Gas 47,220 kJ/kg (20,301 Btu/lb)
[2] *Includes plant control systems, lighting, HVAC, and miscellaneous low voltage loads*

Exhibit 6-26 Case 4c – Advanced/Future turbine with CO_2 capture and EGR overall energy balance

	HHV	Sensible + Latent	Power	Total
Energy In, GJ/hr (MMBtu/hr)				
Natural Gas	6,840 (6,483)	4.6 (4.3)	0 (0)	6,844 (6,487)
GT Air	0 (0)	85.6 (81.1)	0 (0)	86 (81)
Raw Water Withdrawal	0 (0)	77.0 (73.0)	0 (0)	77 (73)
Auxiliary Power	0 (0)	0.0 (0.0)	264 (251)	264 (251)
TOTAL	**6,840 (6,483)**	**167.2 (158.5)**	**264 (251)**	**7,271 (6,892)**
Energy Out, GJ/hr (MMBtu/hr)				
Cooling Tower Blowdown	0 (0)	39.8 (37.7)	0 (0)	40 (38)
Stack Gas	0 (0)	26 (24)	0 (0)	26 (24)
Condenser	0 (0)	924 (876)	0 (0)	924 (876)
CO_2 Product	0 (0)	-70.6 (-66.9)	0 (0)	-71 (-67)
CO_2 Intercoolers	0 (0)	181.2 (171.7)	0 (0)	181 (172)
EGR Cooling	0 (0)	309.6 (293.5)	0 (0)	310 (293)
Amine System Losses	0 (0)	1,252.7 (1,187.4)	0 (0)	1,253 (1,187)
Process Losses*	*0 (0)*	*730 (692)*	*0 (0)*	*730 (692)*
Power	0 (0)	0.0 (0.0)	3,878 (3,676)	3,878 (3,676)
TOTAL	**0 (0)**	**3,393 (3,216)**	**3,878 (3,676)**	**7,271 (6,892)**

Note: Italicized numbers are estimated
** Process losses are estimated to match the heat input to the plant.*
Process losses include losses from: HRSG, combustion reactions, and gas cooling

Exhibit 6-27 Case 4c – Advanced/Future turbine with CO_2 capture and EGR water balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Withdrawal, m^3/min (gpm)	Process Water Discharge, m^3/min (gpm)	Raw Water Usage, m^3/min (gpm)
Amine Capture System	0.08 (20)	0.0 (0)	0.1 (20)	0.0 (0)	0.1 (20)
Condenser Makeup	**0.06 (15)**	**0.0 (0)**	**0.06 (15)**	**0.0 (0)**	**0.1 (15)**
BFW Makeup	0.06 (15)	0.0 (0)	0.06 (15)	0.0 (0)	0.0 (0)
Cooling Tower	**23.8 (6,286)**	**3.5 (912)**	**20.34 (5,375)**	**5.9 (1,567)**	**14.4 (3,808)**
BFW Blowdown	0.00 (0)	0.06 (15)	-0.06 (-15)	0.0 (0)	0.0 (0)
EGR Condensate	0.00 (0)	1.2 (324)	-1.2 (-324)	0.0 (0)	0.0 (0)
Flue Gas/CO_2 Condensate	0.00 (0)	2.2 (573)	-2.2 (-573)	0.0 (0)	0.0 (0)
Total	**23.9 (6,322)**	**3.45 (912)**	**20.51 (5,411)**	**5.9 (1,567)**	**14.5 (3,844)**

Exhibit 6-28 Case 4c – Advanced/Future turbine with CO_2 capture and EGR carbon balance

Carbon In, kg/hr (lb/hr)		Carbon Out, kg/hr (lb/hr)	
Natural Gas	94,413 (208,145)	Stack Gas	9,478 (20,896)
Air (CO_2)	354 (780)	CO_2 Product	85,298 (188,050)
		Convergence Tolerance*	-10 (-21)
Total	**94,767 (208,925)**	**Total**	**94,767 (208,925)**

**by difference*

Emissions are estimated based on user input specifications to models.

Exhibit 6-29 Case 4c – Advanced/Future turbine with CO_2 capture and EGR air emissions

	Kg/GJ ($lb/10^6$ Btu)	Tonne/year (tons/year) 90% capacity	kg/MWh (lb/MWh)
SO_2	negligible	negligible	negligible
NO_X	0.002 (0.004)	82 (91)	0.010 (0.023)
Particulates	negligible	negligible	negligible
Hg	negligible	negligible	negligible
CO_2	5.1 (11.8)	258,602 (285,060)	32 (71)
CO_2[1]			35 (76)

[1] CO_2 emissions based on net power instead of gross power

6.3.2 Major Equipment List

This section contains the equipment list corresponding to the advanced/future turbine design with CO_2 capture and EGR plant configuration for case 4c. This list, along with the heat and material balance and supporting performance data, was used to generate plant costs. The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as N/A.

Account 1 – Coal and Sorbent Handling

N/A

Account 2 – Coal and Sorbent Preparation and Feed

N/A

Account 3 - Feedwater and Miscellaneous Systems and Equipment

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Demineralized Water Storage Tank	Vertical, cylindrical, outdoor	454,253 liters (120,000 gal)	2 (0)
2	Condensate Pumps	Vertical canned	3,785 lpm @ 40 m H_2O (1,000 gpm @ 130 ft H_2O)	2 (1)
3	Boiler Feedwater Pump	Horizontal, split case, multi-stage, centrifugal, with interstage bleed for IP and LP feedwater	HP water: 5,640 lpm @ 1,887 m H_2O (1,490 gpm @ 6,190 ft H_2O) IP water: 7,192 lpm @ 323 m H_2O (1,900 gpm @ 1,060 ft H_2O) LP water: 7,079 lpm @ 9.1 m H_2O (1870 gpm @ 30 ft H_2O)	2 (1)
4	Auxiliary Boiler	Shop fabricated, water tube	18,144 kg /hr, 2.8 MPa, 343°C (40,000 lb /hr, 400 psig, 650°F)	1 (0)
5	Service Air Compressors	Flooded Screw	13 m^3/min @ 0.7 MPa (450 scfm @ 100 psig)	2 (1)
6	Instrument Air Dryers	Duplex, regenerative	13 m^3/min (450 scfm)	2 (1)
7	Closed Cycle Cooling Heat Exchangers	Plate and frame	13 GJ/hr (13 MMBtu/hr)	2 (0)
8	Closed Cycle Cooling Water Pumps	Horizontal centrifugal	5,300 lpm @ 21 m H_2O (1,400 gpm @ 70 ft H_2O)	2 (1)
9	Engine-driven Fire Pump	Vertical turbine, diesel engine	3,785 lpm @ 107 m H_2O (1,000 gpm @ 350 ft H_2O)	1 (1)
10	Fire Service Booster Pump	Two-stage horizontal centrifugal	2,650 lpm @ 76 m H_2O (700 gpm @ 250 ft H_2O)	1 (1)
11	Raw Water Pumps	Stainless steel, single suction	13,627 lpm @ 18 m H_2O (3,600 gpm @ 60 ft H_2O)	2 (1)
12	Filtered Water Pumps	Stainless steel, single suction	360 lpm @ 49 m H_2O (95 gpm @ 160 ft H_2O)	2 (1)
13	Filtered Water Tank	Vertical, cylindrical	344,475 liter (91,000 gal)	1 (0)
14	Makeup Water Demineralizer	Multi-media filter, cartridge filter, RO membrane assembly and electro-deionization unit	795 lpm (210 gpm)	1 (0)
15	Liquid Waste Treatment System		10 years, 24-hour storm	1 (0)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
16	Gas Pipeline	Underground, coated carbon steel, wrapped cathodic protection	86 m^3/min @ 4.1 MPa (3,053 acfm @ 600 psia) 41 cm (16 in) standard wall pipe	16 km 10 mile
17	Gas Metering Station	--	86 m^3/min (3,053 acfm)	1 (0)

Account 4 – Gasifier, Boiler, and Accessories

N/A

Account 5 – Flue Gas Cleanup

N/A

Account 5B – CO_2 Capture and Compression

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Amine CO_2 Capture System	Amine-based CO_2 capture technology	1,589,390 kg/hr (3,504,000 lb/hr) 12.0 wt % CO_2 concentration	2 (0)
2	CO_2 Compressor	Integrally geared, multi-stage centrifugal	171,912 kg/hr @ 15.2 MPa (379,000 lb/hr @ 2,200 psia)	2 (0)
3	Exhaust Gas Recycle Blowers	Centrifugal	11,700 m^3/min @ 12.7 cm WG (413,290 scfm @ 5 in WG)	2 (0)
4	EGR Cooler	Contact Heat Exchanger	137 MMkJ/hr, (130 MMBtu/hr), Gas Stream 1,674,000 kg/hr, (3,691,000 lb/hr) 30,540 m^3/min, (1,079,000 acfm) from 106°C (222.8°F) to 32°C (90°F), Water Stream 6,019,000 kg/hr, (13,270,000 lb/hr) 6,977,000 lpm, (1,843,000 gpm) from 18°C (64.5°F) to 29°C (84.54°F)	1 (0)
5	EGR Cooler Pumps	Horizontal Centrifugal	61,430 lpm @ 18 m H_2O (16,230 gpm @ 60 ft H_2O)	4 (0)

Account 6 – Combustion Turbine Generators and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Gas Turbine	Advanced Future w/ dry low-NOx burner	395 MW	2 (0)
2	Gas Turbine Generator	TEWAC	440 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	2 (0)

Account 7 – Waste Heat Boiler, Ducting, and Stack

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Stack	CS plate, type 409SS liner	46 m (150 ft) high x 8.0 m (26 ft) diameter	2 (0)
2	Heat Recovery Steam Generator	Drum, multi-pressure with economizer section and integral deaerator	Main steam - 332,572 kg/h, 16.5 MPa/593°C (733,194 lb/h, 2,400 psig/1,100°F) Reheat steam - 376,489 kg/h, 2.4 MPa/593°C (830,016 lb/h, 345 psig/1,100°F)	2 (0)
3	SCR Reactor	Space for spare layer	1,347,171 kg/h (2,970,000 lb/h)	2 (0)
4	SCR Catalyst	--	Space available for an additional catalyst layer	1 layer (0)
5	Dilution Air Blowers	Centrifugal	15 m^3/min @ 107 cm WG (530 scfm @ 42 in WG)	2 (1)
6	Ammonia Feed Pump	Centrifugal	3.8 lpm @ 91 m H_2O (1 gpm @ 300 ft H_2O)	2 (1)
7	Ammonia Storage Tank	Horizontal tank	90,851 liter (24,000 gal)	1 (0)

Account 8 – Steam Turbine Generator and Auxiliaries

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Steam Turbine	Tandem compound, HP, IP, and two-flow LP turbines	280 MW 16.5 MPa/593°C/593°C (2,400 psig/ 1100°F/1100°F)	1 (0)
2	Steam Turbine Generator	Hydrogen cooled, static excitation	230 MVA @ 0.9 p.f., 24 kV, 60 Hz, 3-phase	1 (0)
3	Steam Bypass	One per HRSG	50% steam flow @ design steam conditions	2 (0)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
4	Surface Condenser	Single pass, divided waterbox including vacuum pumps	1,012 MMkJ/hr, (960 MMBtu/hr), Inlet water temperature 16°C (60°F), Water temperature rise 11°C (20°F)	1 (0)

Account 9 – Cooling Water System

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	Circulating Water Pumps	Vertical, wet pit	613,241 lpm @ 30.5 m (162,000 gpm @ 100 ft)	2 (1)
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	11°C (51.5°F) wet bulb / 16°C (60°F) CWT / 27°C (80°F) HWT 3,416 MMkJ/hr (3,240 MMBtu/hr) heat load	1 (0)

Account 10 – Ash Spent Sorbent Recovery and Handling

N/A

Account 11 – Accessory Electric Plant

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	CTG Transformer	Oil-filled	24 kV/345 kV, 440 MVA, 3-ph, 60 Hz	2 (0)
2	STG Transformer	Oil-filled	24 kV/345 kV, 260 MVA, 3-ph, 60 Hz	1 (0)
3	High Voltage Auxiliary Transformer	Oil-filled	345 kV/13.8 kV, 16 MVA, 3-ph, 60 Hz	2 (0)
4	Medium Voltage Transformer	Oil-filled	24 kV/4.16 kV, 46 MVA, 3-ph, 60 Hz	1 (1)
5	Low Voltage Transformer	Dry ventilated	4.16 kV/480 V, 7 MVA, 3-ph, 60 Hz	1 (1)
6	CTG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	2 (0)
7	STG Isolated Phase Bus Duct and Tap Bus	Aluminum, self-cooled	24 kV, 3-ph, 60 Hz	1 (0)

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
8	Medium Voltage Switchgear	Metal clad	4.16 kV, 3-ph, 60 Hz	1 (1)
9	Low Voltage Switchgear	Metal enclosed	480 V, 3-ph, 60 Hz	1 (1)
10	Emergency Diesel Generator	Sized for emergency shutdown	750 kW, 480 V, 3-ph, 60 Hz	1 (0)

Account 12 – Instrumentation and Control

Equipment No.	Description	Type	Design Condition	Oper. Qty. (Spares)
1	DCS - Main Control	Monitor/keyboard; Operator printer; Engineering printer	Operator stations/printers and engineering stations/printers	1 (0)
2	DCS - Processor	Microprocessor with redundant input/output	N/A	1 (0)
3	DCS - Data Highway	Fiber optic	Fully redundant, 25% spare	1 (0)

6.3.3 Cost Estimate Results

Capital and operating costs for Cases 4c using the advanced future turbine design were estimated by WorleyParsons based on simulation results, costing software, and vendor quotes/discussions on the projections of advanced machine designs from multiple vendors. All costs are in June 2011 dollars. The cost estimation results for this case are summarized in Exhibit 6-30. The summary and detailed capital cost estimates are shown in Exhibit 6-31 and Exhibit 6-32, respectively. The annual operating cost estimates are shown in Exhibit 6-33.

The equipment cost account numbers are based on standard power plant cost estimation designations. Not all accounts are applicable to NGCC plants, but the numbering was kept consistent to allow comparison between multiple studies. Accounts not applicable to NGCC plants are shown as zero.

Exhibit 6-30 Case 4c - Advanced/Future turbine with CO_2 capture and EGR cost estimation summary

Case	4c
Total Plant Cost (2011$/kW)	**974**
Total Overnight Cost (2011$/kW)	**1,190**
Total As-spent Capital (2011$/kW)	**1,283**
COE[1] Component Details (mills/kWh or $/MWh)	
Capital	17.74
Fixed O&M	4.58
Variable O&M	2.65
Fuel	39.59
CO_2 T&S total	3.11
COE[1] Total	**67.67**
LCOE[1], total (including T&S)	85.78
Cost[1,2] of CO_2 avoided, $/tonne of CO_2 ($/ton of CO_2)	66.86 (60.66)
Cost[1,2] of CO_2 captured, $/tonne of CO_2 ($/ton of CO_2)	49.44 (44.85)

[1] *Capacity factor assumed to be 85 percent*
[2] *Reference base case is 4a – Advanced/Future without capture*

Exhibit 6-31 Case 4c - Advanced/Future turbine with CO_2 capture and EGR capital cost estimate summary

Client: USDOE/NETL **Report Date:** 2012-Apr-04
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 4c - AdvFuture CCS EGR
Plant Size: 1003.9 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
2	COAL & SORBENT PREP & FEED	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
3	FEEDWATER & MISC. BOP SYSTEMS	$32,720	$7,938	$12,523	$0	$0	**$53,181**	$4,367	$0	$9,358	**$66,906**	**$67**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	$0
5A	GAS CLEANUP & PIPING	$0	$9,768	$6,171	$0	$0	**$15,939**	$1,243	$0	$3,436	**$20,618**	$21
5B	CO2 REMOVAL & COMPRESSION	$160,971	$0	$51,495	$0	$0	**$212,467**	$17,739	$34,566	$52,954	**$317,726**	**$317**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$189,000	$0	$10,905	$0	$0	**$199,905**	$16,508	$0	$21,641	**$238,055**	$237
6.2-6.9	Combustion Turbine Other	$0	$1,221	$1,320	$0	$0	**$2,541**	$213	$0	$551	**$3,304**	$3
	SUBTOTAL 6	**$189,000**	**$1,221**	**$12,226**	**$0**	**$0**	**$202,446**	**$16,721**	**$0**	**$22,192**	**$241,359**	**$240**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$43,320	$0	$7,621	$0	$0	**$50,941**	$4,230	$0	$5,517	**$60,688**	$60
7.2-7.9	SCR System, Ductwork and Stack	$2,838	$1,783	$2,217	$0	$0	**$6,837**	$572	$0	$1,173	**$8,582**	$9
	SUBTOTAL 7	**$46,158**	**$1,783**	**$9,837**	**$0**	**$0**	**$57,778**	**$4,802**	**$0**	**$6,690**	**$69,270**	**$69**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$40,600	$0	$6,606	$0	$0	**$47,206**	$3,726	$0	$5,093	**$56,025**	$56
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$15,434	$1,116	$9,239	$0	$0	**$25,789**	$1,884	$0	$4,051	**$31,725**	$32
	SUBTOTAL 8	**$56,034**	**$1,116**	**$15,845**	**$0**	**$0**	**$72,995**	**$5,611**	**$0**	**$9,145**	**$87,750**	**$87**
9	COOLING WATER SYSTEM	$9,103	$9,551	$8,870	$0	$0	**$27,523**	$2,214	$0	$4,323	**$34,060**	$34
10	ASH/SPENT SORBENT HANDLING SYS	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	**$0**	$0
11	ACCESSORY ELECTRIC PLANT	$37,754	$10,403	$21,903	$0	$0	**$70,060**	$5,262	$0	$8,119	**$83,441**	$83
12	INSTRUMENTATION & CONTROL	$9,787	$1,107	$8,298	$0	$0	**$19,192**	$1,575	$960	$2,494	**$24,221**	$24
13	IMPROVEMENTS TO SITE	$2,765	$1,502	$7,828	$0	$0	**$12,095**	$1,072	$0	$2,633	**$15,800**	$16
14	BUILDINGS & STRUCTURES	$0	$6,424	$6,692	$0	$0	**$13,116**	$1,043	$0	$2,124	**$16,282**	$16
	TOTAL COST	**$544,291**	**$50,813**	**$161,687**	**$0**	**$0**	**$756,791**	**$61,646**	**$35,526**	**$123,469**	**$977,432**	**$974**

