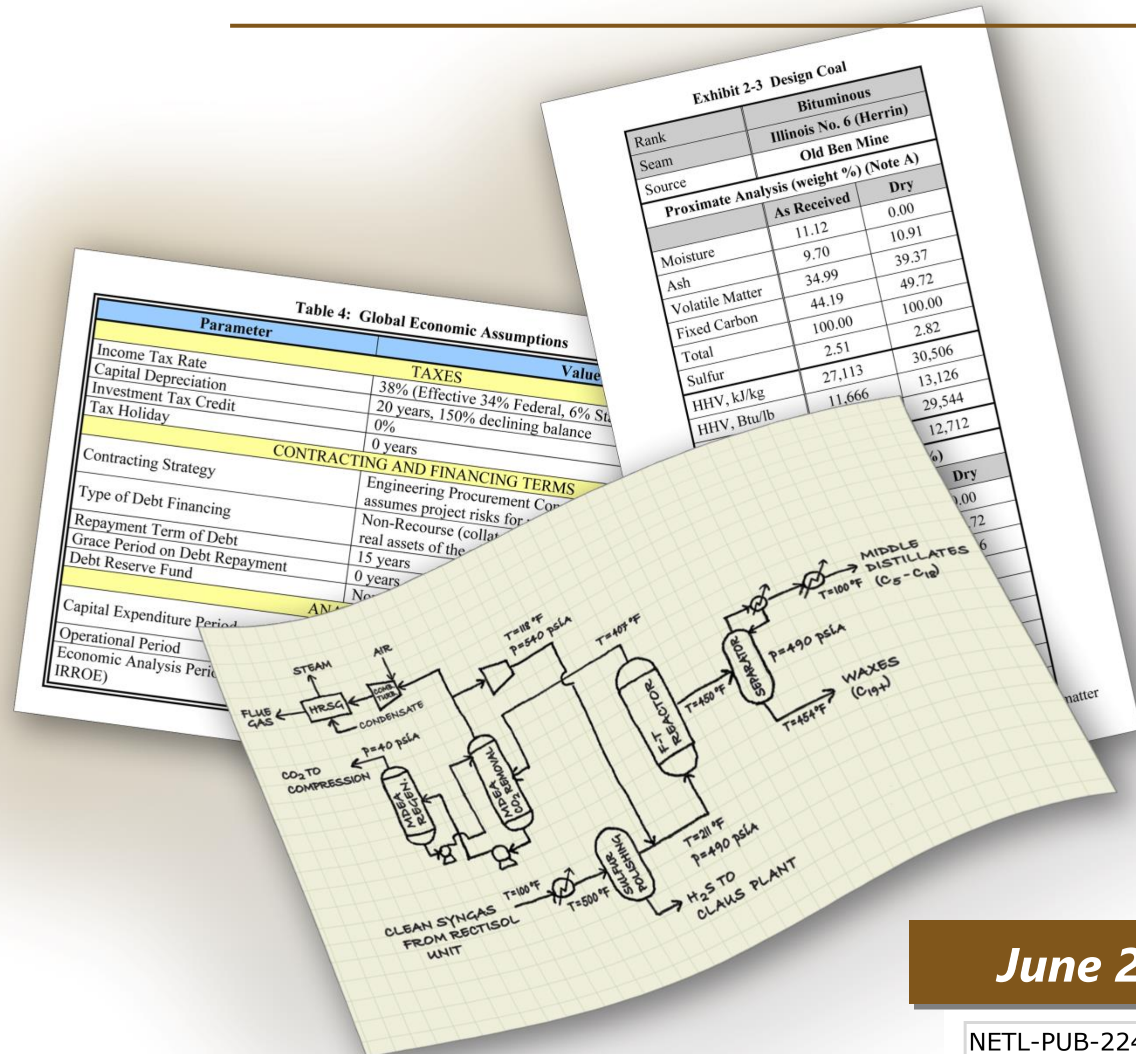
NATIONAL ENERGY TECHNOLOGY LABORATORY

QUALITY GUIDELINES FOR ENERGY SYSTEM STUDIES

Process Modeling Design Parameters



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Acronyms and Abbreviations

ACI	Activated carbon injection
Ar	Argon
Aspen	Aspen Plus®
ASU	Air separation unit
$CaCO_3$	Calcium carbonate
CFB	Circulating fluidized bed
CO	Carbon monoxide
CO_2	Carbon dioxide
CoP	ConocoPhillips
COS	Carbonyl sulfide
ELECNRTL	Electrolyte Non-Random Two Liquid
EPRI	Electric Power Research Institute
FGD	Flue gas desulfurization
ft	Feet
GEP	General Electric Power
H_2O	Water
H_2S	Hydrogen sulfide
HCl	Hydrogen chloride
HCN	Hydrogen cyanide
HCO_3	Bicarbonate
Hg	Mercury
HP	High pressure
hr	Hour
HRSG	Heat recovery steam generator
HTS	High temperature shift
IGCC	Integrated gasification combined cycle
in. Hg	Inches mercury
in. Hg Abs.	Inches mercury absolute
IP	Intermediate pressure
ISO	International Organization for Standardization
kg/MMacm	Kilogram per million actual cubic meters
kJ/kg	Kilojoule per kilogram
kPa	Kilopascal
kV	Kilovolt
kW	Kilowatt
kWe	Kilowatt electric
lb	Pound
lb/hr	Pounds per hour
lb/MMacf	Pounds per million actual cubic feet
lbmol	Pound mole
LK-PLOCK	Lee-Kesler-Plöcker
LP	Low pressure
LTS	Low temperature shift
m	Meter
m^3	Cubic meter
MDEA	Methyldiethanolamine
MMBtu	Million British thermal unit
MPa	Megapascal
MWe	Megawatt electric
N_2	Nitrogen
NBS	National Bureau of Standards
NETL	National Energy Technology Laboratory
NGCC	Natural gas combined cycle
NIST	National Institute of Standards and Technology
NOx	Oxides of nitrogen
NRC	National Research Council
NTU	Nephelometric Turbidity Units
O_2	Oxygen
PC	Pulverized coal
PENG-ROB	Peng-Robinson
POTW	Publicly owned treatment works
ppm	Parts per million
ppmv	Parts per million volume
ppmvd	Parts per million dry volume
ppmw	Parts per million weight
PRB	Powder River Basin
psi	Pound per square inch
psia	Pound per square inch absolute
QGESS	Quality Guidelines for Energy System Studies
SCR	Selective catalytic reduction process or equipment
SDE	Spray dryer evaporator
SO_2	Sulfur dioxide
SO_3	Sulfur trioxide
STEAMNBS	Steam tables
TDS	Total dissolved solids
TEG	Triethylene glycol
TGTU	Tail gas treatment unit
tph	Tons per hour
TRIG™	Transport Reactor Integrated Gasifier
U.S.	United States
USC	Ultra-supercritical
V	Volt
wt%	Weight percent
°C	Degrees Celsius
°F	Degrees Fahrenheit
µS/cm	Micro-Siemens per centimeter

1 Introduction

The National Energy Technology Laboratory (NETL) conducts systems analysis studies that require a large number of inputs, from ambient conditions to parameters for Aspen Plus® (Aspen) process blocks. The sheer number of assumptions required makes it impractical to document all of them in each issued report. The purpose of this section of the Quality Guidelines for Energy System Studies (QGESS) is to document the assumptions most commonly used in system analysis studies and the basis for those assumptions.

In order to develop the systems analysis models presented in various NETL reports, significant vendor data has been obtained, and this data enhances the model outputs. Much of the vendor data obtained is considered proprietary and not suitable for public release, or attribution to a specific vendor. As such, several sub-systems common in NETL reports and their process parameter data are not reported in this document to protect proprietary vendor information.

The values and ranges of values presented in this report represent assumptions that have been made in previous studies. Studies that use values other than the recommended values should contain a statement similar to the following:

Process design parameter assumptions are taken from QGESS, except for [identify parameters], which are different because [state reasons].

2 Site Conditions and Characteristics

This section provides the conditions and characteristics of sites commonly used in NETL system studies. The sites include locations in Montana and North Dakota, along with International Organization for Standardization (ISO) conditions, representative of a generic Midwest, United States (U.S.) location. Ambient conditions are required for estimating performance of the power plant configurations and to size the equipment so that an accurate cost estimate can be made. The ambient site conditions and characteristics of two locations plus a generic ISO site are presented in Exhibit 2-1 and Exhibit 2-2. The assumed design makeup water composition is provided in Exhibit 2-3. The quality of the source-water will vary depending on source and location; it can be expected to vary significantly throughout any given site, especially if ground water is used.

The makeup water composition reported in Exhibit 2-3 is based on water qualities from actual operations. The design concentration of each constituent is individually representative of a plant configuration comparable to those in NETL studies. [1] [2] However, due to the interaction and interdependencies of each constituent and the multitude of potential species, the makeup water quality cannot be considered representative as a whole. The makeup water quality is intended to inform users of the contaminants likely present, and at what concentrations they may be expected at, to facilitate appropriate equipment selection and design.

Exhibit 2-1. Site Characteristics

Site Characteristics	Montana [1]	North Dakota [1]	Midwest ISO [2]
Topography	Level	Level	Level
Size (Pulverized Coal or Integrated Gasification Combined Cycle), acres[a]	300	300	300
Size (Natural Gas Combined Cycle), acres	100	100	100
Transportation	Rail or Highway	Rail or Highway	Rail or Highway
Ash/Slag Disposal	Offsite	Offsite	Offsite
Water and Make-up Water	50% Municipal and 50% Ground water	50% Municipal and 50% Ground water	50% Municipal and 50% Ground water

[a]For calculation convenience, acreage values for coal-based plants were assumed to be equal.

Exhibit 2-2. Site Conditions

Site Conditions	Montana [1]	North Dakota [1]	Midwest ISO [2]
Elevation, m (ft)	1,036 (3,400)	579 (1,900)	0 (0)
Barometric Pressure, MPa (psia)	0.090 (13.0)	0.095 (13.8)	0.101 (14.7)
Average Ambient Dry Bulb Temperature, °C (°F)	5.6 (42)	4.4 (40)	15 (59)
Average Ambient Wet Bulb Temperature, °C (°F)	2.8 (37)	2.2 (36)	10.8 (51.5)
Design Ambient Relative Humidity, %	62	68	60
Cooling Water Temperature, °C (°F)[a]	8.9 (48)	8.9 (48)	15.6 (60)
Air composition based on published psychometric data, mass %			
N_2	75.220	75.231	75.055
O_2	23.049	23.052	22.998
Ar	1.283	1.283	1.280
H_2O	0.398	0.384	0.616
CO_2	0.050	0.050	0.050
Total	100.00	100.00	100.00

[a]The cooling water temperature is the cooling tower cooling water exit temperature.
This is set to 8.5°F(4.8°C) above ambient wet bulb conditions in ISO cases and 11°F (6.1°C) otherwise.