Exhibit 6-32 Case 4c - Advanced/Future turbine with CO_2 capture and EGR capital cost estimate detail

Client:	USDOE/NETL	**Report Date:**	2012-Apr-04
Project:	Costing Support for NGCC with CCS Analyses		

TOTAL PLANT COST SUMMARY

Case:	Case 4c - AdvFuture CCS EGR				
Plant Size:	1003.9 MW,net	**Estimate Type:**	Conceptual	**Cost Base (Jun)**	2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING											
	SUBTOTAL 1.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
2	COAL & SORBENT PREP & FEED											
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
3	FEEDWATER & MISC. BOP SYSTEMS											
3.1	Feedwater System	$3,977	$4,119	$3,363	$0	$0	$11,460	$923	$0	$1,857	$14,240	$14
3.2	Water Makeup & Pretreating	$3,217	$332	$1,651	$0	$0	$5,200	$429	$0	$1,126	$6,755	$7
3.3	Other Feedwater Subsystems	$1,863	$616	$514	$0	$0	$2,994	$231	$0	$484	$3,709	$4
3.4	Service Water Systems	$388	$775	$2,496	$0	$0	$3,659	$311	$0	$794	$4,764	$5
3.5	Other Boiler Plant Systems	$2,617	$978	$2,249	$0	$0	$5,845	$476	$0	$948	$7,269	$7
3.6	Natural Gas, incl. pipeline	$17,831	$891	$771	$0	$0	$19,493	$1,608	$0	$3,165	$24,267	$24
3.7	Waste Treatment Equipment	$1,123	$0	$650	$0	$0	$1,774	$153	$0	$385	$2,312	$2
3.8	Misc. Equip.(cranes,AirComp.,Comm.)	$1,703	$227	$827	$0	$0	$2,757	$236	$0	$599	$3,591	$4
	SUBTOTAL 3.	**$32,720**	**$7,938**	**$12,523**	**$0**	**$0**	**$53,181**	**$4,367**	**$0**	**$9,358**	**$66,906**	**$67**
4	GASIFIER & ACCESSORIES											
	SUBTOTAL 4.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
5A	GAS CLEANUP & PIPING											
5A.6	Exhaust Gas Recycle System	$0	$9,768	$6,171	$0	$0	$15,939	$1,243	$0	$3,436	$20,618	$21
	SUBTOTAL 5.	**$0**	**$9,768**	**$6,171**	**$0**	**$0**	**$15,939**	**$1,243**	**$0**	**$3,436**	**$20,618**	**$21**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$132,810	$0	$40,021	$0	$0	$172,831	$14,420	$34,566	$44,363	$266,181	$265
5B.2	CO2 Compression & Drying	$28,161	$0	$11,474	$0	$0	$39,636	$3,318	$0	$8,591	$51,545	$51
	SUBTOTAL 5.	**$160,971**	**$0**	**$51,495**	**$0**	**$0**	**$212,467**	**$17,739**	**$34,566**	**$52,954**	**$317,726**	**$317**
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	$189,000	$0	$10,905	$0	$0	$199,905	$16,508	$0	$21,641	$238,055	$237
6.2	Combustion Turbine Accessories	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$1,221	$1,320	$0	$0	$2,541	$213	$0	$551	$3,304	$3
	SUBTOTAL 6.	**$189,000**	**$1,221**	**$12,226**	**$0**	**$0**	**$202,446**	**$16,721**	**$0**	**$22,192**	**$241,359**	**$240**

Exhibit 6-32 Case 4c - Advanced/Future turbine with CO_2 capture and EGR capital cost estimate detail (continued)

Client: USDOE/NETL **Report Date:** 2012-Apr-04
Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 4c - AdvFuture CCS EGR
Plant Size: 1003.9 MW,net **Estimate Type:** Conceptual **Cost Base (Jun)** 2011 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	$43,320	$0	$7,621	$0	$0	$50,941	$4,230	$0	$5,517	$60,688	$60
7.2	HRSG Accessories	$2,838	$1,192	$1,662	$0	$0	$5,691	$477	$0	$925	$7,093	$7
7.3	Ductwork	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.4	Stack	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7.9	HRSG,Duct & Stack Foundations	$0	$591	$554	$0	$0	$1,145	$96	$0	$248	$1,489	$1
	SUBTOTAL 7.	**$46,158**	**$1,783**	**$9,837**	**$0**	**$0**	**$57,778**	**$4,802**	**$0**	**$6,690**	**$69,270**	**$69**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$40,600	$0	$6,606	$0	$0	$47,206	$3,726	$0	$5,093	$56,025	$56
8.2	Turbine Plant Auxiliaries	$261	$0	$579	$0	$0	$840	$72	$0	$91	$1,003	$1
8.3	Condenser & Auxiliaries	$2,340	$0	$1,615	$0	$0	$3,955	$333	$0	$429	$4,717	$5
8.4	Steam Piping	$12,833	$0	$5,201	$0	$0	$18,035	$1,229	$0	$2,890	$22,153	$22
8.9	TG Foundations	$0	$1,116	$1,843	$0	$0	$2,959	$250	$0	$642	$3,851	$4
	SUBTOTAL 8.	**$56,034**	**$1,116**	**$15,845**	**$0**	**$0**	**$72,995**	**$5,611**	**$0**	**$9,145**	**$87,750**	**$87**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$5,410	$0	$1,650	$0	$0	$7,060	$589	$0	$765	$8,414	$8
9.2	Circulating Water Pumps	$2,622	$0	$179	$0	$0	$2,801	$214	$0	$302	$3,317	$3
9.3	Circ.Water System Auxiliaries	$201	$0	$27	$0	$0	$228	$19	$0	$25	$271	$0
9.4	Circ.Water Piping	$0	$6,245	$1,414	$0	$0	$7,659	$574	$0	$1,235	$9,468	$9
9.5	Make-up Water System	$468	$0	$601	$0	$0	$1,069	$88	$0	$174	$1,331	$1
9.6	Component Cooling Water Sys	$402	$480	$308	$0	$0	$1,190	$95	$0	$193	$1,478	$1
9.9	Circ.Water System Foundations	$0	$2,825	$4,691	$0	$0	$7,515	$634	$0	$1,630	$9,779	$10
	SUBTOTAL 9.	**$9,103**	**$9,551**	**$8,870**	**$0**	**$0**	**$27,523**	**$2,214**	**$0**	**$4,323**	**$34,060**	**$34**
10	ASH/SPENT SORBENT HANDLING SYS											
	SUBTOTAL 10.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
11	ACCESSORY ELECTRIC PLANT											
11.1	Generator Equipment	$10,107	$0	$5,979	$0	$0	$16,086	$1,321	$0	$1,306	$18,713	$19
11.2	Station Service Equipment	$3,356	$0	$288	$0	$0	$3,644	$300	$0	$296	$4,240	$4
11.3	Switchgear & Motor Control	$4,129	$0	$717	$0	$0	$4,846	$401	$0	$525	$5,772	$6
11.4	Conduit & Cable Tray	$0	$2,158	$6,216	$0	$0	$8,374	$698	$0	$1,361	$10,432	$10
11.5	Wire & Cable	$0	$6,934	$3,943	$0	$0	$10,877	$654	$0	$1,730	$13,260	$13
11.6	Protective Equipment	$0	$1,075	$3,732	$0	$0	$4,807	$413	$0	$522	$5,743	$6
11.7	Standby Equipment	$164	$0	$153	$0	$0	$317	$27	$0	$34	$379	$0
11.8	Main Power Transformers	$19,997	$0	$274	$0	$0	$20,271	$1,376	$0	$2,165	$23,813	$24
11.9	Electrical Foundations	$0	$236	$601	$0	$0	$837	$71	$0	$181	$1,089	$1
	SUBTOTAL 11.	**$37,754**	**$10,403**	**$21,903**	**$0**	**$0**	**$70,060**	**$5,262**	**$0**	**$8,119**	**$83,441**	**$83**

Exhibit 6-32 Case 4c - Advanced/Future turbine with CO_2 capture and EGR capital cost estimate detail (continued)

Client:	USDOE/NETL	**Report Date:**	2012-Apr-04
Project:	Costing Support for NGCC with CCS Analyses		
Case:	Case 4c - AdvFuture CCS EGR		
Plant Size:	1003.9 MW,net	**Estimate Type:** Conceptual	**Cost Base (Jun)** 2011 ($x1000)

TOTAL PLANT COST SUMMARY

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
12	INSTRUMENTATION & CONTROL											
12.1	IGCC Control Equipment	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0	$0	$0
12.2	Combustion Turbine Control	w/6.1	$0	w/6.1	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	w/8.1	$0	w/8.1	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,245	$0	$792	$0	$0	$2,037	$171	$102	$346	$2,656	$3
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0	$0	$0
12.6	Control Boards,Panels & Racks	$372	$0	$227	$0	$0	$599	$50	$30	$102	$781	$1
12.7	Computer & Accessories	$5,952	$0	$182	$0	$0	$6,134	$504	$307	$694	$7,638	$8
12.8	Instrument Wiring & Tubing	$0	$1,107	$1,959	$0	$0	$3,066	$220	$153	$516	$3,956	$4
12.9	Other I & C Equipment	$2,219	$0	$5,137	$0	$0	$7,356	$630	$368	$835	$9,189	$9
	SUBTOTAL 12.	**$9,787**	**$1,107**	**$8,298**	**$0**	**$0**	**$19,192**	**$1,575**	**$960**	**$2,494**	**$24,221**	**$24**
13	IMPROVEMENTS TO SITE											
13.1	Site Preparation	$0	$148	$3,138	$0	$0	$3,286	$287	$0	$715	$4,287	$4
13.2	Site Improvements	$0	$1,354	$1,789	$0	$0	$3,143	$280	$0	$685	$4,108	$4
13.3	Site Facilities	$2,765	$0	$2,901	$0	$0	$5,666	$505	$0	$1,234	$7,405	$7
	SUBTOTAL 13.	**$2,765**	**$1,502**	**$7,828**	**$0**	**$0**	**$12,095**	**$1,072**	**$0**	**$2,633**	**$15,800**	**$16**
14	BUILDINGS & STRUCTURES											
14.1	Combustion Turbine Area	$0	$431	$228	$0	$0	$659	$51	$0	$106	$816	$1
14.2	Steam Turbine Building	$0	$2,784	$3,704	$0	$0	$6,488	$522	$0	$1,051	$8,061	$8
14.3	Administration Building	$0	$708	$479	$0	$0	$1,187	$92	$0	$192	$1,471	$1
14.4	Circulation Water Pumphouse	$0	$225	$111	$0	$0	$336	$26	$0	$54	$417	$0
14.5	Water Treatment Buildings	$0	$683	$622	$0	$0	$1,305	$103	$0	$211	$1,619	$2
14.6	Machine Shop	$0	$614	$392	$0	$0	$1,006	$78	$0	$163	$1,247	$1
14.7	Warehouse	$0	$397	$239	$0	$0	$636	$49	$0	$103	$787	$1
14.8	Other Buildings & Structures	$0	$119	$86	$0	$0	$205	$16	$0	$33	$254	$0
14.9	Waste Treating Building & Str.	$0	$465	$829	$0	$0	$1,294	$105	$0	$210	$1,609	$2
	SUBTOTAL 14.	**$0**	**$6,424**	**$6,692**	**$0**	**$0**	**$13,116**	**$1,043**	**$0**	**$2,124**	**$16,282**	**$16**
	TOTAL COST	**$544,291**	**$50,813**	**$161,687**	**$0**	**$0**	**$756,791**	**$61,646**	**$35,526**	**$123,469**	**$977,432**	**$974**

Exhibit 6-32 Case 4c - Advanced/Future turbine with CO_2 capture and EGR capital cost estimate detail (continued)

Client: USDOE/NETL — Report Date: 2012-Apr-04

Project: Costing Support for NGCC with CCS Analyses

TOTAL PLANT COST SUMMARY

Case: Case 4c - AdvFuture CCS EGR

Plant Size: 1003.9 MW,net — Estimate Type: Conceptual — Cost Base (Jun) 2011 ($x1000)

Acct 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 $	TOTAL PLANT COST $/kW
	TOTAL COST	**$544,291**	**$50,813**	**$161,687**	**$0**	**$756,791**	**$61,646**	**$35,526**	**$123,469**	**$977,432**	**$974**
	Owner's Costs										
	Preproduction Costs										
	6 Months All Labor									$7,341	$7
	1 Month Maintenance Materials									$1,306	$1
	1 Month Non-fuel Consumables									$636	$1
	1 Month Waste Disposal									$0	$0
	25% of 1 Months Fuel Cost at 100% CF									$7,253	$7
	2% of TPC									$19,549	$19
	Total									**$36,084**	**$36**
	Inventory Capital										
	60 day supply of consumables at 100% CF									$874	$1
	0.5% of TPC (spare parts)									$4,887	$5
	Total									**$5,761**	**$6**
	Initial Cost for Catalyst and Chemicals									$2,140	$2
	Land									$300	$0
	Other Owner's Costs									$146,615	$146
	Financing Costs									$26,391	$26
	Total Overnight Costs (TOC)									**$1,194,722**	**$1,190**
	TASC Multiplier							(IOU, high-risk, 33 year)		1.078	
	Total As-Spent Cost (TASC)									**$1,287,911**	**$1,283**

Exhibit 6-33 Case 4c - Advanced/Future turbine with CO_2 capture and EGR operating cost estimate

INITIAL & ANNUAL O&M EXPENSES						Cost Base (Jun)	2011
Case 4c - AdvFuture CCS EGR						Heat Rate-net (Btu/kWh):	6,458
						MWe-net:	1004
						Capacity Factor (%):	85
OPERATING & MAINTENANCE LABOR							
Operating Labor							
Operating Labor Rate(base):	39.70	$/hour					
Operating Labor Burden:	30.00	% of base					
Labor O-H Charge Rate:	25.00	% of labor					
			Total				
Skilled Operator	1.0		1.0				
Operator	3.3		3.3				
Foreman	1.0		1.0				
Lab Tech's, etc.	1.0		1.0				
TOTAL-O.J.'s	6.3		6.3				
						Annual Cost	Annual Unit Cost
						$	$/kW-net
Annual Operating Labor Cost						$2,861,816	$2.851
Maintenance Labor Cost						$8,883,381	$8.849
Administrative & Support Labor						$2,936,299	$2.925
Property Taxes and Insurance						$19,548,636	$19.473
TOTAL FIXED OPERATING COSTS						**$34,230,132**	**$34.099**
VARIABLE OPERATING COSTS							
							$/kWh-net
Maintenance Material Cost						**$13,325,071**	**$0.00178**
Consumables	Consumption		Unit	Initial Fill			
	Initial Fill	/Day	Cost	Cost			
Water (/1000 gallons)	0.00	3,895.67	1.67	**$0**		**$2,023,243**	**$0.00027**
Chemicals							
MU & WT Chem.(lbs)	0.00	23,209.28	0.27	$0		$1,928,623	$0.00026
MEA Solvent (ton)	591.30	0.83	3,481.91	$2,058,863		$897,035	$0.00012
Activated Carbon (lb)	0.00	991.93	1.63	$0		$500,163	$0.00007
Corrosion Inhibitor	0.00	0.00	0.00	$81,008		$3,858	$0.00000
SCR Catalyst (m3)	w/equip.	0.10	8,938.80	$0		$275,099	$0.00004
Ammonia (19% NH3) (ton)	0.00	8.34	330.00	$0		$854,166	$0.00011
Subtotal Chemicals				**$2,139,871**		**$4,458,943**	**$0.00060**
Other							
Supplemental Fuel (MBtu)	0.00	0.00	0.00	$0		$0	$0.00000
Gases,N2 etc. (/100scf)	0.00	0.00	0.00	$0		$0	$0.00000
L.P. Steam (/1000 pounds)	0.00	0.00	0.00	$0		$0	$0.00000
Subtotal Other				**$0**		**$0**	**$0.00000**
Waste Disposal							
Flyash (ton)	0.00	0.00	0.00	$0		$0	$0.00000
Bottom Ash (ton)	0.00	0.00	0.00	$0		$0	$0.00000
Subtotal Waste Disposal				**$0**		**$0**	**$0.00000**
By-products							
Sulfur (tons)	0.00	0.00	0.00	$0		$0	$0.00000
Subtotal By-products				**$0**		**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$2,139,871**		**$19,807,257**	**$0.00265**
Fuel (MMBtu)	0	155,590	6.13	**$0**		**$295,906,718**	**$0.03956**

7 Summary Comparison

The purpose of this study is to present the cost and performance of natural gas combined cycle (NGCC) power plants using state-of-the-art (SOA) and advanced gas turbines, both non-capture configurations and with post combustion carbon capture based on an advanced solvent process.

The simulation and cost estimation results for the cases in this study are summarized in Exhibit 7-1. The results for each turbine with the addition of CO_2 capture alone and CO_2 capture with EGR are approximately equal for the projected cost of electricity (COE) and the overall process efficiency. The addition of EGR that was set at 35 percent of the flue gas exhaust improves case efficiencies by approximately 0.5 percentage points. The net output and efficiency increase with each turbine design improvement. As a result of the improvements, the normalized total overnight cost (TOC) and cost of electricity (COE) values decrease as the turbine design improves.

The efficiencies estimated for each case are shown in Exhibit 7-2. The addition of CO_2 capture alone and CO_2 capture with EGR reduce the efficiencies of each case by between 10 and 13 percent with the reduction decreasing slightly as the turbine design improves.

More detailed stream, performance, and cost data for each case are listed in Exhibit 7-3, Exhibit 7-4, and Exhibit 7-5, respectively, for comparison purposes.

The normalized annual CO_2 emissions for each case are shown in Exhibit 7-6. The emissions per MW decrease by approximately 3.5 to 5.8 percent for each turbine design improvement with the overall decrease of 12 to 14 percent going from the current SOA to the advanced future turbine design. The emissions from the current SOA turbine without capture case are estimated at 760 lb/MWh_{gross}. The Environmental Protection Agency (EPA) recently proposed a CO_2 emissions limit of 1000 lb/MWh_{gross} for new power plants. This rule would result in carbon capture not being required for NGCC.

The normalized raw water withdrawal, process water discharge, and raw water consumption for each case are shown in Exhibit 7-7. The cases without capture have the lowest water usage values. The withdrawal rates for the CO_2 capture plus EGR cases were 4 to 6 percent higher than those for the CO_2 capture cases without EGR, but the reverse is true for the consumption rates. All the water usage rates fall as the turbine design improves.