Exhibit 2-3. Design Makeup Water Quality

Parameter	Ground Water (Range)	POTW Water (Range)	Makeup Water (Design Basis)
pH	6.6–7.9	7.1–8.0	7.4
Specific Conductance, µS/cm	1,096–1,484	1,150–1,629	1312
Turbidity, NTU		<50	<50
Total Dissolved Solids, ppm			906
M-Alkalinity as $CaCO_3$, ppm[a]	200–325	184–596	278
Sodium as Na, ppm	102–150	172–336	168
Chloride as Cl, ppm	73–100	205–275	157
Sulfate as SO	100–292	73–122	153
Calcium as Ca, ppm	106–160	71–117	106
Magnesium as Mg, ppm	39–75	19–33	40
Potassium as K, ppm	15–41	11–21	18
Silica as SiO	5–12	21–26	16
Nitrate as N, ppm	0.1–0.8	18–34	12
Total Phosphate as PO	0.1–0.2	1.3–6.1	1.6
Strontium as Sr, ppm	2.48–2.97	0.319–0.415	1.5
Fluoride as F, ppm	0.5–1.21	0.5–0.9	0.8
Boron as B, ppm	0.7–0.77		0.37
Iron as Fe, ppm	0.099–0.629	0.1	0.249
Barium as Ba, ppm	0.011–0.52	0.092–0.248	0.169
Aluminum as Al, ppm	0.068–0.1	0.1–0.107	0.098
Selenium as Se, ppm	0.02–0.15	0.0008	0.043
Lead as Pb, ppm	0.002–0.1		0.026
Arsenic as As, ppm	0.005–0.08		0.023
Copper as Cu, ppm	0.004–0.03	0.012–0.055	0.018
Nickel as Ni, ppm	0.02–0.05		0.018
Manganese as Mn, ppm	0.007–0.015	0.005–0.016	0.009
Zinc as Zn, ppm	0.005–0.024		0.009
Chromium as Cr, ppm	0.01–0.02		0.008
Cadmium as Cd, ppm	0.002–0.02		0.006
Silver as Ag, ppm	0.002–0.02		0.006
Mercury as Hg, ppm	0.0002–0.001		3E-04

[a] *Alkalinity is reported as $CaCO_3$ equivalent, rather than the concentration of HCO_3. The concentration of HCO_3 can be obtained by dividing the alkalinity by 0.82.*

A suggested method to establish site conditions is provided in Exhibit 2-4 so that additional sites can be defined in a consistent manner. These guidelines should be used in the absence of any compelling market-, project-, or site-specific requirements. Following the provided methodology may result in different site conditions than those listed in the above exhibits because parameters may change with time (e.g., average temperature).

Exhibit 2-4. Method to Establish Site Conditions

Site Conditions	Method
Elevation	The site elevation is the average elevation in the state of interest. Average state elevations are available through numerous internet sources, including http://en.wikipedia.org/wiki/List_of_U.S._states_by_elevation http://www.netstate.com/states/tables/state_elevation_mean.htm
Barometric Pressure	The barometric pressure of atmospheric air varies with altitude as well as with local weather conditions. Only altitude effects are considered in the pressure calculation [3] as follows **P = 14.696 * (1 - (6.8753 x 10^$^{-6)}$ * Z)^5.2559** Z = Elevation (altitude) in ft P= Barometric pressure in psia Barometric pressure, site elevations, and other climate data can also be obtained from the public domain like National Climatic Data Center (https://www.ncdc.noaa.gov/cdo-web/) and U.S. Geological Survey's National Elevation Dataset (http://ned.usgs.gov//) by searching for locations and specific parameters of interest.
Design Ambient Dry Bulb Temperature	The dry bulb temperature can be obtained for the site from the public domain like National Climatic Data Center (https://www.ncdc.noaa.gov/cdo-web/) by searching for locations and specific parameters of interest. The yearly temperatures are averaged to obtain the ambient design dry bulb temperature of the particular site in consideration.
Design Ambient Wet Bulb Temperature	With known dry bulb temperature and relative humidity, wet bulb temperature for the site can be obtained from the psychrometric chart.
Design Ambient Relative Humidity	The relative humidity for the selected site is available from the public domain like National Climatic Data Center (https://www.ncdc.noaa.gov/cdo-web/) by searching for locations and specific parameters of interest. The average annual relative humidity is considered as the design ambient relative humidity.
Cooling Water Temperature, °C (°F) [4]	Typical cooling tower approach temperatures are in the range of 4.4–11.1°C (8–20°F) for power plant applications. Cold water temperatures for NETL systems studies assume an approach to wet bulb of 8.5°F (4.8°C) for ISO condition locations and 11°F (6.1°C) for the Montana and North Dakota locations. In all cases the cooling water range is assumed to be 11.1°C (20°F), which sets the cooling water process outlet temperature.

Site Conditions	Method
Air Composition, wt%, dry [5]	Dry air is mainly composed of N_2 (75.47%), O_2 (23.20%), Argon (1.28%), and CO_2 (0.06%). Air temperature affects potential moisture content. As air temperature rises, its ability to hold water vapor increases significantly. The amount of water vapor in air at ground level can vary from almost zero to about five percent. With the water vapor content, the remaining constituents can be calculated based on dry air composition. Water vapor content can be obtained from the psychrometric chart or another relevant method.
Makeup Water Quality	The assumed make-up water quality, provided by Black & Veatch, was used to represent Midwest ISO conditions. The quality of the source-water will vary dramatically from source to source (municipal versus ground water) or from site to site and can be expected to vary significantly throughout any given site, especially if ground water is used.

3 Property Methods

A summary of the property methods used for modeling various sections of energy systems is given in Exhibit 3-1.

Exhibit 3-1. Property Methods

Section	Property Method
Gasification and Coal Boiler	Peng-Robinson (PENG-ROB)
Air Separation Unit	PENG-ROB
Compressor and Gas Turbine	PENG-ROB
HRSG and Steam Turbine	STEAMNBS
Sour Water System	Electrolyte Non-Random Two Liquid (ELECNRTL)
Gray Water System	ELECNRTL
Sulfur Recovery Unit	PENG-ROB
CO_2 Capture	PENG-ROB
CO_2 Compression	Lee-Kesler-Plöcker (LK-PLOCK)

The gas side modeling for the gasification and boiler systems uses the Peng-Robinson (PENG-ROB) equation of state based on the Aspen User Manual [6] recommendations and an evaluation of high-temperature syngas quench systems conducted by the National Institute of Standards and Technology (NIST) for the Electric Power Research Institute (EPRI). [7]

Steam turbines and the steam side of heat recovery steam generators (HRSGs) are modeled using steam table property values. The steam table is the standard for water-based systems and uses an enthalpy reference state of the triple point of water at 32.02°F (0.01°C) and 0.089 psia (0.0006 MPa). Aspen recommends the steam table (STEAMNBS) property method for pure water and steam, and for the free-water phase when present. The STEAMNBS property method is based on the 1984 U.S. National Bureau of Standards (NBS)/Canadian National Research Council (NRC) steam table correlations for thermodynamic properties. [8] These correlations minimize continuity problems that occur at the boundaries between regions of the pressure-temperature space and can lead to Aspen model convergence problems. Because the steam tables are a common source of enthalpy data, all enthalpy values in NETL system studies are adjusted to the steam table reference conditions.

In integrated gasification combined cycle (IGCC) plants, the sour water system uses the Electrolyte Non-Random Two Liquid (ELECNRTL) property method. The ELECNRTL method more accurately predicts the solubility of ionic species in water.

The sulfur recovery unit and CO_2 capture process use the PENG-ROB equation of state. According to Aspen, "this property method is particularly suitable in the high temperature and high-pressure regions, such as in hydrocarbon processing applications or supercritical extractions." [6]

The CO_2 compression system uses the Lee-Kesler-Plöcker (LK-PLOCK) equation of state based on discussions with CO_2 compressor vendors concerning the performance predictability of various equation of state models. According to Aspen, "The LK-PLOCK property method is consistent in the critical region." [6]

The property methods of smaller process subsystems in each model should be specified based on the surrounding model blocks and streams to ensure consistency in the balance calculations unless there are compelling reasons to do otherwise.

When comparing energy values in streams from different sections that use different property methods, the energy value should be converted to a standard reference condition, as different property methods use different reference points; not doing so would result in energy balance issues.

4 Process Parameters for Modeling Bituminous Applications

The process parameters used for Aspen modeling and spreadsheet modeling of the Bituminous Baseline [2] are documented in the following subsections. Parameters associated with the Low-Rank Baseline [1] are provided in Section 5. For each parameter associated with a unit operation, a single value is provided. If parameter values differ across baseline models, a single value is provided, along with a range of values. The parameter value represents one case, which is specified in the "Notes" column, while the range represents the range of values used across models. When no entry appears in the range column, it does not imply that a range of values is not possible.

When available, a reference source is provided for the design parameter and range. In many cases, the source is engineering judgment. Additional explanation is provided in the "Notes" column, as warranted.

4.1 MOTOR EFFICIENCIES

Electric motors are used to drive pumps and compressors in many applications. The motor efficiency is a function of motor sizes as documented in Exhibit 4-1. The generator efficiency is also provided in Exhibit 4-1.

Exhibit 4-1. Electric Motor and Generator Efficiencies

Equipment and Parameter	Parameter Value	Range	Source	Notes
Electric Motor Efficiency, %	<1,000 kW: 95 <10,000 kW: 96.5 >10,000 kW: 97		Engineering Judgment	
Generator Efficiency, %	98.5	98.5–99	Engineering Judgment	The parameter value represents the generator efficiency in PC cases, while the range is inclusive of all cases.

The net efficiency of an electric pump, compressor, fan, etc., can be determined by multiplying the equipment efficiency by the motor efficiency.

4.2 COAL COMBUSTION SYSTEMS

The process parameters listed in Exhibit 4-2 through Exhibit 4-4 are for pulverized coal combustion systems. Process parameters for natural gas and syngas systems can be found in Section 4.3 and Section 4.4.

Exhibit 4-2. Process Parameters for Coal Combustion Systems

Equipment and Parameter	Parameter Value	Range	Source	Notes
Boiler				
Heat Loss, %	1.0		[9, p. 11] [10, pp. 23-7]	Radiative losses, as a percentage of energy output. Literature suggests average radiative losses at less than 1%.
Air Infiltration, %	2		[10, pp. 10-16]	Infiltration air percentage is based on theoretical (stoichiometric) air.
Excess Oxygen, vol%	2.6		[10, pp. 10-15]	Design parameter is on a dry basis upstream of the air heater.
Combustion Air Preheater				
Air Leakage, %	5.5		[10, pp. 20-13]	Air leakage is 5.5% of total combustion air flow and divided between primary and secondary air based on a ratio of pressure differences between the fan outlet and the air heater outlet. Literature suggests that air heater leakages range from 5 to 15%.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Pressure Drop, %	1.2		[10, pp. 20-13]	Pressure drop assumed to be 5 inches of water at ISO conditions.
Flue Gas Exit Temperature, °C (°F)	143 (289)		[11] [12]	The minimum flue gas temperature is dictated by the flue gas acid dew point.
Primary Air Fan				
Polytropic Efficiency, %	75		[10, pp. 25-11]	Backward curved blade type. Efficiency for this blade type ranges from 75 to 85%.
Pressure Rise, kPa (psi)	10.0 (1.44)		[10, pp. 25-12]	Pressure rise is based on the inlet pressure and set to accommodate a total pressure drop of 1.744 psi across the furnace (including the air preheater).
Portion of Total Combustion Air, %	23.5		[11]	Does not account for leaks or infiltration air.
Forced Draft Fan				
Polytropic Efficiency, %	75		[10, pp. 25-11]	Backward curved blade type. Efficiency for this blade type ranges from 75 to 85%.
Pressure Rise, kPa (psi)	3.8 (0.556)		[10, pp. 25-12]	Pressure rise is based on the inlet pressure and set to accommodate a total pressure drop of 0.856 psi across the furnace (including the air preheater).
Portion of Total Combustion Air, %	76.5		[11]	Does not account for leaks or infiltration air.
Induced Draft Fan				
Polytropic Efficiency, %	75		[10, pp. 25-11]	Backward curved blade type. Efficiency for this blade type ranges from 75 to 85%.
Pressure Rise, kPa (psi)	7.5 (1.087)		[10, pp. 25-12]	Pressure ratio is adjusted to provide one inch of H_2O above ambient pressure at the stack base.
Oxidation Air Blowers				
Polytropic Efficiency, %	70		[10, pp. 25-16]	Radial Tipped Blade. Efficiency for this blade type ranges from 60 to 70%.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Discharge Pressure, kPa (psia)	310.3 (45)		[10, pp. 25-12]	

Steam cycle conditions for combustion-based subcritical and supercritical coal units in NETL systems studies are based on a market survey that was conducted in 2005. [13] Interviews with steam turbine vendors were also included. [16] The conditions chosen at the steam turbine throttle valve are representative of currently available commercial offerings and are shown in Exhibit 4-3. There is no consensus regarding the boundary between supercritical and ultra-supercritical steam conditions. A literature review conducted in 2007 did not provide definitive ultra-supercritical (USC) steam conditions; however, based on the review, the conditions shown in Exhibit 4-3 were chosen. [14] Study-specific requirements can override the baseline steam conditions.