The normalized capital costs (TOC and TASC) are shown by component for each case in Exhibit 7-8. All values are in June 2011 dollars. As the turbine design improves the capital costs per MW decrease. The reduction in TOC for modifications from SOA to the advanced future turbine design is approximately 20 percent for the without capture cases and 25 percent for the cases with capture. The capital costs for the capture cases (both with and without EGR) are approximately twice the amount as the non-capture cases for each turbine design. This is due primarily to the high additional capital costs for the capture technology.

The first year COE values are shown for each case in Exhibit 7-9. All values are in June 2011 dollars. As the turbine design (performance efficiency) improves the COE decreases. The COE for the capture cases (both with and without EGR) are 38 to 46 percent higher than the non-capture cases for each turbine design. The difference decreases slightly as the turbine design improves.

The costs of CO_2 avoided and captured are shown for each case in Exhibit 7-10. All values are in June 2011 dollars. As the turbine designs improve the costs per unit of CO_2 captured decrease.

The fuel component accounts for the largest portion of the COE for NGCC plants (approximately 72 percent for without capture and 58 percent for with capture cases.) This is a major difference when compared with coal power plants. The sensitivities of the COEs to the price of natural gas are shown in Exhibit 7-11. The values at the $6.13/MMBtu price assumed for this study are along the vertical line shown in the chart. As the price increases, the COEs increase. The non-capture cases are slightly more sensitive than the capture cases, primarily because the capital component becomes more significant in the capture cases. A natural gas cost reduction of 51 percent (to $3/MMBtu) results in an average of 37 percent decrease in the non-capture values but only a 29 percent decrease in the capture case values. An increase of 31 percent (to $8/MMBtu) results in an average of 22 percent increase in the non-capture values but only an 18 percent increase in the capture case values. The impact of the price on the COE is approximately the same for all turbine designs since the annual fuel costs are a large portion of the COEs (71 to 73 percent of the non-capture cases and 55 to 59 percent of the capture cases)

The sensitivities of the COEs to capacity factor are shown in Exhibit 7-12. The values at the 85 percent capacity factor assumed for this study are along the vertical line shown in the chart. As the capacity factor increases, the COEs decrease. The calculations were made with the assumption that no addition or reduction in equipment or capital would be needed to operate at higher or lower capacity factors. The capacity factor has a smaller impact as the turbine design improves.

Options for carbon dioxide storage include both storage in a saline reservoir and storage/use in EOR. The EOR option may be attractive even without the passage of regulations depending on the price of oil. The higher oil prices climb, the more incentive there is to recover more oil using enhanced techniques like CO_2 injection which could result in an increase of the sale price for CO_2 to oil recovery operations. The impact of selling the captured CO_2 for EOR was estimated and the results are listed in Exhibit 7-13. Eliminating the CO_2 T&S charges and adding revenue from the EOR sales reduces the COEs (excluding CO_2 T&S) by approximately 5 percent for an EOR credit of $10/tonne. The sensitivities of the COEs (excluding CO_2 T&S) to CO_2 plant gate sales price are shown in Exhibit 7-14. The horizontal lines represent the non-capture case values. As the CO_2 sales price increases, the COEs decrease and approach the non-capture values. The CO_2 sales price value at the point where each capture case line crosses the corresponding non-capture line is equal to the cost of CO_2 captured for that capture case.

Exhibit 7-1 Case results summary
(Values shown are for total 2 GT x 2 HRSG x 1 ST system)

Turbine	Case / Technology		Efficiency (% HHV/ LHV)	Net Power (MWe)	TOC ($/kW)	COE without CO_2 T&S ($/MWh)	COE with CO_2 T&S ($/MWh)	Cost of CO_2 avoided ($/tonne)	Cost of CO_2 captured ($/tonne)
SOA (based on "7FA.05")	1a	w/o CO_2 capture	51.8 / 57.4	634	829	57.14	57.14	n/a	n/a
	1b	w CO_2 capture	45.2 / 50.1	553	1,674	80.62	84.27	86.59	64.24
	1c	w CO_2 +EGR	45.7 / 50.6	563	1,568	78.32	81.92	78.94	58.75
SOA (based on "H")	2a	w/o CO_2 capture	53.7 / 59.5	820	756	54.19	54.19	n/a	n/a
	2b	w CO_2 capture	47.2 / 52.2	721	1,499	75.03	78.53	80.45	59.53
	2c	w CO_2 +EGR	47.7 / 52.9	738	1,396	72.71	76.16	72.48	53.70
Advanced (based on "J")	3a	w/o CO_2 capture	56.5 / 62.6	982	684	50.73	50.73	n/a	n/a
	3b	w CO_2 capture	50.1 / 55.5	870	1,343	69.17	72.47	75.60	56.02
	3c	w CO_2 +EGR	50.6 / 56.1	889	1,251	67.17	70.42	68.35	50.56
Advanced Future turbine	4a	w/o CO_2 capture	58.8 / 65.2	1,108	661	49.17	49.17	n/a	n/a
	4b	w CO_2 capture	52.5 / 58.1	989	1,271	66.21	69.35	73.00	54.23
	4c	w CO_2 +EGR	52.8 / 58.5	1,004	1,190	64.56	67.67	66.86	49.44

COEs based on a natural gas price of $6.13/MMBtu and 85% capacity factor in June 2011 dollars

CO_2 capture technology represents an advanced solvent process

COE = (Annual Capital Charges + O&M + Fuel ($/yr)) / (Annual MWh_{net})

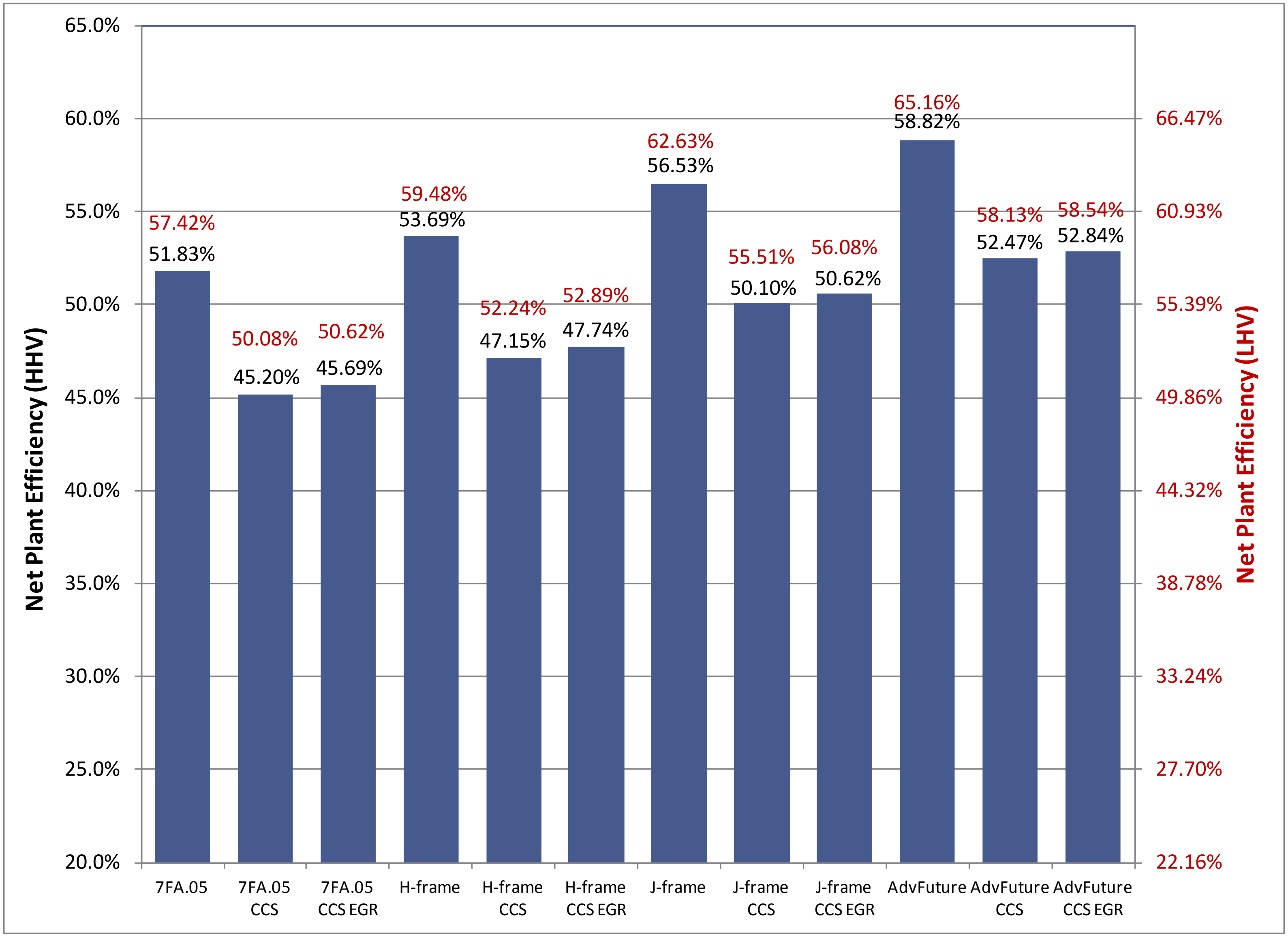
Cost of CO_2 avoided = ($COE_{with\ capture}$ – $COE_{w/o\ capture}$ ($/MWh)) / ($Emissions_{w/o\ capture}$ – $Emissions_{with\ capture}$) (tons/MWh)), includes CO_2 T&S

Cost of CO_2 captured = ($COE_{with\ capture}$ – $COE_{w/o\ capture}$ ($/MWh)) / ($CO_{2\ captured}$ (tons/MWh)), excludes CO_2 T&S

Reference case for Cost of CO_2 avoided and Cost of CO_2 captured calculation is matching turbine without capture case.

See Section 2.8 for calculation details.

Exhibit 7-2 Net Plant efficiency



Source: NETL

Exhibit 7-3 Summary stream data for all cases

Case	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c
Turbine	7FA.05	7FA.05	7FA.05	H-frame	H-frame	H-frame	J-frame	J-frame	J-frame	Advanced	Advanced	Advanced
Technology	None	CCS	CCS+EGR	None	CCS	CCS+EGR	None	CCS	CCS+EGR	None	CCS	CCS+EGR
Air Feed Flowrate (lb/hr)	7,986,960	7,986,960	5,205,600	9,342,000	9,342,000	6,120,000	9,511,200	9,511,200	6,230,880	9,511,200	9,511,200	6,243,840
Air Feed Pressure (psia)	14.6	14.6	14.7	14.6	14.6	14.7	14.6	14.6	14.7	14.6	14.6	14.7
Air Feed Temperature (°F)	59	59	59	59	59	59	59	59	59	59	59	59
NG Feed Flowrate (lb/hr)	185,544	185,544	186,984	231,840	231,840	234,432	263,520	263,520	266,328	285,840	285,840	288,216
NG Feed Pressure (psia)	399.7	399.7	399.7	411.5	411.5	600.0	600.0	600.0	600.0	600.0	600.0	600.0
NG Feed Temperature (°F)	100	100	100	100	100	100	100	77	100	100	100	100
NG from Fuel Heater Flowrate (lb/hr)	n/a	n/a	n/a	231,840	231,840	234,432	263,520	263,520	266,328	285,840	285,840	288,216
NG from Fuel Heater Pressure (psia)	n/a	n/a	n/a	411.5	411.5	411.5	411.5	411.5	411.5	411.5	411.5	411.5
NG from Fuel Heater Temperature (°F)	n/a	n/a	n/a	400	400	400	400	400	400	400	400	400
Gas to Turbine Flowrate (lb/hr)	3,663,432	3,663,432	36,547,200	3,964,320	3,964,320	3,970,080	4,014,720	4,014,720	4,014,000	4,025,880	4,025,880	4,028,040
Gas to Turbine Pressure (psia)	235	235	234.9	277	277	277	318	318	317	415	415	414
Gas to Turbine Temperature (°F)	2,479	2,479	2,486.1	2,709	2,709	2,709	2,948	2,948	2,944	3,107	3,107	3,104
Gas to HRSG Flowrate (lb/hr)	8,172,000	8,172,000	8,151,120	9,573,840	9,573,840	9,587,520	9,774,720	9,774,720	9,771,840	9,797,040	9,797,040	9,801,360
Gas to HRSG Pressure (psia)	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
Gas to HRSG Temperature (°F)	1,120	1,120	1,139	1,146	1,146	1,160	1,177	1,177	1,191	1,182	1,182	1,197
Gas to CCS Flowrate (lb/hr)	n/a	8,172,360	5,298,120	n/a	9,573,480	6,231,960	n/a	9,774,360	6,351,840	n/a	9,796,680	6,370,920
Gas to CCS Pressure (psia)	n/a	15	15	n/a	15	15	n/a	15	15	n/a	15	15
Gas to CCS Temperature (°F)	n/a	231	225	n/a	229	223	n/a	231	224	n/a	235	227
Stack Flowrate (lb/hr)	8,172,360	7,558,200	4,689,360	9,573,480	8,786,880	5,460,480	9,774,360	8,847,720	5,460,120	9,796,680	8,767,800	5,395,320
Stack Pressure (psia)	14.7	14.7	14.7	14.7	14.7	14.7	15	14.7	14.7	15	14.7	14.7
Stack Temperature (°F)	190	95	95	190	95	95	190	95	95	190	95	95
EGR Flowrate (lb/hr)	n/a	n/a	2,758,320	n/a	n/a	3,233,520	n/a	n/a	3,275,280	n/a	n/a	3,268,800
EGR Pressure (psia)	n/a	n/a	14.7	n/a	n/a	14.7	n/a	n/a	14.7	n/a	n/a	14.7
EGR Temperature (°F)	n/a	n/a	92	n/a	n/a	92	n/a	n/a	92	n/a	n/a	92
CO_2 Flowrate (lb/hr)	n/a	445,320	447,480	n/a	556,200	560,880	n/a	631,800	636,840	n/a	684,720	689,040
CO_2 Pressure (psia)	n/a	2,214.7	2,200.0	n/a	2,214.7	2,200.0	n/a	2,214.7	2,200.0	n/a	2,214.7	2,200.0
CO_2 Temperature (°F)	n/a	101	101	n/a	101	101	n/a	101	101	n/a	101	101
Steam to CCS Flowrate (lb/hr)	n/a	532,440	505,152	n/a	671,040	663,048	n/a	756,000	717,624	n/a	819,720	776,160
Steam to CCS Pressure (psia)	n/a	73.5	49.0	n/a	73.5	48.5	n/a	73.5	47.6	n/a	73.5	47.6
Steam to CCS Temperature (°F)	n/a	306	557	n/a	306	457	n/a	306	557	n/a	306	557
Condensate From CCS Flowrate (lb/hr)	n/a	532,440	505,152	n/a	671,040	663,048	n/a	756,000	717,624	n/a	819,720	776,160
Condensate From CCS Pressure (psia)	n/a	71.0	56.7	n/a	71.0	48.5	n/a	71.0	47.6	n/a	71.0	47.6
Condensate From CCS Temperature (°F)	n/a	304	280	n/a	304	279	n/a	304	278	n/a	304	278
Steam to ST Flowrate (lb/hr)	882,000	882,360	936,000	1,137,240	1,138,320	1,193,760	1,248,840	1,251,000	1,304,280	1,271,520	1,273,680	1,333,080
Steam to ST Pressure (psia)	2,415.0	2,415.0	2,415.0	2,414.7	2,414.7	2,414.7	2,414.7	2,414.7	2,414.7	2,414.7	2,414.7	2,414.7
Steam to ST Temperature (°F)	1,050	1,050	1,050	1,075	1,075	1,075	1,100	1,100	1,100	1,100	1,100	1,100
Condensate to HRSG Flowrate (lb/hr)	1,268,280	750,240	815,760	1,507,680	875,520	948,960	1,578,960	865,080	943,920	1,593,360	819,720	905,760
Condensate to HRSG Pressure (psia)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Condensate to HRSG Temperature (°F)	90	90	90	90	90	90	90	90	90	90	90	90