Steam conditions for the bottoming cycle of IGCC and natural gas combined cycle (NGCC) plants were established based on typical vendor offerings. The conditions and ranges are documented in Exhibit 4-5**Error! Reference source not found.**.

Exhibit 4-3. Process Parameters for Steam Turbines and Feedwater Systems

Equipment and Parameter	Parameter Value	Range	Source	Notes
Subcritical Single Reheat Steam Cycle (2,415 psia/1050°F/1050°F) (650 MWe)				
Inlet Pressure, MPa (psia)	16.6 (2,415)		[10, pp. 2-18]	Taken directly from literature.
Max Steam Temperature, °C (°F)	565.5 (1,050)		[15, pp. 1-14]	
Reheat Steam Temperature, °C (°F)	565.5 (1,050)		Engineering Judgment	
HP Exhaust Pressure, MPa (psia)	4.2 (620)		[10, pp. 2-18]	Literature suggests HP turbine operating pressure of 607.0 psi.
IP Inlet Pressure, MPa (psia)	4.2 (608)		Engineering Judgment	
IP Exhaust Pressure, MPa (psia)	0.52 (75)		Engineering Judgment	
HP Isentropic Efficiency, %	91.5		[16]	
IP Isentropic Efficiency, %	94.0		[16]	
LP Isentropic Efficiency, %	89.2		[16]	Parameter value includes exhaust losses.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Supercritical Single Reheat Steam Cycle (3,515 psia/1100°F/1100°F) (650 MWe)				
Inlet Pressure, MPa (psia)	24.2 (3,515)		[10, pp. 26-7]	Value is taken directly from literature.
Max Steam Temperature, °C (°F)	593 (1,100)		Engineering Judgment	
Reheat Steam Temperature, °C (°F)	593 (1,100)		Engineering Judgment	
HP Exhaust Pressure, MPa (psia)	4.9 (711)		[10, pp. 2-16]	Literature suggests HP turbine operating pressure of 714.9 psi.
IP Inlet Pressure, MPa (psia)	4.8 (697)		Engineering Judgment	
IP Exhaust Pressure, MPa (psia)	0.52 (75)		Engineering Judgment	
HP Isentropic Efficiency, %	90.3		[16]	
IP Isentropic Efficiency, %	94.0		[16]	
LP Isentropic Efficiency, %	89.2		[16]	Parameter value includes exhaust losses.
Surface Condenser				
Operating Pressure, MPa (psia) [in. Hg]	0.0068 (0.982) [2.0]		[10, pp. 2-16]	Operating pressure depends on cooling water temperature. Design parameter is for ISO conditions cooling water. Parameter value taken directly from literature.
Terminal Temperature Difference, °C (°F)	11.7 (21)		[17]	Terminal temperature difference is higher than typical to account for lack of a summer design condition. Literature suggests typical terminal temperature differences ranging from 5.4 to 7.2°F.
Condensate Pumps				
Discharge Pressure, MPa (psia)	1.3 (191)	1.26-1.32 (183-191)	[10, pp. 2-18]	For cases with a supercritical steam cycle and carbon capture, the discharge pressure will be 1.26 MPa (183 psia). This is due to the condensate return eliminating the first stage of feedwater heating.
Efficiency, %	80		Engineering Judgment	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Deaerator				
Operating Pressure, MPa (psia)	0.50 (72)		[18]	
Operating Temperature, °C (°F)	152 (305)		Engineering Judgment	The deaerator maintains a saturated liquid product stream. Therefore, the temperature is a product of pressure.
Vent Loss, %	0.2		[18]	Percent of feedwater flow
Boiler Feed Water Pump Turbine				
Inlet Pressure, MPa (psia)	0.50 (73.5)		[10, pp. 2-16]	Literature suggests an inlet pressure of 137.9 psi.
Exhaust Pressure, MPa (psia)	0.014 (2.0)		[10, pp. 2-16]	Literature suggests an exhaust pressure of 2.5 in. Hg Abs. (1.2 psi).
Isentropic Efficiency, %	80		Engineering Judgment	
Boiler Feed Water Pump – Subcritical Steam Cycle (2,415 psia/1050°F/1050°F)				
Discharge Pressure, MPa (psia)	19.0 (2,752)		[10, pp. 2-18]	Literature suggests a discharge pressure of 3,018 psi.
Efficiency, %	80		Engineering Judgment	
Boiler Feed Water Pump – Supercritical Steam Cycle (3,515 psia/1100°F/1100°F)				
Discharge Pressure, MPa (psia)	28.8 (4,172)		[10, pp. 2-16]	Literature suggests a discharge pressure of 4,250 psi.
Efficiency, %	80		Engineering Judgment	
LP Feed Water Heaters				
Cold/Hot End Temperature Approach, °C (°F)	5.56 (10)		[10, pp. 2-16]	Parameter value taken directly from literature.
Pressure Drop, %	4		Engineering Judgment	Pressure drop per exchanger (4 total).
IP Feed Water Heater				
Cold/Hot End Temperature Approach, °C (°F)	5.56 (10)		[10, pp. 2-16]	Parameter value taken directly from literature.
Pressure Drop, %	4		Engineering Judgment	Pressure drop per exchanger (1 total).

Equipment and Parameter	Parameter Value	Range	Source	Notes
HP Feed Water Heater				
Cold/Hot End Temperature Approach, °C (°F)	5.56 (10)		[10, pp. 2-16]	Parameter value taken directly from literature.
Pressure Drop, %	4		Engineering Judgment	Pressure drop per exchanger (2 total). The pressure drop across the HP feed water heater, along with the pressure drop across the superheater, together account for the pressure drop associated with line losses.
Feed Water Superheater				
Pressure Drop, %	4.8		[19]	The pressure drop across the HP feed water heater, along with the pressure drop across the superheater, together account for the pressure drop associated with line losses.

Exhibit 4-4. Process Parameters for Environmental Systems Associated with Coal Combustion

Equipment and Parameter	Parameter Value	Range	Source	Notes
SCR				
Operating Temperature, °C (°F)	385 (725)		[11] [10, pp. 34-4]	
Catalyst	Titanium/ Vanadium Oxide		[10, pp. 34-5]	
NOx Production, lb/MMBtu	0.35		[11]	This value reflects current low-NOx burner with over fire air system technology. Further reductions with advanced systems (e.g., ultra-low NOx systems) could further reduce this value.
NOx Reduction, %	78	75–79	[10, pp. 29-23]	NOx production and removal are estimated. NOx reduction is set to meet the plant NOx emissions target. Parameter value represents supercritical, capture cases. Values from other cases are represented in the range. SCR systems have been demonstrated to achieve up to 90% NOx reduction on fossil fuel boilers.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Ammonia Slip, ppmv	2		Engineering Judgment	
Baghouse				
Pressure Drop, %	1.5		[10, pp. 33-10]	
Particulate Removal Efficiency, %	99.87	99.85–99.88	[10, pp. 32-10]	Range depends on inlet solids loading (including solids from dry FGD applications). Parameter value represents supercritical, capture cases. Values from other cases are represented in the range.
Activated Carbon Injection				
Carbon Feed Rate, kg/MMacm (lb/MMacf)	16 (1.0)		[20]	Brominated activated carbon.
Hg Removal Efficiency, %	97.6	97.2–97.7	[20]	Combined co-benefit capture and ACI. Vendor provided a minimum removal efficiency of 96.7%. Parameter value represents supercritical, capture cases. Values from other cases are represented in the range.
Dry Sorbent Injection				
Hydrated Lime Feed Rate, lb/lb SO_3	3.5		[20]	Enhanced hydrated lime.
SO_3 Removal Efficiency, %	96.4		[20]	Vendor suggested that the dry sorbent injection would reduce the SO_3 concentration from 59 ppmvd to 2 ppmvd.
Wet FGD Absorber Module				
SO_2 Removal Efficiency, %	98	98–99+	[10, pp. 32-9]	Used with high sulfur bituminous coal. Literature reports efficiencies greater than 97%. Parameter value represents supercritical, non-capture cases. Values from other cases are represented in the range.
HCl Removal Efficiency, %	99		[11]	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Exit Temperature, °C (°F)	57 (135)		[10, pp. 35-10]	The exit temperature is controlled to ensure that sufficient water is condensed out of the flue gas to achieve the required moisture content in the gypsum product stream. Literature suggests an exit temperature of 129 °F (53.9°C).
Pressure Drop, %	2.6		[10, pp. 35-3]	Literature suggests a pressure drop between 0.2 and 0.7 kPa.
Limestone Slurry Feed Pumps				
Discharge Pressure, MPa (psia)	0.10 (15)		[10, pp. 35-10]	
Efficiency, %	65		Engineering Judgment	
Spray Dryer Evaporator				
Flue Gas Extraction Temperature, °C (°F)	386 (726)		[21]	Spray dryers typically require flue gas temperature above 600 °F (315.6°C).
SDE Exit Temperature, °C (°F)	143 (289)		[21]	The outlet temperature is selected to match the air preheater outlet temperature.
Blowdown Chloride Concentration (ppmw)	19,992		[21]	Blowdown flowrate is calculated to maintain set chloride concentration.
Pressure Drop, %	1.2		[21]	Pressure drop is calculated such that the SDE outlet pressure is equivalent to flue gas pressure.

4.3 COMBINED CYCLE SYSTEMS

The steam turbine system unit operation data is given in Exhibit 4-5.

Exhibit 4-5. Steam Turbine System Unit Operation Data

Unit Operation	Design Parameter	Range	Source	Notes
Single Reheat Subcritical Steam Turbine (NGCC: 2400psia/1085°F/1085°F / IGCC: 1800psia/1050°F/1050°F)				
Max Steam Temperature, °C (°F)	585 (1,085) / 566 (1,050)	- / 533–566 (991–1,050)	[22] / [15, pp. 1-14]	Syngas cases vary based on combustion turbine outlet temperature. CO_2 capture cases are lower than non-capture cases and are represented by the range.
Reheat Steam Temperature, °C (°F)	585 (1,085) / 565.5 (1,050)	- / 533–566 (991–1,050)	[22] / Engineering Judgment	Syngas cases vary based on combustion turbine outlet temperature. CO_2 capture cases are lower than non-capture cases and are represented by the range.
HP Inlet Pressure, MPa (psia)	16.5 (2,393) / 12.5 (1,815)		[22] / [15, pp. 1-14]	
HP Exhaust Pressure, MPa (psia)	3.7 (542) / 3.5 (501)		[22] / Engineering Judgment	Includes HP governing and HP turbine stages.
IP Inlet Pressure, MPa (psia)	3.5 (509) / -		[22] / Engineering Judgment	
IP Exhaust Pressure, MPa (psia)	0.52 (75) / 0.45 (66)		[22] / Engineering Judgment	
LP Inlet Pressure, MPa (psia)	0.51 (74) / 0.45 (65)		[22] / Engineering Judgment	
HP Isentropic Efficiency, %	91 / 91		[22] / [16]	
IP Isentropic Efficiency, %	92.5 / 93.5		[22] / [16]	
LP Isentropic Efficiency, %	88.2 / 88.2		[22] / [16]	Parameter value includes exhaust losses.
Blowdown, % of feedwater flow	- / 0.5–1.0		[22] / Engineering Judgment	In NGCC cases, a condensate purifier is used instead of blowdown. Syngas cases have an LP blowdown of 0.5% and an HP blowdown of 1%.