Exhibit 7-4 Summary performance data for all cases

Case	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c
Turbine	7FA.05	7FA.05	7FA.05	H-frame	H-frame	H-frame	J-frame	J-frame	J-frame	Advanced	Advanced	Advanced
Technology	None	CCS	CCS+EGR	None	CCS	CCS+EGR	None	CCS	CCS+EGR	None	CCS	CCS+EGR
Gas Turbine Power (kWe)	420,816	420,816	418,558	551,220	551,220	553,926	689,832	689,832	694,394	810,862	810,862	811,186
Steam Turbine Power (kWe)	229,607	185,503	196,582	289,730	235,081	247,554	314,517	252,117	263,964	320,546	252,770	266,140
Gross Total (kWe)	**650,423**	**606,319**	**615,140**	**840,950**	**786,301**	**801,480**	**1,004,349**	**941,949**	**958,358**	**1,131,408**	**1,063,632**	**1,077,326**
Condensate Pumps (kWe)	416	248	268	0	2	262	0	7	255	0	13	245
Boiler Feedwater Pumps (kWe)	4,577	4,581	4,834	6,085	6,157	6,400	6,725	6,790	6,872	6,848	6,902	7,023
Exhaust Gas Recycle Fan			376			440			444			443
Amine CO_2 Capture System Auxiliaries (kWe)	0	15,971	13,128	0	18,745	15,104	0	19,206	15,684	0	19,249	6,110
CO_2 Compression (kWe)	0	18,977	18,815	0	23,702	23,575	0	26,921	26,766	0	29,183	28,961
Circulating Water Pump (kWe)	2,337	4,030	4,463	2,791	4,910	5,409	2,941	5,290	5,857	2,964	5,520	4,452
Exhaust Gas Coolant Pump			301			374			414			490
Ground Water Pumps (kWe)	240	350	370	290	420	450	300	440	480	300	450	640
Cooling Tower Fans (kWe)	1,747	2,704	2,846	2,085	3,284	3,491	2,180	3,539	3,751	2,193	3,675	3,890
SCR (kWe)	10	10	10	10	10	10	10	10	10	10	10	10
Gas Turbine Auxiliaries (kWe)	860	860	860	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097
Steam Turbine Auxiliaries (kWe)	488	395	556	615	500	656	672	538	669	684	540	671
Miscellaneous Balance of Plant (kWe)	2,603	2,346	2,147	3,279	2,981	3,606	3,434	3,106	4,523	3,508	3,157	5,155
Transformer Losses (kWe)	3,252	3,032	3,000	4,205	3,932	3,000	5,022	4,710	3,000	5,657	5,318	3,000
Net Auxiliary Load (kWe)	**16,531**	**53,503**	**51,975**	**20,457**	**65,741**	**63,894**	**22,381**	**71,655**	**69,822**	**23,262**	**75,114**	**73,466**
Net Plant Power (kWe)	**633,892**	**552,816**	**563,165**	**820,493**	**720,560**	**737,586**	**981,968**	**870,294**	**888,536**	**1,108,147**	**988,518**	**1,003,860**
Net Plant Efficiency (HHV)	51.8%	45.2%	45.7%	53.7%	47.2%	47.7%	56.5%	50.1%	50.6%	58.8%	52.5%	52.8%
Net Plant Efficiency (LHV)	57.4%	50.1%	50.6%	59.5%	52.2%	52.9%	62.6%	55.5%	56.1%	65.2%	58.1%	58.5%
Net Plant Heat Rate (HHV) (Btu/kWh)	6,583	7,549	7,468	6,355	7,236	7,148	6,036	6,810	6,741	5,801	6,503	6,458
Net Plant Heat Rate (LHV) (Btu/kWh)	5,942	6,814	6,741	5,736	6,532	6,452	5,448	6,147	6,085	5,237	6,193 (5,870)	5,829
Natural Gas Feed Flow (lb/hr)	185,544	185,544	186,984	231,840	231,840	234,432	263,520	263,520	266,328	285,840	285,840	288,216
Thermal Input (HHV) (kWt)	1,223,006	1,223,006	1,232,595	1,528,164	1,528,164	1,545,122	1,736,982	1,736,982	1,755,410	1,884,103	1,884,103	1,899,942
Thermal Input (LHV) (kWt)	1,103,919	1,103,919	1,112,558	1,379,364	1,379,364	1,394,650	1,567,848	1,567,848	1,584,459	1,700,644	1,700,644	1,714,916
Condenser Duty (MMBtu/hr)	1,220	730	790	1,460	850	920	1,530	840.0	920	1,530	790	880
Raw Water Withdrawal (gpm)	2,665	3,823	4,109	3,170	4,604	4,940	3,309	4,876	5,268	3,329	5,006	5,411
Raw Water Consumption (gpm)	2,210	3,126	3,069	2,629	3,759	3,626	2,744	3,967	3,889	2,760	4,063	3,844

Exhibit 7-5 Summary cost estimation data for all cases

(All Costs are annual dollar values in June 2011 dollars)

Case	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c
Turbine	7FA.05	7FA.05	7FA.05	H-frame	H-frame	H-frame	J-frame	J-frame	J-frame	Advanced	Advanced	Advanced
Technology	None	CCS	CCS+EGR	None	CCS	CCS+EGR	None	CCS	CCS+EGR	None	CCS	CCS+EGR
Bare Erected Cost by Account												
A3 – Feedwater & Misc. BOP Systems	41,488,323	44,403,141	45,608,842	45,590,023	49,128,696	50,613,642	47,253,721	51,041,140	52,372,062	47,767,401	51,796,514	53,180,603
A5A – Gas Cleanup & Piping	0	0	15,088,200	0	0	15,883,033	0	0	15,948,999	0	0	15,938,800
A5B – CO_2 Capture & Compression & EGR	0	207,713,286	161,619,349	0	239,162,146	186,471,580	0	259,311,302	202,108,222	0	272,901,237	212,466,576
A6 – Combustion Turbine and Accessories	112,396,975	112,396,975	118,155,928	142,067,516	142,067,516	148,669,615	162,652,886	162,652,886	170,213,713	192,927,001	192,927,001	202,446,309
A7 – HRSG, Ducting & Stack	47,609,281	46,315,272	47,449,930	55,028,585	53,665,555	54,866,835	57,587,865	56,145,529	57,290,043	58,111,377	56,489,213	57,777,561
A8 – Steam Turbine Generator	63,093,559	55,648,331	58,352,288	74,957,656	66,182,785	68,978,469	79,671,620	69,739,448	72,410,673	80,894,303	69,993,609	72,994,575
A9 – Cooling Water System	16,017,984	21,151,823	22,655,224	17,859,060	23,900,908	25,517,682	18,348,564	25,062,007	26,788,451	18,458,485	25,785,076	27,523,488
A11 – Accessory Electric Plant	40,007,717	52,442,601	52,535,221	44,683,271	58,390,255	58,615,242	47,385,034	61,817,940	62,137,059	54,601,300	69,971,161	70,059,936
A12 – Instrumentation & Controls	14,017,269	15,419,604	15,515,593	15,951,384	17,553,273	17,614,397	16,845,421	18,530,965	18,601,444	17,244,298	19,088,871	19,192,058
A13 – Improvements To Site	9,064,072	9,205,081	9,261,407	10,328,710	10,529,995	10,590,509	11,000,709	11,277,334	11,324,634	11,790,288	12,021,827	12,095,100
A14 – Building & Structures	10,965,759	10,566,903	10,833,914	12,405,406	11,951,603	12,225,834	13,028,847	12,538,889	12,799,852	13,368,051	12,828,740	13,116,068
Total BEC	**354,660,938**	**575,263,018**	**557,075,896**	**418,871,611**	**672,532,735**	**650,046,838**	**453,774,666**	**728,117,439**	**701,995,151**	**495,162,504**	**783,803,249**	**756,791,075**
Eng'g CM H.O.& Fee	28,624,705	46,952,566	45,633,262	33,845,017	54,925,835	53,322,821	36,696,548	59,502,672	57,653,351	40,025,736	64,018,735	61,646,190
Process Contingencies	0	36,640,676	27,418,127	0	41,967,205	31,411,813	0	45,343,920	33,892,111	0	47,609,573	35,525,781
Project Contingencies	45,526,129	99,853,048	93,274,540	53,428,958	115,910,951	108,101,941	57,598,242	125,230,989	116,438,389	62,266,841	133,409,897	123,468,772
Total Plant Cost (TPC)	**428,811,772**	**758,709,309**	**723,401,825**	**506,145,586**	**885,336,725**	**842,883,412**	**548,069,456**	**958,195,020**	**909,979,002**	**597,455,081**	**1,028,841,453**	**977,431,819**
Total Plant Cost (TPC) ($/kW)	**676.5**	**1,372.4**	**1,284.5**	**616.9**	**1,228.7**	**1,142.8**	**558.1**	**1,101.0**	**1,024.1**	**539.1**	**1,040.8**	**973.7**
Total Overnight Costs (TOC)	**525,221,757**	**925,472,523**	**883,204,362**	**619,957,731**	**1,080,125,919**	**1,029,321,853**	**671,443,596**	**1,169,235,122**	**1,111,512,317**	**732,621,532**	**1,256,292,488**	**1,194,722,472**
Total Overnight Costs (TOC) ($/kW)	**828.6**	**1,674.1**	**1,568.3**	**755.6**	**1,499.0**	**1,395.5**	**683.8**	**1,343.5**	**1,250.9**	**661.1**	**1,270.9**	**1,190.1**
Total As-spent Cost (TASC)	**564,613,389**	**997,659,379**	**952,094,302**	**666,454,561**	**1,164,375,741**	**1,109,608,957**	**721,801,866**	**1,260,435,461**	**1,198,210,277**	**787,568,147**	**1,354,283,302**	**1,287,910,824**
Total As-spent Cost (TASC) ($/kW)	**890.7**	**1,804.7**	**1,690.6**	**812.3**	**1,615.9**	**1,504.4**	**735.1**	**1,448.3**	**1,348.5**	**710.7**	**1,370.0**	**1,283.0**
Total Fixed Operating Costs	15,862,074	25,680,103	25,115,266	18,213,121	29,369,032	28,672,617	19,487,660	31,491,551	30,670,268	22,502,622	35,112,799	34,230,132
Maintenance Material Cost (100%CF)	6,296,740	9,781,620	9,981,119	7,432,322	11,414,157	11,629,664	8,047,939	12,353,479	12,555,414	10,909,938	15,471,107	15,676,554
Consumables (100%CF)	3,397,666	5,457,991	5,706,199	4,021,617	6,584,346	6,885,989	4,168,285	7,025,803	7,374,789	4,188,496	7,267,471	7,626,101
Fuel (100%CF)	224,080,457	224,096,139	225,842,095	279,998,158	279,984,214	283,114,377	318,281,285	318,256,872	321,635,422	345,195,102	345,193,873	348,125,550

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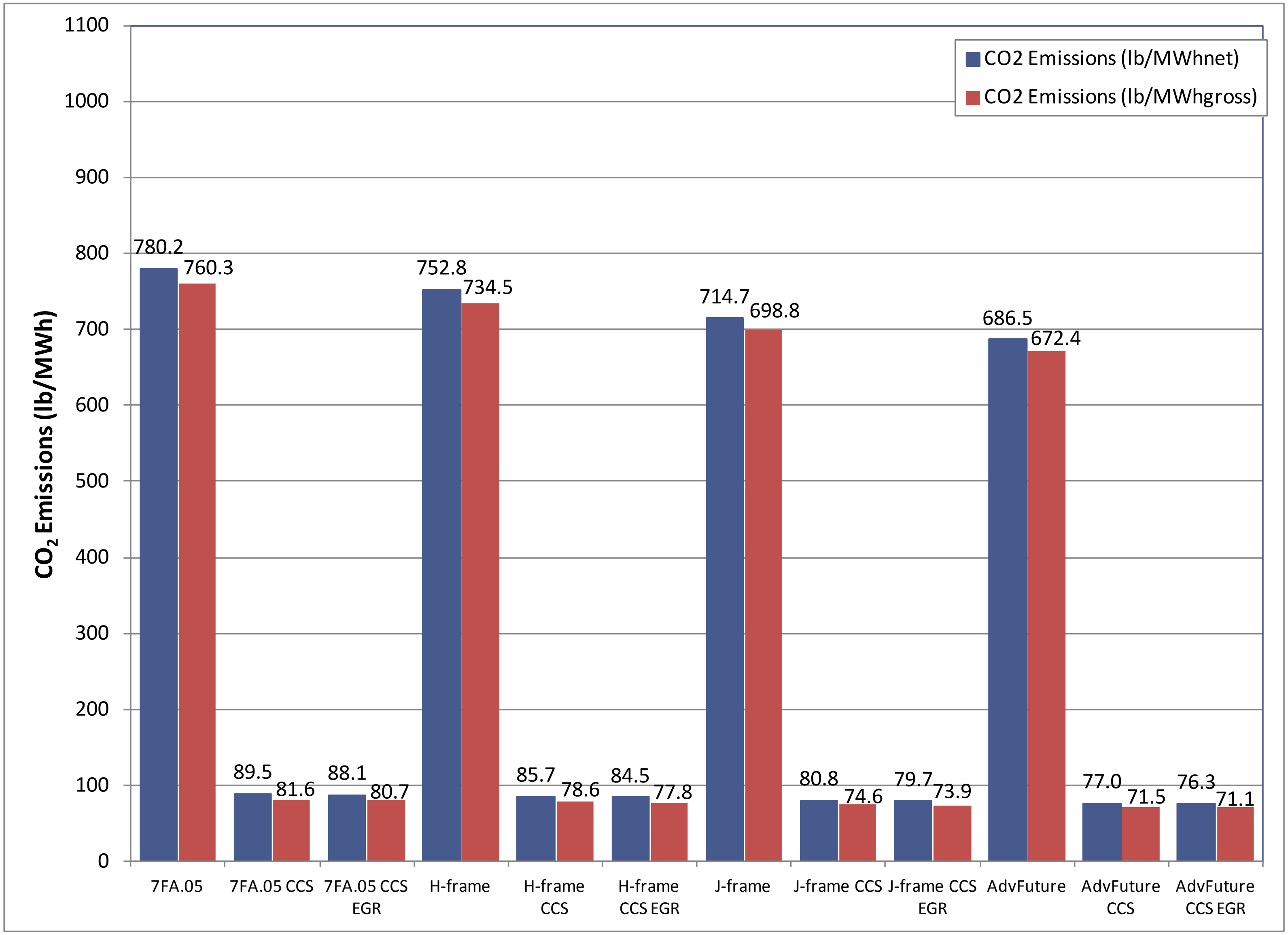
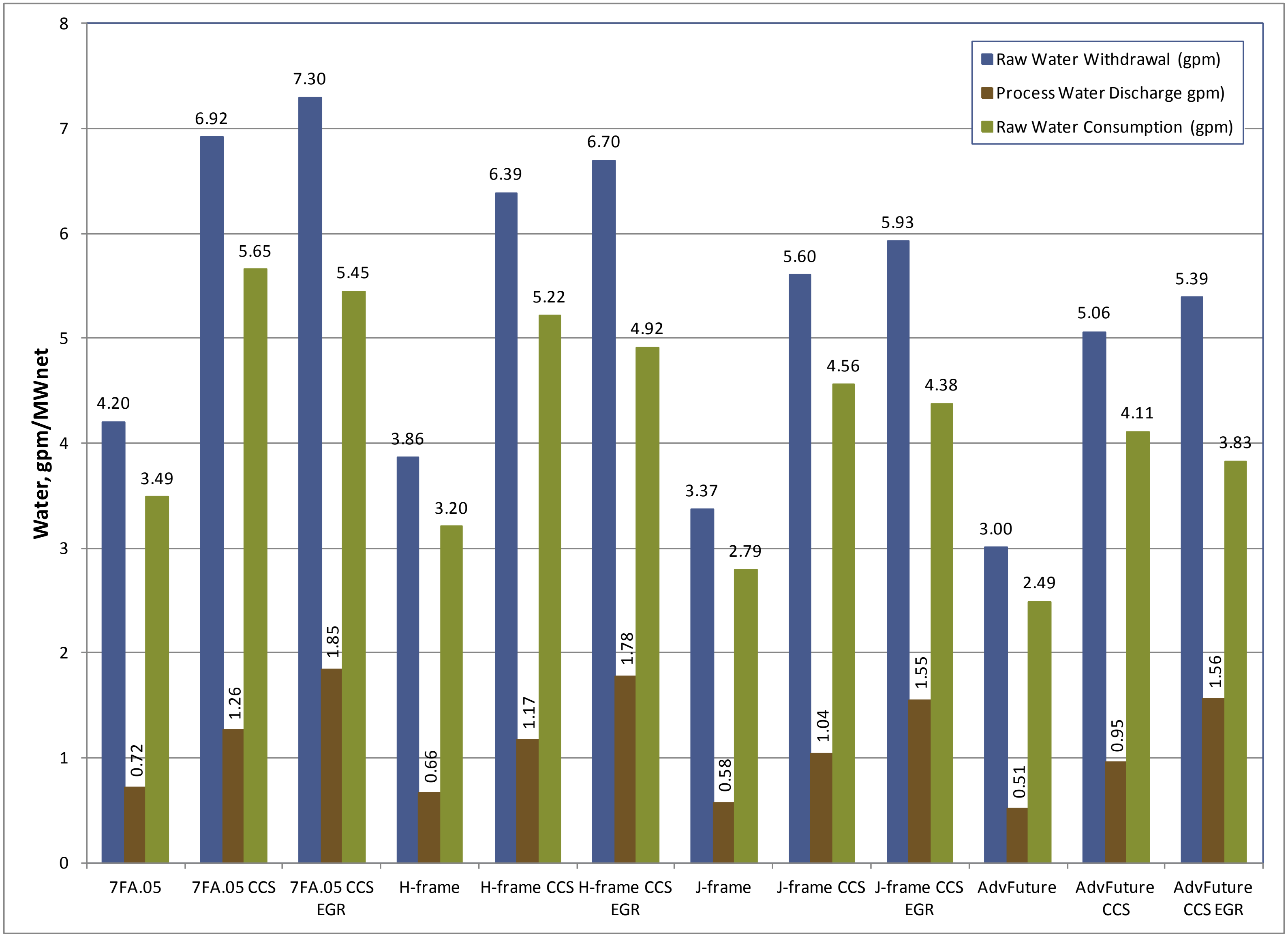
Exhibit 7-6 CO_2 emission rates



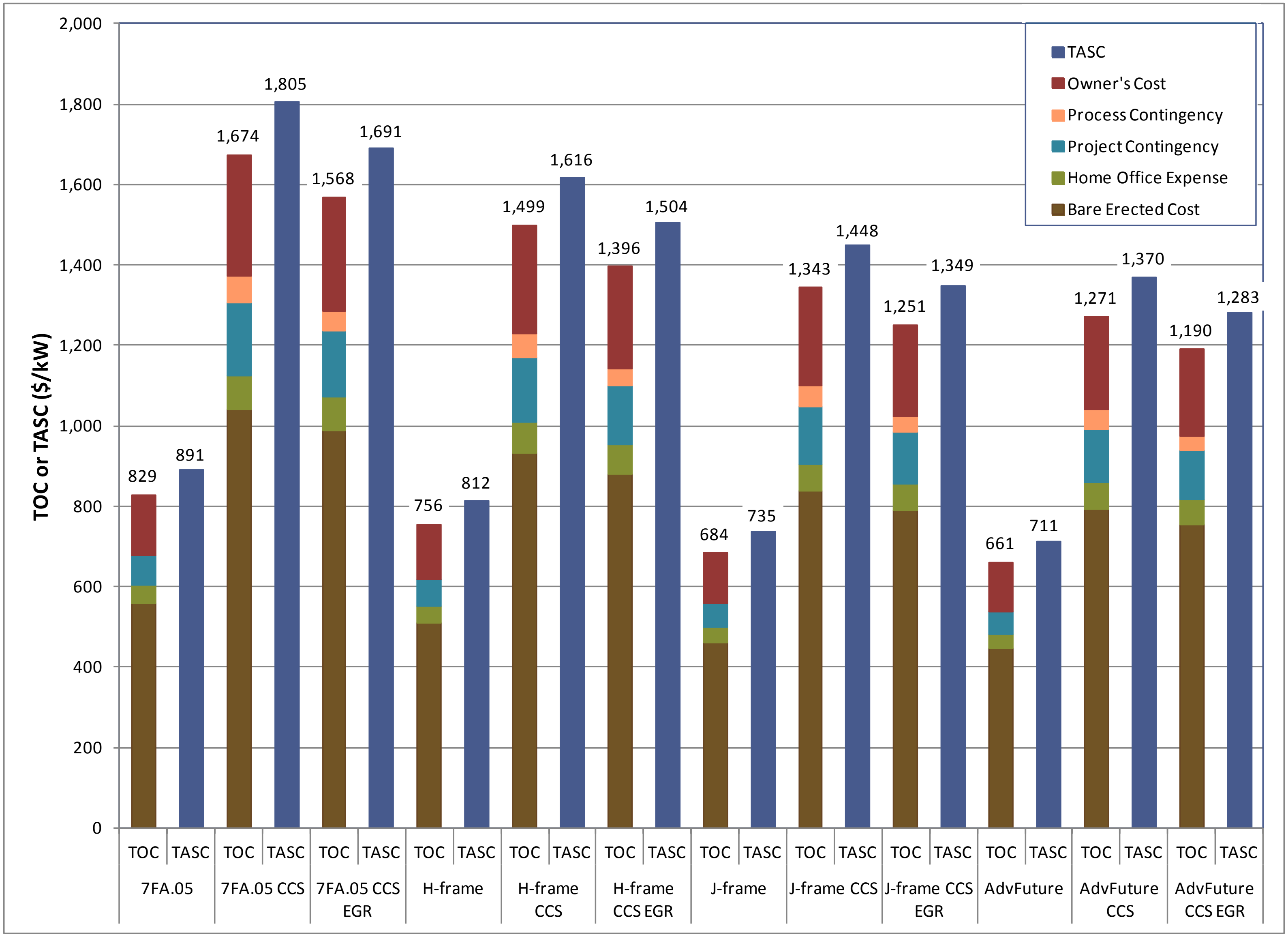
Source: NETL

Exhibit 7-7 Raw water withdrawal and consumption



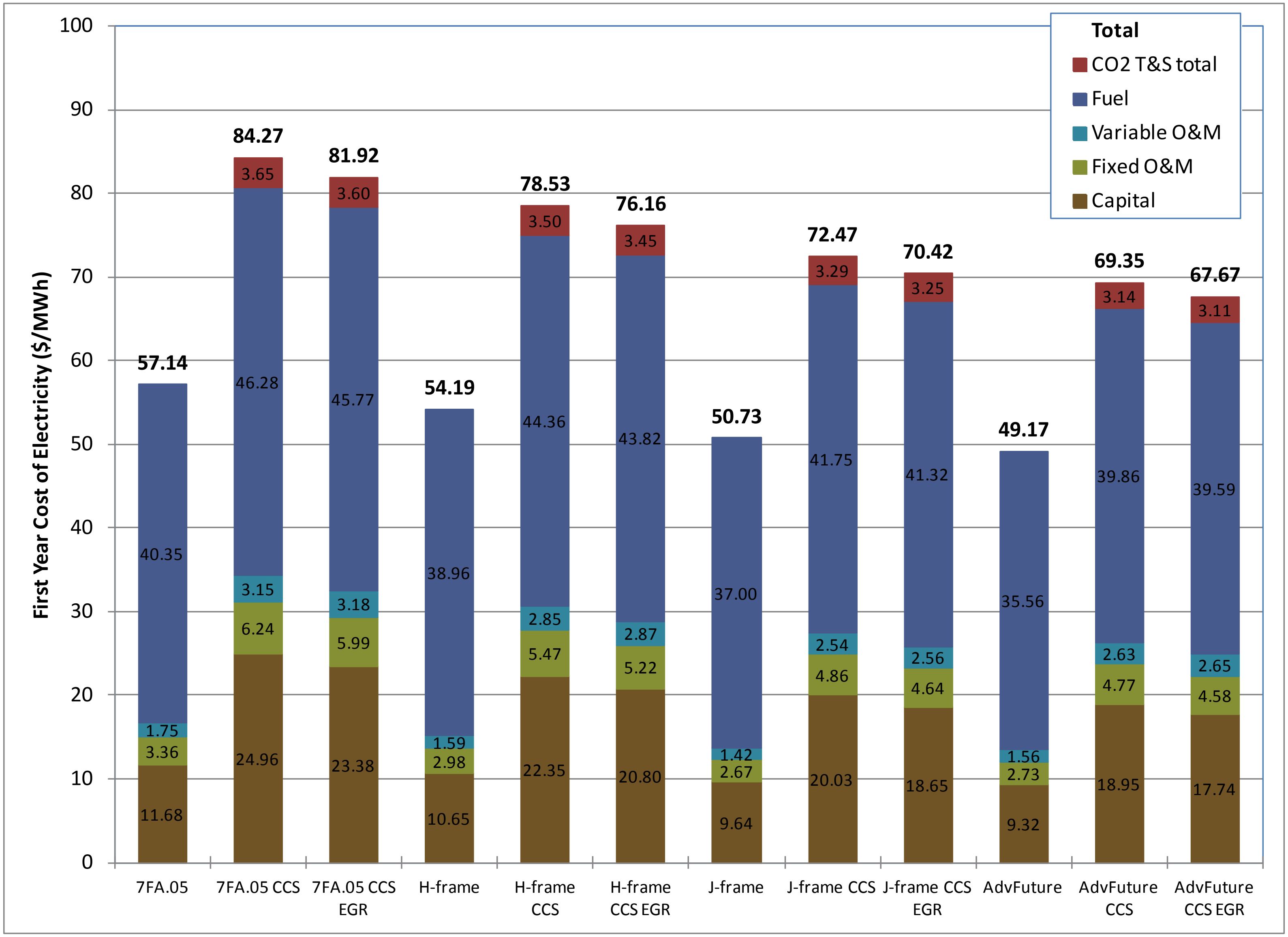
Source: NETL

Exhibit 7-8 Plant capital costs



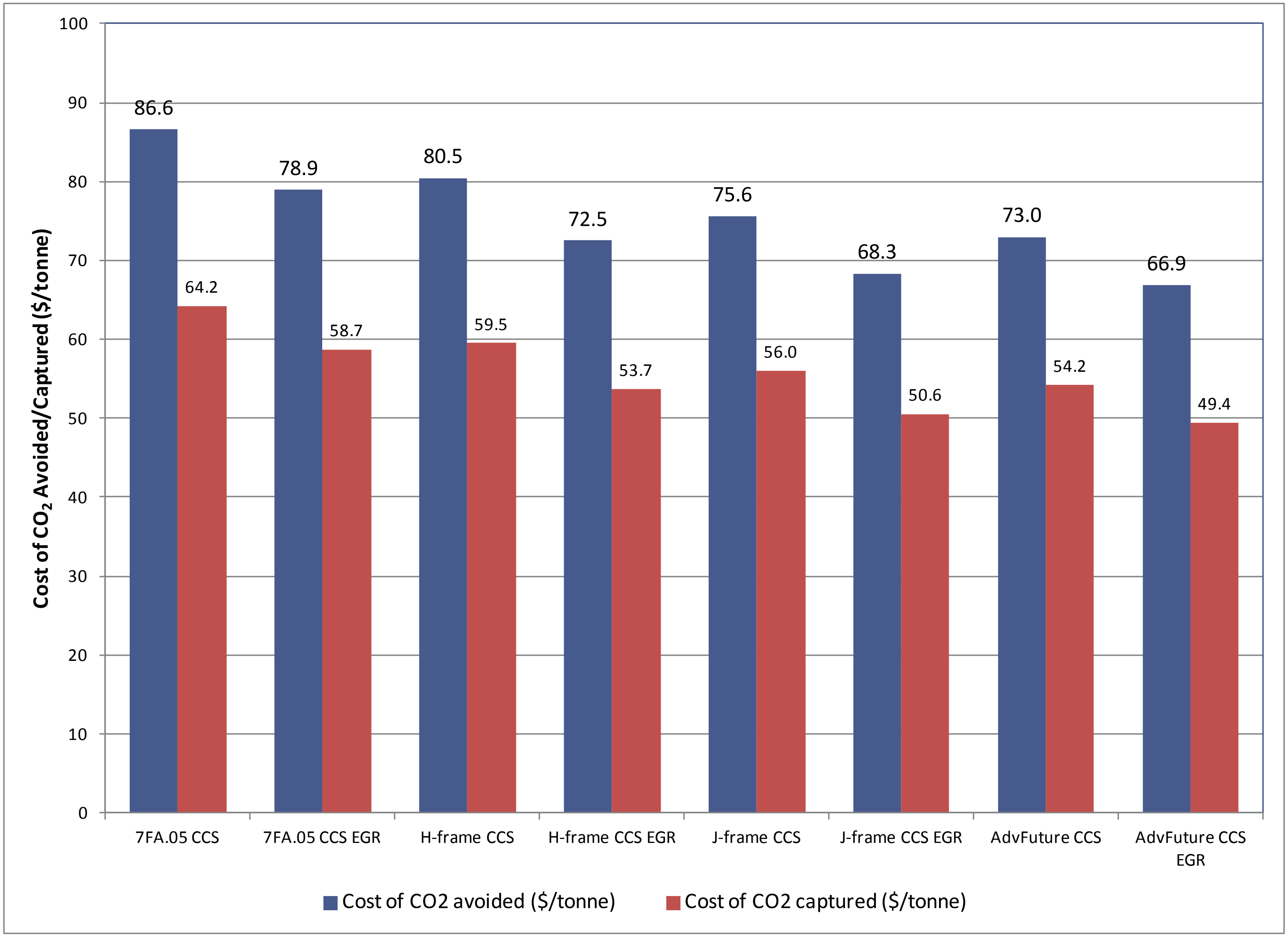
Source: NETL (All Costs are in June 2011 dollars)

Exhibit 7-9 COE by cost component



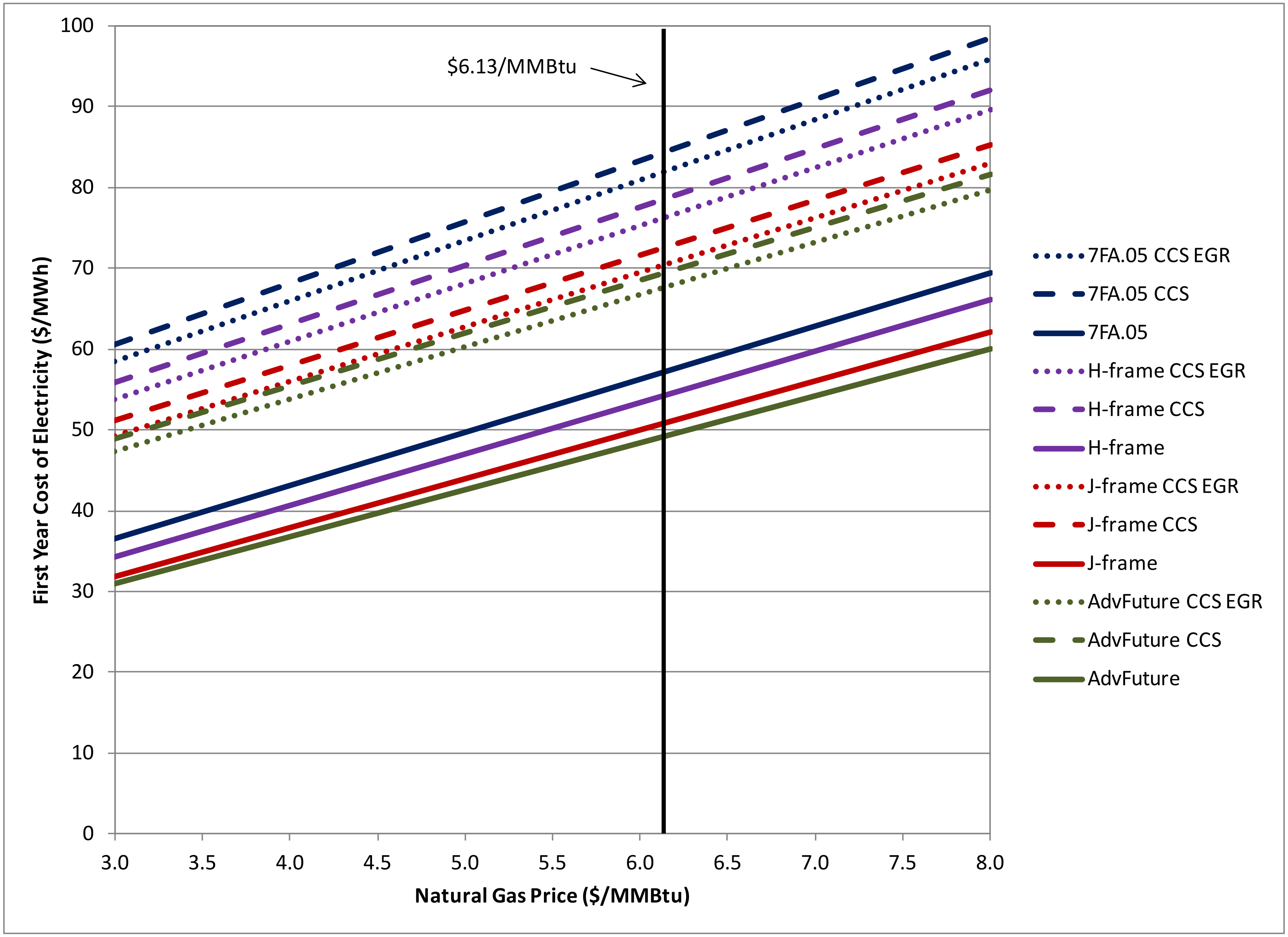
Source: NETL (All Costs are in June 2011 dollars, 85% capacity factor)

Exhibit 7-10 Cost of CO_2 avoided/captured



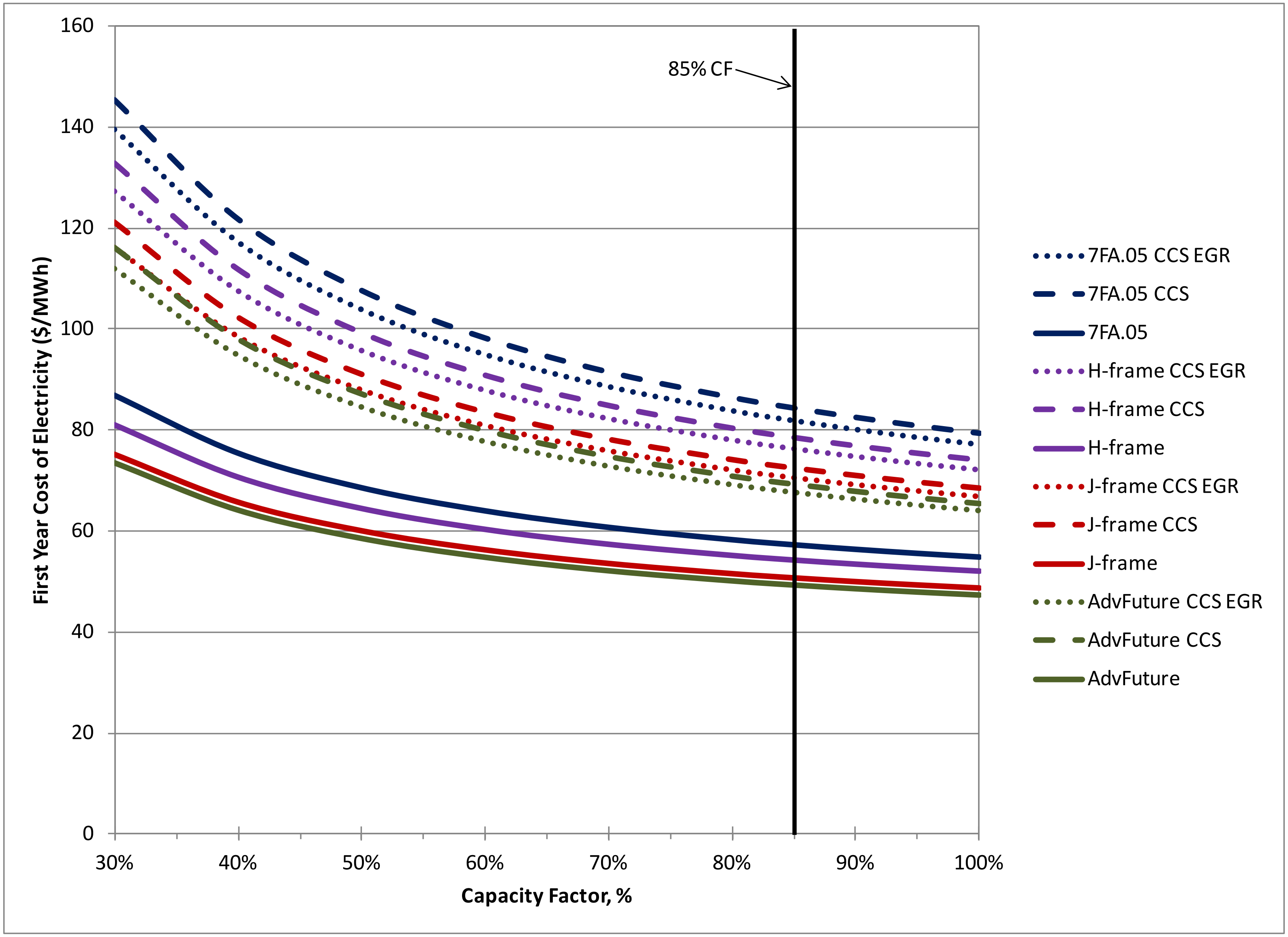
Source: NETL (All Costs are in June 2011 dollars, 85% capacity factor)

Exhibit 7-11 COE sensitivity to natural gas price



Source: NETL (All Costs are in June 2011 dollars, 85% capacity factor)