Process parameters for environmental systems associated with natural gas systems are presented in Exhibit 4-6.

Exhibit 4-6. Process Parameters for Environmental Systems Associated with NGCC Systems

Equipment and Parameter	Parameter Value	Range	Source	Notes
SCR				
Catalyst	Titanium/ Vanadium Oxide		[10, pp. 34-5]	
NOx Reduction, %	85	85–87	[11]	The SCR efficiency is calculated to achieve the lower detection limit of 1.8 ppm outlet concentration. Parameter value represents a non-capture case, while the range covers all cases.
Ammonia Slip, ppmv	2		Engineering Judgment	

4.4 GASIFICATION AND ASSOCIATED SYNGAS SYSTEMS

Exhibit 4-7 provides a list of reports where performance data can be obtained for various types of gasifiers.

Exhibit 4-7. Gasifier Performance Data Reports

Gasifier Type	Report Name
GEP	Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 4 (also referred to as Bituminous Baseline Studies) [2]
CoP	Cost and Performance Baseline for Fossil Energy Plants Volume 3a: Low Rank Coal to Electricity: IGCC Cases, DOE/NETL-2010/1399 (also referred to as Low-Rank Baseline Studies) [1] Bituminous Baseline Studies [2]
Shell	Low-Rank Baseline Studies [1] Bituminous Baseline Studies [2]
Siemens	Low-Rank Baseline Studies [1]
TRIG	Low-Rank Baseline Studies [1]

The syngas processing, sour water, and mercury removal systems unit operation data is given in Exhibit 4-8.

Exhibit 4-8. Syngas Processing Systems Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
Single-Stage Syngas Recycle Compressor				
Discharge Pressure, MPa (psia)	4.3 (625)	4.3–5.5 (625–800)	[23]	Parameter value represents Shell gasifier cases. Other cases are represented by the range.
Isentropic Efficiency, %	84		[23]	
Syngas Scrubbing Tower				
HCl Separation Efficiency, %	96.0	96.0–99.9	[24] [25]	All cases target a separation efficiency of 96%, with some cases reaching the upper bound of the range.
NaOH Feed Concentration, wt%	50		[26]	
NaOH Concentration at Blowdown, ppmw	164		[11]	
Chloride Blowdown Concentration, ppmw	5,000	2,700–5,000	[27]	The maximum allowable is 5,000. The plant is designed to meet the maximum, when possible. Parameter value represents all cases except for GE Power Quench gasifier cases.
Pressure Drop, %	2.6		[10]	
Water Pressure, psi	120		[28]	Above inlet gas stream pressure.
Grey Water Vacuum Flash				
LP Flash Pressure, MPa (psia)	0.48 (70.0)		[29]	
Vacuum Flash Pressure, MPa (psia)	0.05 (7.5)		[29]	
Overhead Flash Pressure, MPa (psia)	0.24 (35.0)		[29]	
Brine Concentrator				
Inlet Pressure, MPa (psia)	0.12 (17.4)		Engineering Judgment	
Outlet Pressure, MPa (psia)	0.10 (14.7)		[10]	
Vapor Re-Compressor Outlet Pressure, MPa (psia)	0.14 (20.5)	(20.3–20.6)	[30]	Outlet pressure varies to provide heat to pre-heater. Parameter value represents a non-capture, Shell gasifier case. Other cases are represented by the range.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Heat Loss, %	2.0		[30]	
Preheater Approach Temperature, °C (°F)	5.6 (10)		[21]	Preheater outlet temperature is controlled to maintain this approach temperature.
TDS of Effluent	250,000		[21]	Literature suggests a range of 200,000–300,000 TDS.
Crystallizer				
Inlet Pressure, MPa (psia)	0.10 (14.9)		[31]	
Outlet Pressure, MPa (psia)	0.10 (14.7)		[31]	Crystallizer effluent is saturated, such that the outlet temperature is determined by the outlet pressure.
Solids Moisture Content, wt%	40		[11]	Moisture concentration consists of both water and dissolved solids.
Ammonia Wash				
Wash Water Temperature, °C (°F)	70	15–21 (59–70)	Engineering Judgment	Lowest available temperature. Parameter value represents Shell gasifier cases. Other cases are represented by the range.
Wash Water Pressure, MPa (psia)	3.7 (530)	3.3–4.9 (474–709)	Engineering Judgment	At column gas exit pressure. Parameter value represents a non-capture, Shell gasifier case. Other cases are represented by the range.
Column Pressure Drop, %	2.6		[10, pp. 35-3]	Literature suggests a pressure drop between 0.2 and 0.7 kPa.
Ammonia Concentration in Clean Syngas, ppmv	10		[32] [33]	Wash water injection rate varied to control for outlet concentration.
Sour Water Stripper				
Preheat Temperature, °C (°F)	100 (213)		Engineering Judgment	
Acid Gas Pressure, MPa (psia)	0.11 (16)		[34]	
Effluent Pressure, MPa (psia)	0.15 (22)		[35]	
Ammonia Separation, %	99.5		[35]	
Water Recovery, %	99.6		[35]	
Steam Pressure, MPa (psia)	0.45 (65)		[36]	
Column Stages	40		[35]	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Sour CO-Shift[a]				
High Temperature Shift (HTS) Catalyst			[37] [38]	Iron-chromium oxide catalysts.
Low Temperature Shift (LTS) Catalyst			[37] [38]	Copper-zinc oxide-aluminum oxide catalysts.
Steam to Dry Gas Ratio	0.25		Engineering Judgment	Steam injection rate is varied to control for ratio. If moisture content of syngas exceeds requirement, no additional controls are taken.
CO Conversion, %	94.5	93.0–97.2	Engineering Judgment	Temperature approach to equilibrium (CO conversion rate) is varied to control carbon capture rate at 90 percent. Parameter value represents Shell gasifier case. Other cases are represented by the range.
Inlet Temperature to LTS Reactors, °C (°F)	253 (487)		[37] [38]	
HTS Pressure Drop, %	1.3		[37]	Per stage.
LTS Pressure Drop, %	0.6		[37]	Per stage.
COS/HCN Hydrolysis Reactor[b]				
Catalyst			[36]	Activated alumina-based catalysts.
Pressure Drop, %	1.3		[36]	
COS Conversion efficiency, %	95		[36] [39]	This value is associated with a catalyst volume of 60 m^3 and an approach to equilibrium of 24°F (-4.4°C).
Inlet temperature above dew point, °C (°F)[c]	12.8 (23)	12.8–15 (23–27)	[36]	Parameter value represents Shell gasifier case. Other cases are represented by the range.
Low Temperature Gas Cooling Heat Exchangers				
Pressure Drop, %	2		[23]	This value is the pressure drop across each heat exchanger. The last stage is modeled as a knockout drum, the remaining are modeled as shell and tube heat exchangers.
Outlet Temperature, °C (°F)	29 (85)		[23]	
Knockout Drums				
Pressure Drop, %	0.7		[23]	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Mercury Removal Bed Preheater				
Outlet Temperature, °C (°F)	5.6 (10)		[40]	Degrees above the syngas dew point temperature.
Pressure Drop, %	2		[40]	
Mercury Removal Bed				
Adsorbent Type			[41] [42]	Sulfur-impregnated activated carbon.
Operating Temperature, °C (°F)	37 (98)	37–38 (98–100)	[41]	Inlet temperature to first mercury removal bed. Parameter value represents a non-capture, Shell gasifier case. Other cases are represented by the range.
Pressure Drop, %	0.7		[41]	Per bed.
Removal Efficiency, %	97	96–97	[41]	Total for all beds. Parameter value represents Shell gasifier cases. Other cases are represented by the range.