Exhibit 7-12 COE sensitivity to capacity factor

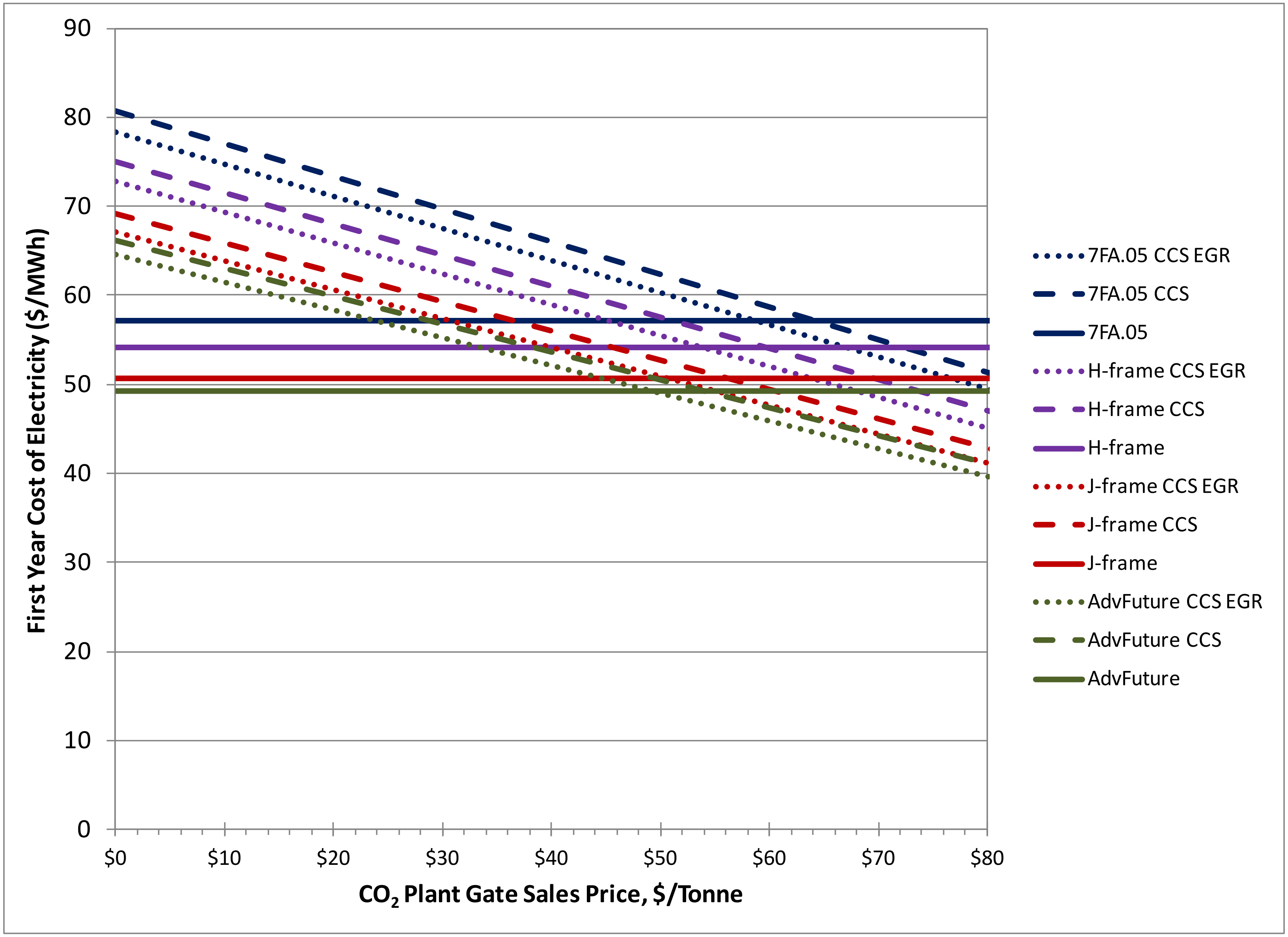


Source: NETL (All Costs are in June 2011 dollars, 85% capacity factor)

Exhibit 7-13 Capture case results with EOR

Turbine	CO_2 Capture Configuration		TOC ($/kW)	COE without CO_2 T&S ($/MWh)	COE with CO_2 T&S ($/MWh)	With $10/Tonne CO_2 Plant Gate Sales Price
						COE without CO_2 T&S ($/MWh)
SOA (based on "7FA.05")	1b	CO_2 capture	1,674	80.62	84.27	76.96
	1c	capture + EGR	1,568	78.32	81.92	74.71
SOA (based on "H")	2b	CO_2 capture	1,499	75.03	78.53	71.53
	2c	capture + EGR	1,396	72.71	76.16	69.26
Advanced (based on "J")	3b	CO_2 capture	1,343	69.17	72.47	65.88
	3c	capture + EGR	1,251	67.17	70.42	63.92
Advanced Future turbine	4b	CO_2 capture	1,271	66.21	69.35	63.06
	4c	capture + EGR	1,190	64.56	67.67	61.45

Exhibit 7-14 COE sensitivity to EOR credit



Source: NETL (All Costs are in June 2011 dollars, 85% capacity factor)

This study provides the following analysis tools and findings:

- Process simulation models of NGCC plants representing both SOA and advanced gas turbines, with and without an advanced post combustion capture system, are available to compare with coal power plants. Additionally, as new and evolving capture technologies develop, the models can be easily modified to evaluate the benefits.
- The performance penalty for carbon capture is approximately 6-7 absolute percentage points for the advanced solvent process represented.
- EGR greater than 35 percent may be required to further improve results.
- Natural gas fuel costs account for approximately 72 percent of the COE for the non-capture cases and approximately 57 percent for the CO_2 capture cases when based on a price of $5.81/GJ ($6.13/MMBtu). This implies that comparisons with coal power plants, which are less sensitive to fuel costs, will be greatly influenced by natural gas prices.
- The EPA recently proposed CO_2 emissions limit of 1000 lb/MWh_{gross} for new power plants, which would result in carbon capture not being required for NGCC.
- Carbon capture plants require a sales price for CO_2 of approximately $50 to $65/tonne for capture cases to have a COE equivalent to non-capture cases.

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Appendix

Case 1a - SOA turbine without CO2 capture heat and mass balance diagram

Case 1b - SOA turbine with CO2 capture heat and mass balance diagram

Case 1c - SOA turbine with CO2 capture and EGR heat and mass balance diagram

Case 2a - “H” frame turbine without CO2 capture heat and mass balance diagram

Case 2b - “H” frame turbine with CO2 capture heat and mass balance diagram

Case 2c – “H” frame turbine with CO2 capture and EGR heat and mass balance diagram

Case 3a – “J” frame turbine without CO2 capture heat and mass balance diagram

Case 3b – “J” frame turbine with CO2 capture heat and mass balance diagram

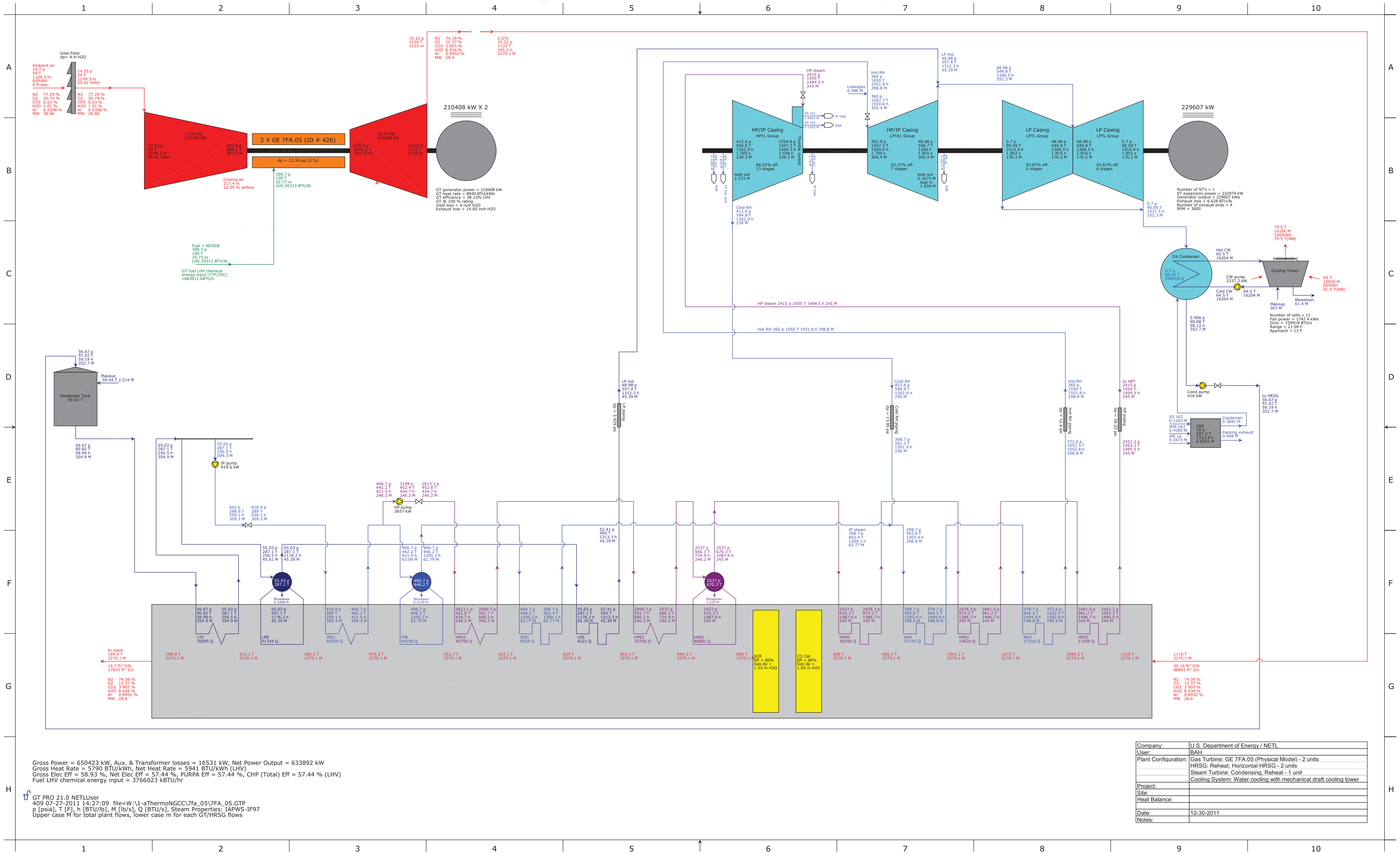
Case 3c – “J” frame turbine with CO2 capture and EGR heat and mass balance diagram

Case 4a - Advanced/Future turbine without CO2 capture heat and mass balance diagram

Case 4b – Advanced/Future turbine with CO2 capture heat and mass balance diagram

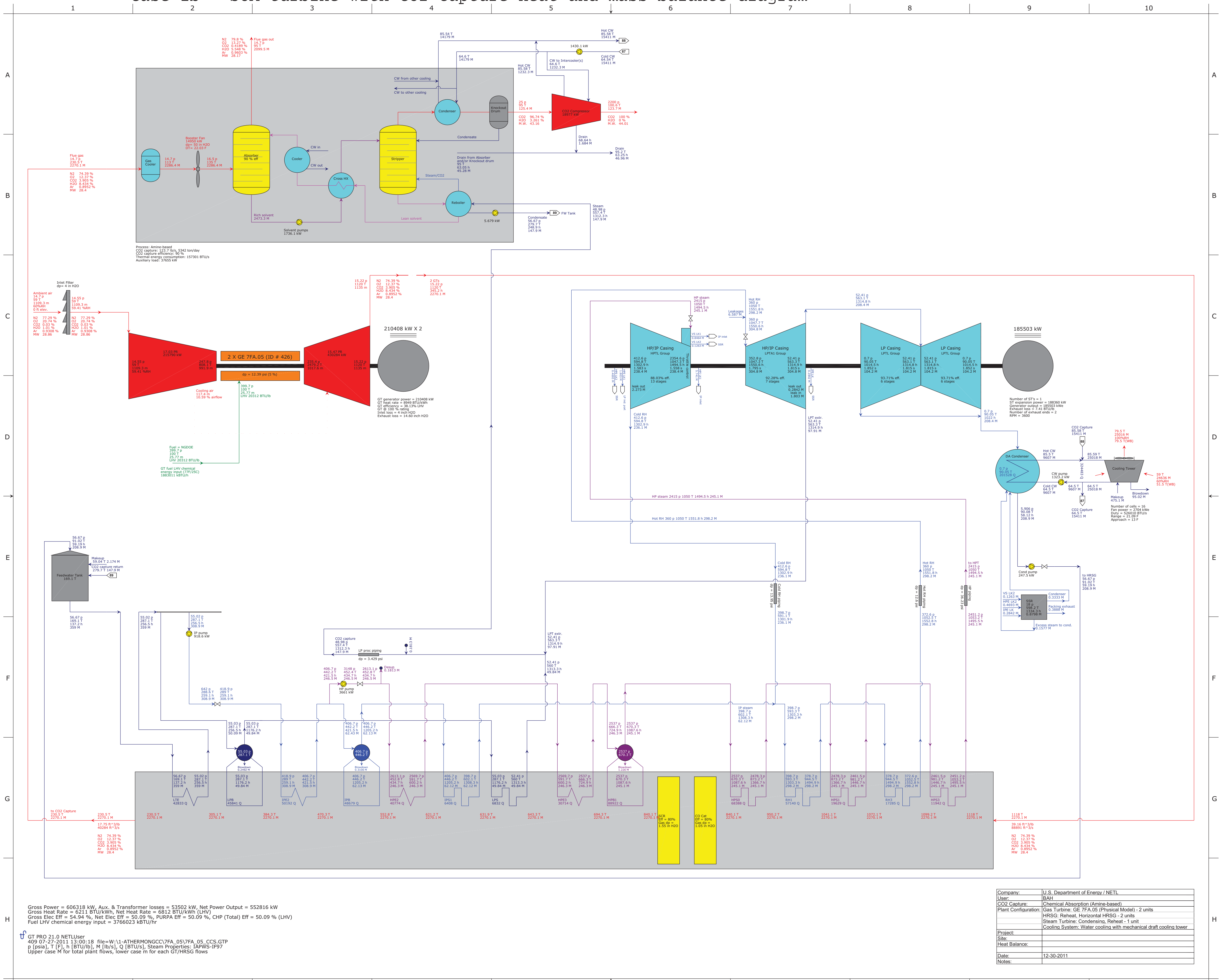
Case 4c - Advanced/Future turbine with CO2 capture and EGR heat and mass balance diagram

Case 1a - SOA turbine without CO2 capture heat and mass balance diagram



Source: NETL

Case 1b - SOA turbine with CO2 capture heat and mass balance diagram

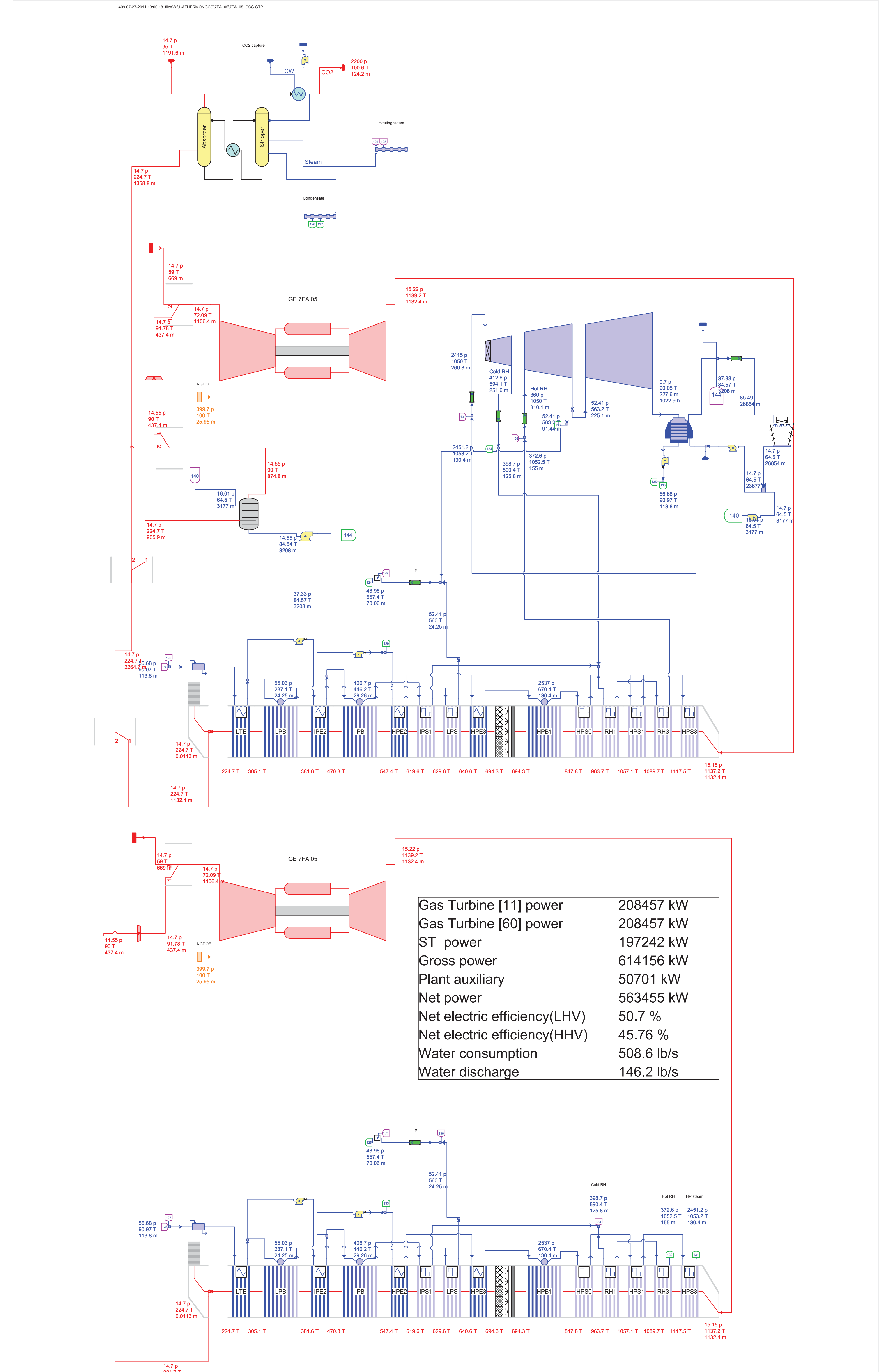


Source: NETL

Case 1c - SOA turbine with CO2 capture and EGR heat and mass balance diagram

THERMOFLEX Version 21.0 Revision 1 NETLUser U.S. Department of Energy / NETL

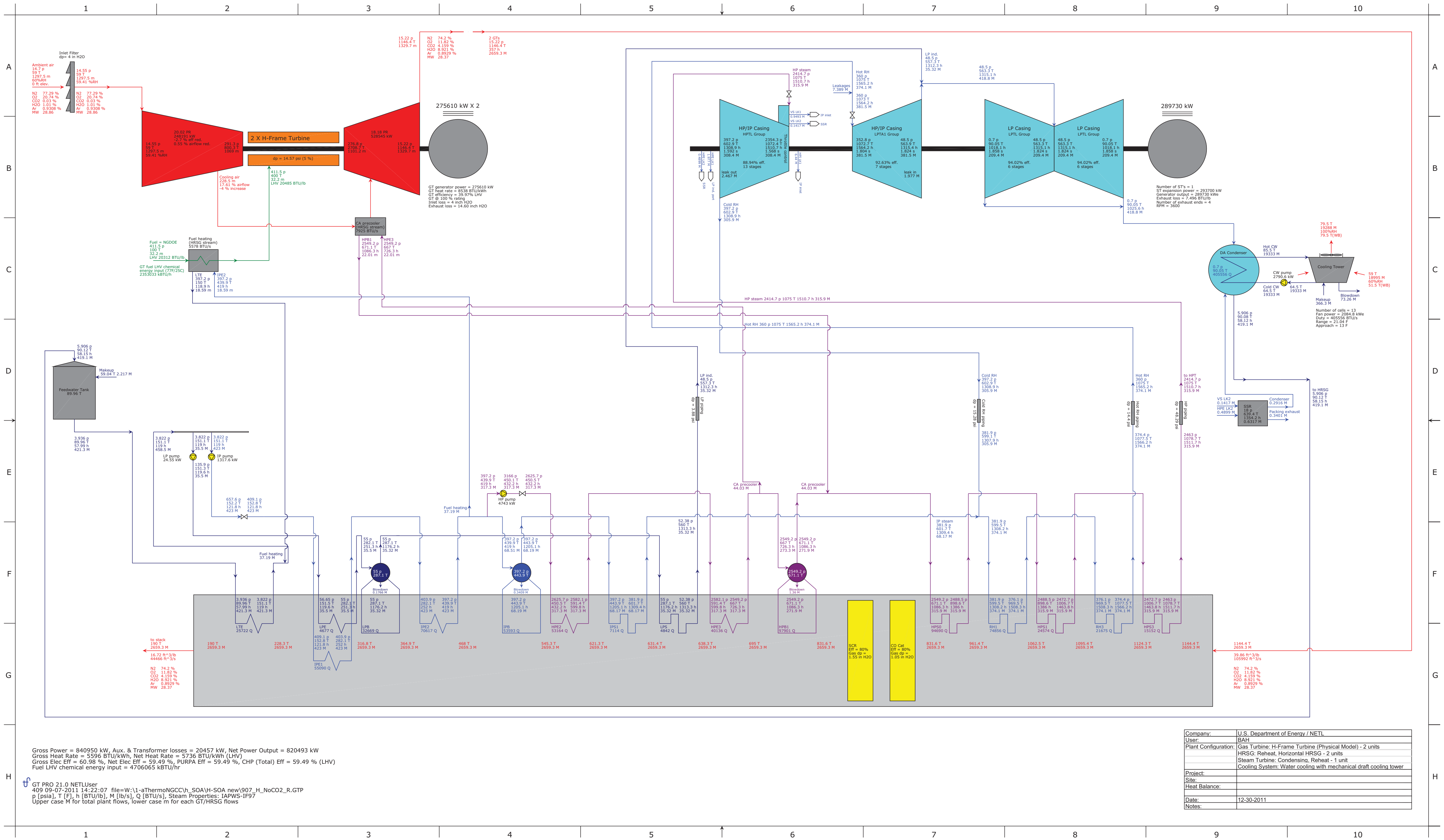
psia | F
lb/s | BTU/lb



Gas Turbine [11] power	208457 kW
Gas Turbine [60] power	208457 kW
ST power	197242 kW
Gross power	614156 kW
Plant auxiliary	50701 kW
Net power	563455 kW
Net electric efficiency(LHV)	50.7 %
Net electric efficiency(HHV)	45.76 %
Water consumption	508.6 lb/s
Water discharge	146.2 lb/s

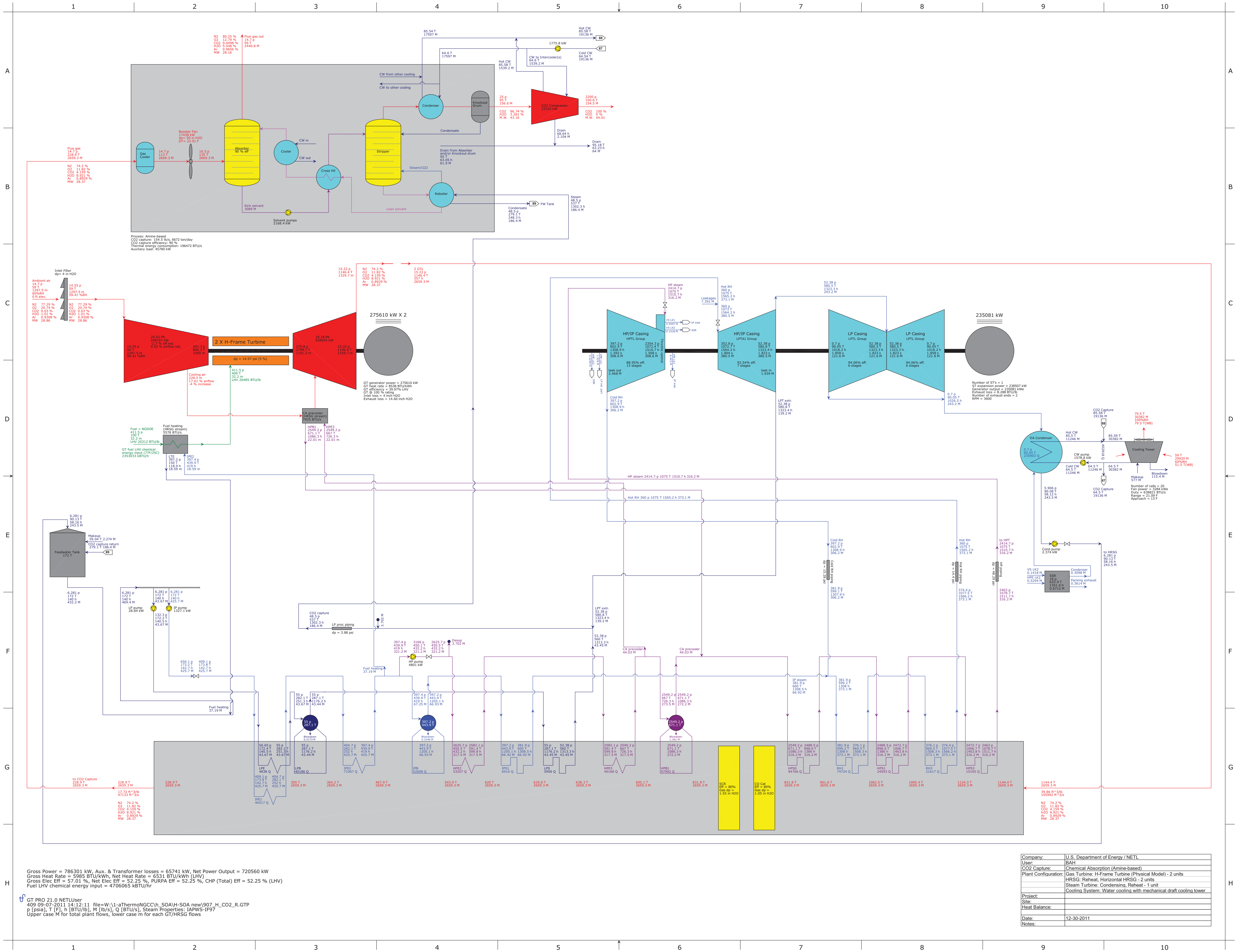
Source: NETL

Case 2a - "H" frame turbine without CO2 capture heat and mass balance diagram



Source: NETL

Case 2b - “H” frame turbine with CO2 capture heat and mass balance diagram

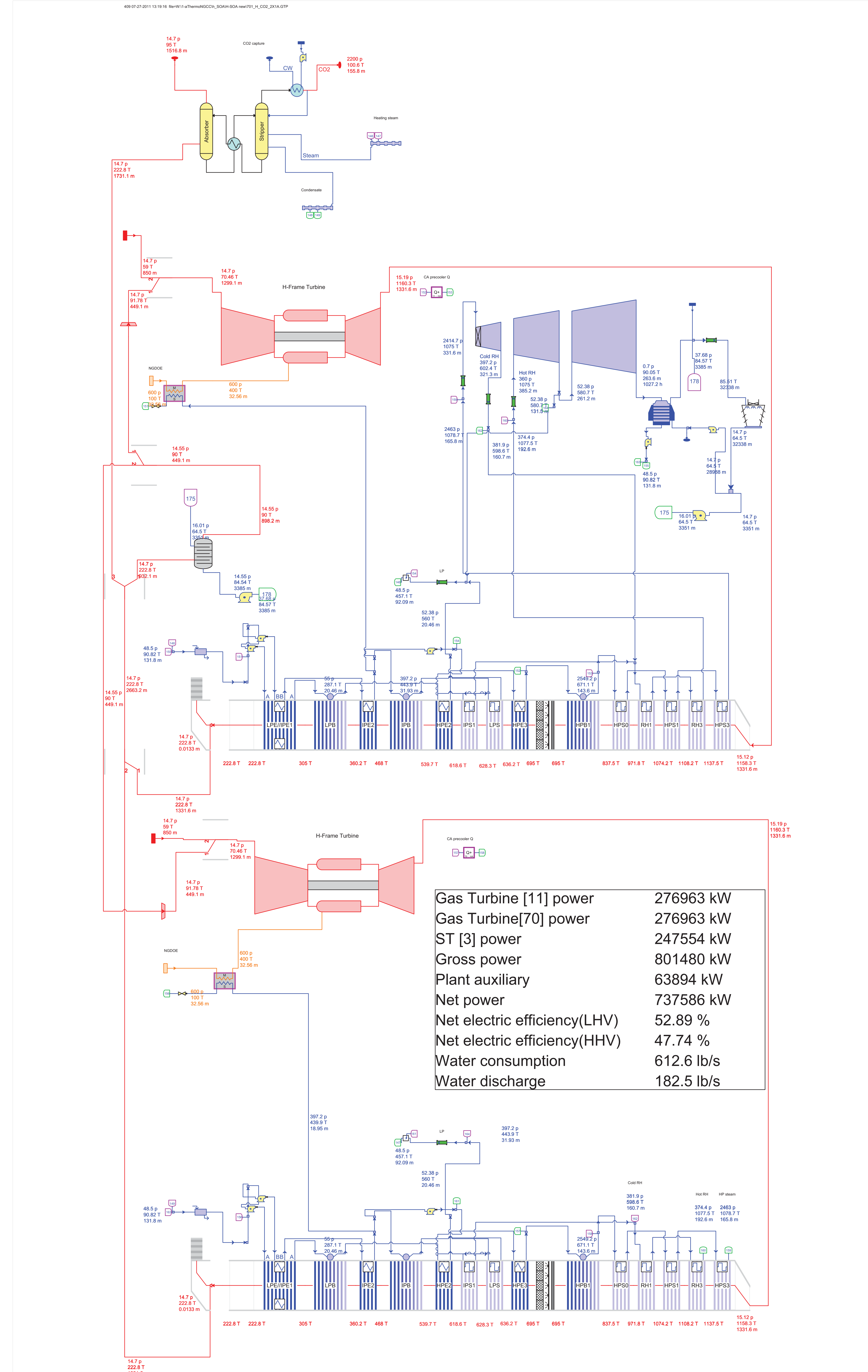


Source: NETL

Case 2c – "H" frame turbine with CO2 capture and EGR heat and mass balance diagram

THERMOFLEX Version 21.0 Revision 1 NETLUser U.S. Department of Energy / NETL

psia | F
lb/s | BTU/lb

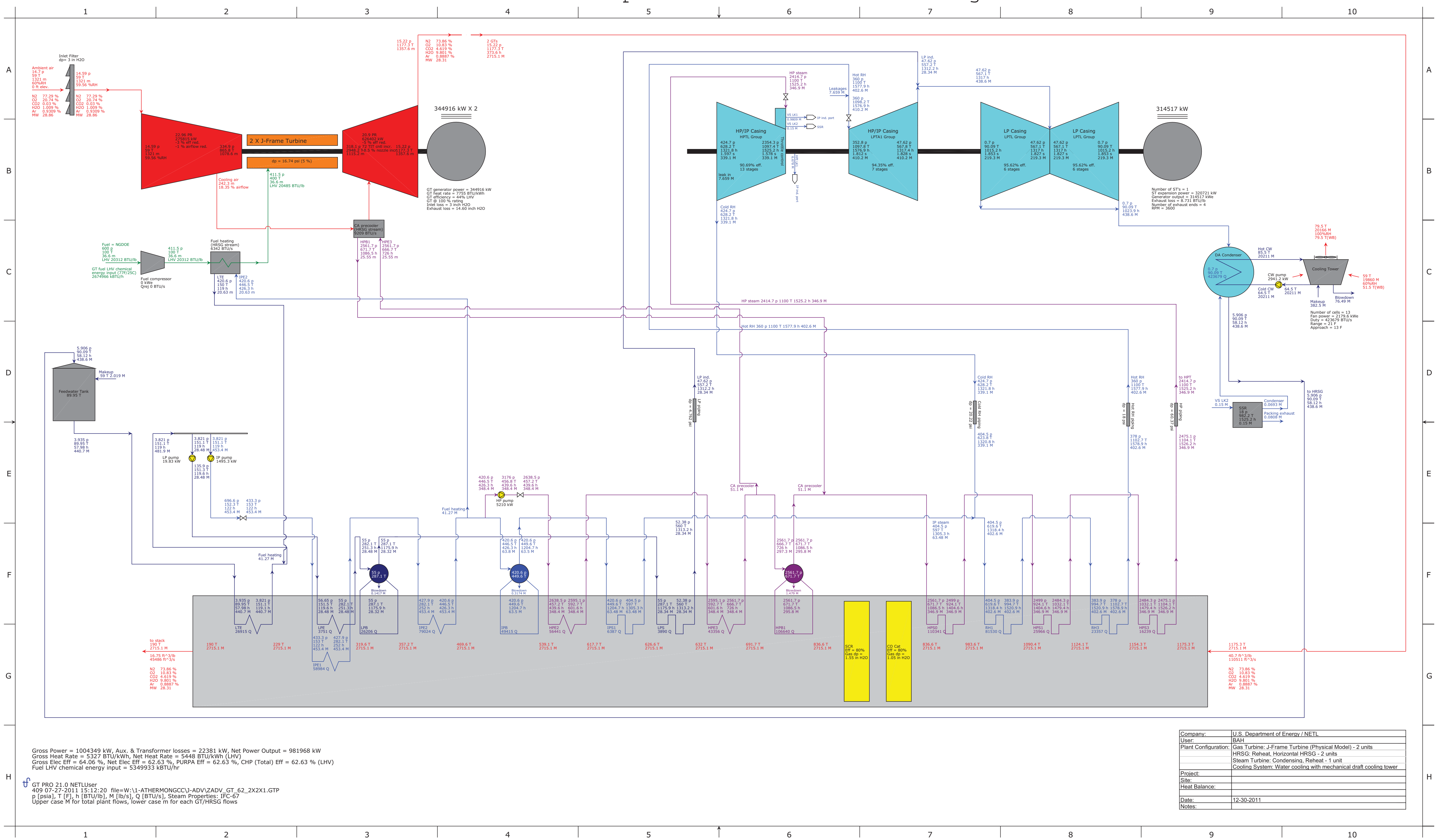


Gas Turbine [11] power	276963 kW
Gas Turbine[70] power	276963 kW
ST [3] power	247554 kW
Gross power	801480 kW
Plant auxiliary	63894 kW
Net power	737586 kW
Net electric efficiency(LHV)	52.89 %
Net electric efficiency(HHV)	47.74 %
Water consumption	612.6 lb/s
Water discharge	182.5 lb/s

Source: NETL

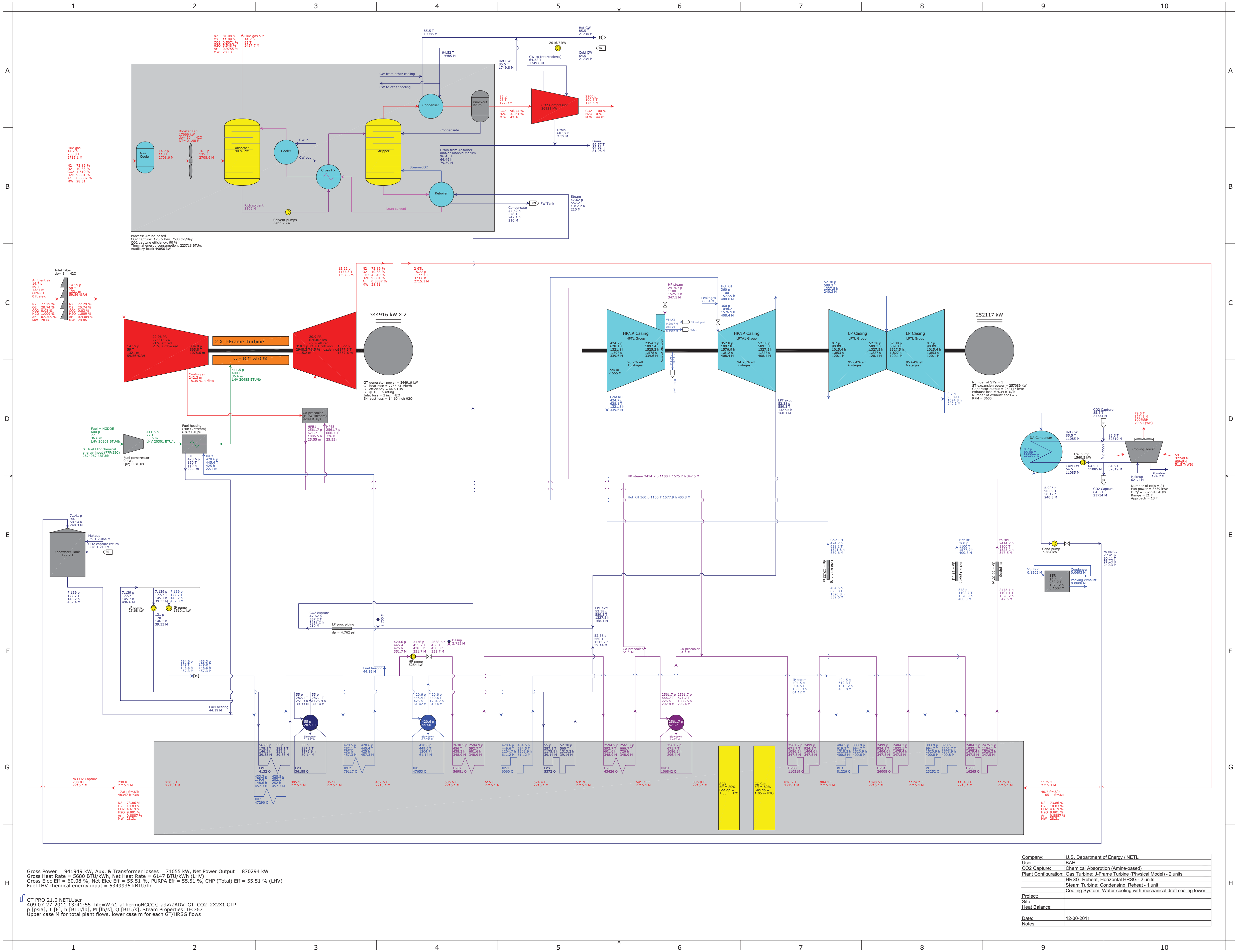
Sheet 1: GT 1-2

Case 3a – "J" frame turbine without CO2 capture heat and mass balance diagram



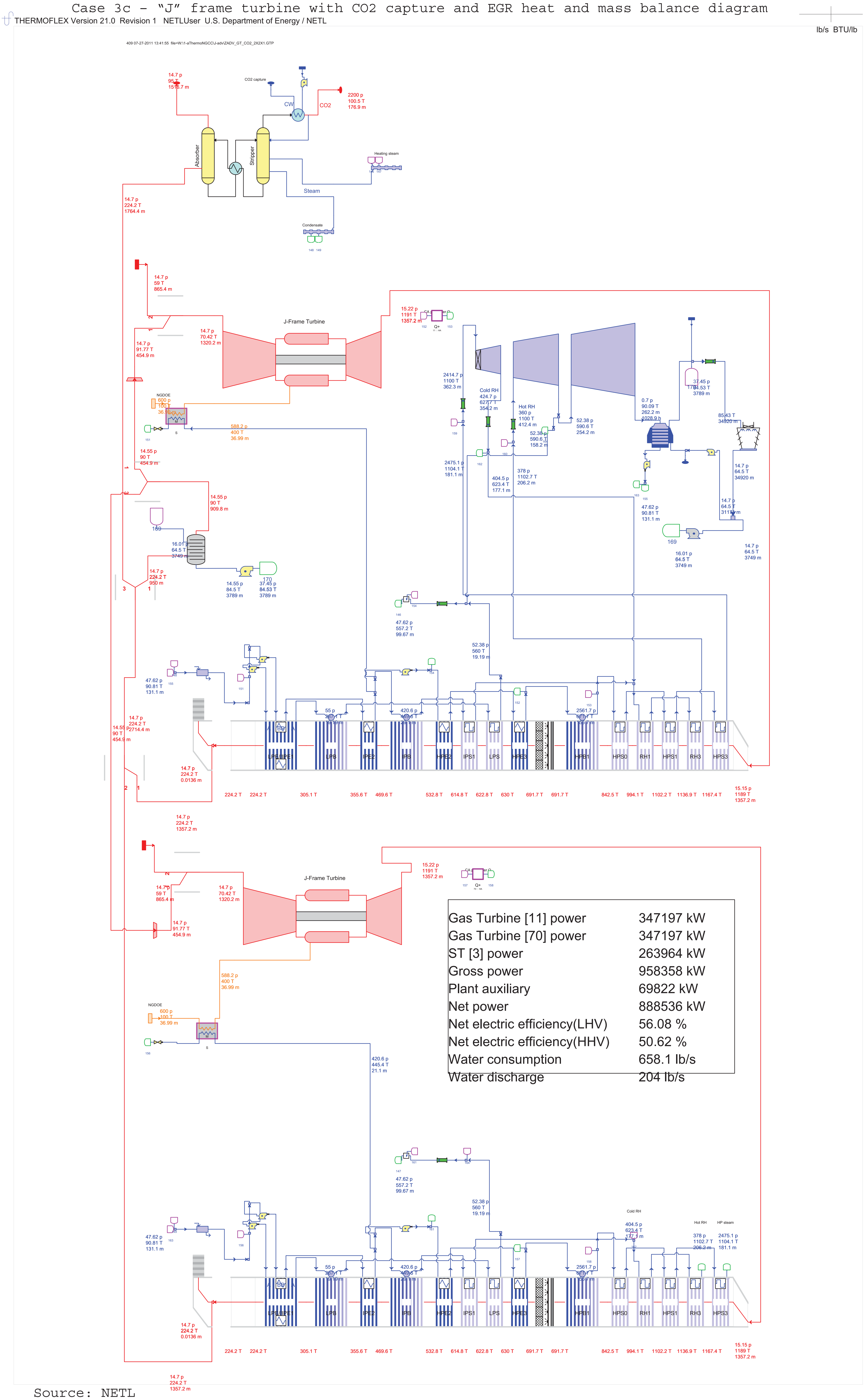
Source: NETL

Case 3b – "J" frame turbine with CO2 capture heat and mass balance diagram



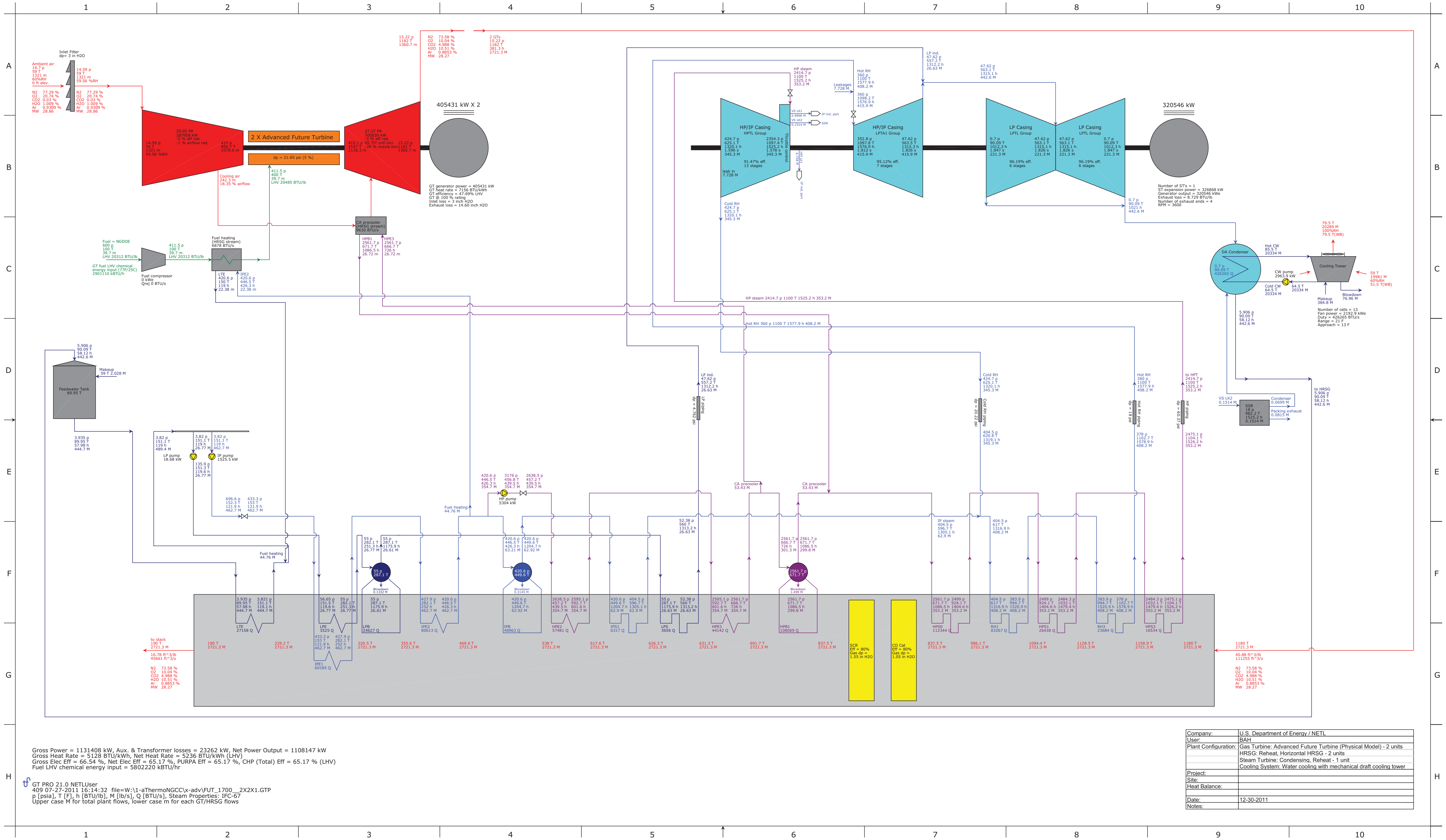
Source: NETL

Case 3c – "J" frame turbine with CO2 capture and EGR heat and mass balance diagram



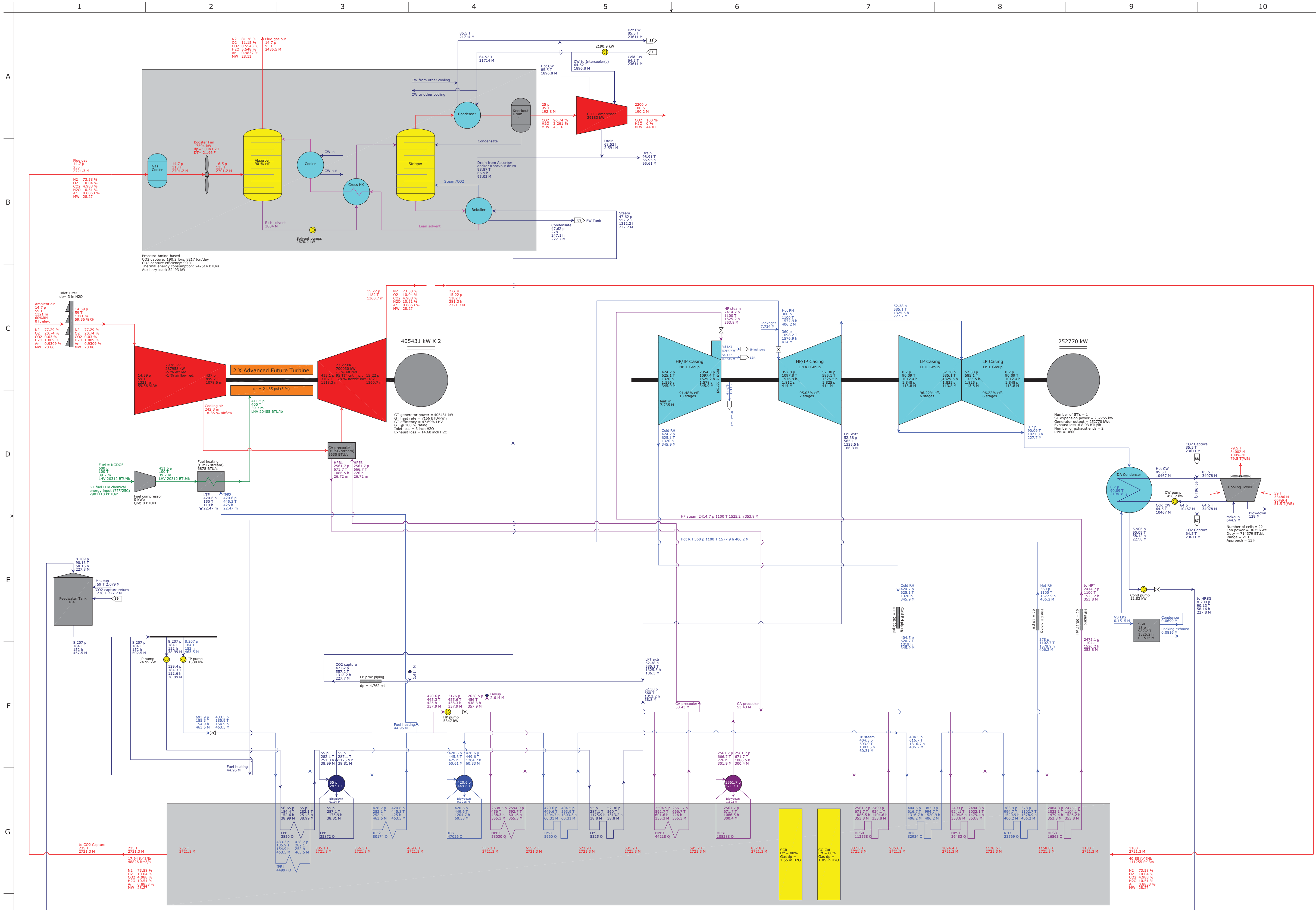
Source: NETL

Case 4a - Advanced/Future turbine without CO2 capture heat and mass balance diagram



Source: NETL

Case 4b - Advanced/Future turbine with CO2 capture heat and mass balance diagram



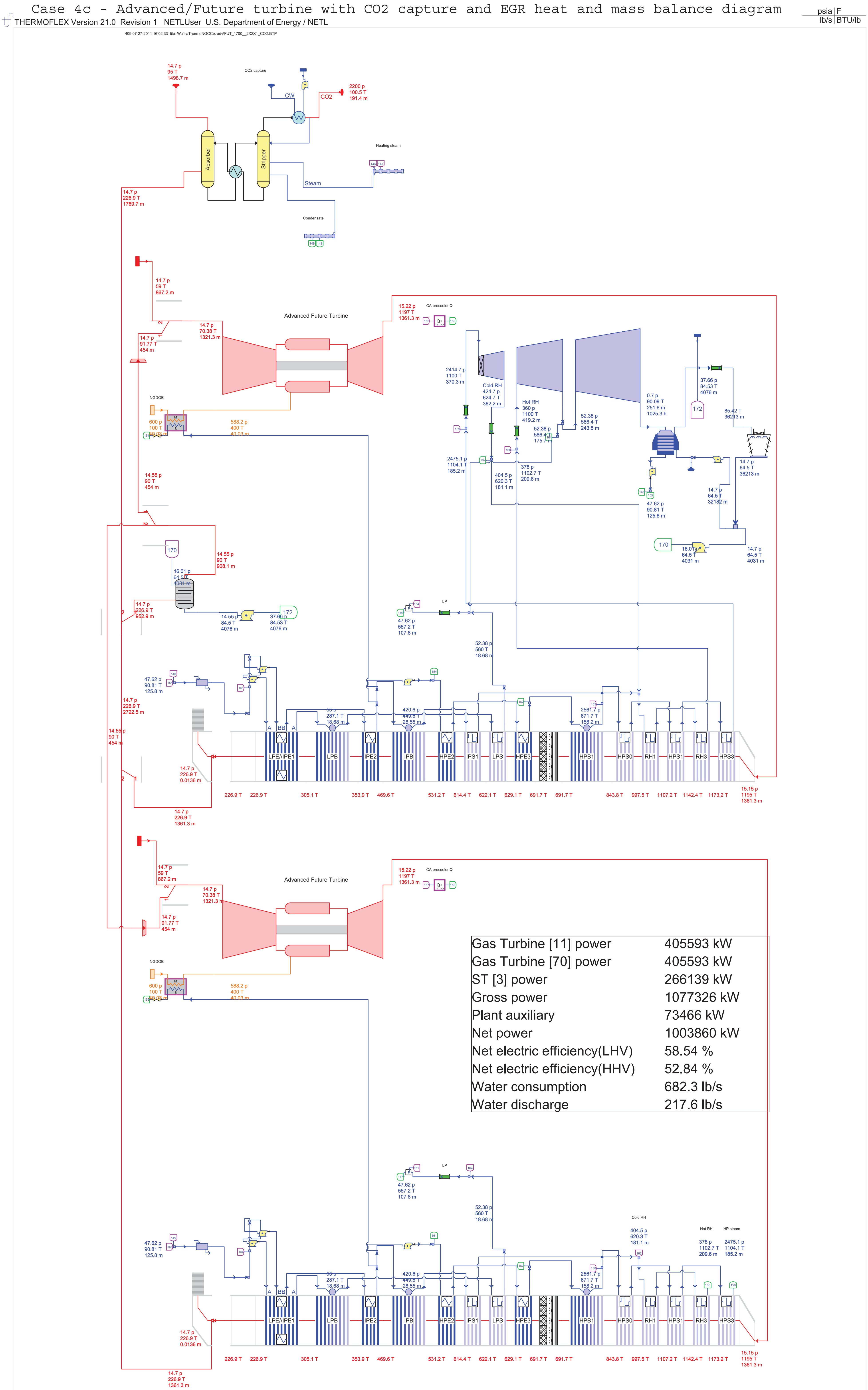
Gross Power = 1063632 kW, Aux. & Transformer losses = 75114 kW, Net Power Output = 988518 kW
Gross Heat Rate = 5455 BTU/kWh, Net Heat Rate = 5870 BTU/kWh (LHV)
Gross Elec Eff = 62.55 %, Net Elec Eff = 58.13 %, PURPA Eff = 58.13 %, CHP (Total) Eff = 58.13 % (LHV)
Fuel LHV chemical energy input = 5802220 kBTU/hr

GT PRO 21.0 NETLUser
409 07-27-2011 16:02:33 file=W:\1-aThermoNGCC\x-adv\FUT_1700__2X2X1_CO2.GTP
p [psia], T [F], h [BTU/lb], M [lb/s], Q [BTU/s], Steam Properties: IFC-67
Upper case M for total plant flows, lower case m for each GT/HRSG flows

Company:	U.S. Department of Energy / NETL
User:	BAH
CO2 Capture:	Chemical Absorption (Amine-based)
Plant Configuration:	Gas Turbine: Advanced Future Turbine (Physical Model) - 2 units
	HRSG: Reheat, Horizontal HRSG - 2 units
	Steam Turbine: Condensing, Reheat - 1 unit
	Cooling System: Water cooling with mechanical draft cooling tower
Project:	
Site:	
Heat Balance:	
Date:	12-30-2011
Notes:	

Source: NETL

Case 4c - Advanced/Future turbine with CO2 capture and EGR heat and mass balance diagram



Gas Turbine [11] power	405593 kW
Gas Turbine [70] power	405593 kW
ST [3] power	266139 kW
Gross power	1077326 kW
Plant auxiliary	73466 kW
Net power	1003860 kW
Net electric efficiency(LHV)	58.54 %
Net electric efficiency(HHV)	52.84 %
Water consumption	682.3 lb/s
Water discharge	217.6 lb/s

Source: NETL