[a] *Used in CO_2 capture plants*
[b] *Used in non-CO_2 capture plants*
[c] *A COS hydrolysis vendor suggested that the conversion rate would increase with decreasing temperatures, with the minimum inlet temperature suggested at 250°F (121°C). However, the conversion rate would decrease with decreasing water composition.*

The sulfur processing system unit operation data is given in Exhibit 4-9.

Exhibit 4-9. Sulfur Processing Systems Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
Overall Claus Plant				
Sulfur recovery, %	98.9	98.4– 98.9	[43]	Per pass through system. Parameter value represents a non-capture, Shell gasifier case. Other cases are represented by the range. Literature reports sulfur recoveries between 97.5 and 99.5%.
Claus Reaction Furnace				
Furnace Temperature, °C (°F)	1,316 (2,400)		[44]	Parameter value is minimum required for ammonia destruction.
Pressure Drop, %	2		Engineering Judgment	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Heat Loss, MMBtu/lb-H_2S	80		Engineering Judgment	Oxygen rate is varied to control heat loss from reactor.
H_2S:SO_2 Ratio in Exhaust	1:1		Engineering Judgment	Reactor bypass is varied to control for a 1 to 1 ratio at the inlet to the tail gas hydrolysis reactor.
Claus Waste Heat Boiler				
Outlet Temperature, °C (°F)	329 (625)		[43]	
Steam Pressure, MPa (psia)	12.8 (1,852)		Engineering Judgment	Steam generated.
Claus Condenser				
Outlet Temperature, °C (°F)	188 (370)	160–188 (320–370)	[43]	Parameter value is the outlet temperature of the first condenser, while the range covers the outlet temperatures of all stages (except the final condenser).
Steam Pressure, MPa (psia)	1.76 (255)		Engineering Judgment	Steam generated.
Pressure Drop, %	2		[43]	Pressure drop per condenser.
Claus Final Condenser				
Exit Temperature, °C (°F)	149 (300)		Engineering Judgment	
Generated Steam Pressure, MPa (psia)	1.8 (255)		Engineering Judgment	Steam generated.
Pressure Drop, %	2		Engineering Judgment	
Claus Reheat Exchanger				
Outlet Temperature, °C (°F)	219 (427)	191–219 (375–427)	[43]	Parameter value is the outlet temperature of the first reheat exchanger. The range covers the outlet temperatures of the remaining reheat exchangers.
Pressure Drop, %	2		[43]	Pressure drop per reheat exchanger.
Claus Reactor				
Catalyst			[44]	Alumina-based with promoting agents.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Exit Temperature, °C (°F)	293 (560)	197–331 (387–628)	Engineering Judgment	Parameter value is the outlet temperature of the first reactor. The range covers the exit temperatures of the remaining reactors.
Steam Pressure, MPa (psia)	1.76 (255)		Engineering Judgment	Steam generated.
Pressure Drop, %	2		Engineering Judgment	Pressure drop per reactor.

The tail gas treatment system unit operation data is given in Exhibit 4-10.

Exhibit 4-10. Tail Gas Treatment Systems Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
TGTU Hydrogenation Reactor				
Catalyst			[45]	Cobalt molybdate on alumina.
Operating Temperature, °C (°F)	288 (550)		[45]	

4.5 ACID GAS REMOVAL SYSTEMS AND CARBON DIOXIDE COMPRESSION

The acid gas removal system unit operation data is given in Exhibit 4-11.

Exhibit 4-11. Gas Removal System Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
Single-Stage Selexol				
Inlet Gas Pressure, MPa (psia)	4.5 (657)		[46]	
Inlet Gas Temperature, °C (°F)	37 (99)		[46]	
H_2S Concentration in Acid Gas, wt%	15.4		[46]	
Acid Gas Outlet Pressure, MPa (psia)	4.5 (651)		[46]	
Acid Gas Outlet Temperature, °C (°F)	44 (112)		[46]	
Treated Gas Outlet Pressure, MPa (psia)	4.5 (651)		[46]	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Treated Gas Outlet Temperature, °C (°F)	44 (112)		[46]	
Two-Stage Selexol				
Inlet Gas Pressure, MPa (psia)	3.1 (445)	3.0–4.3 (439–624)	[47] [48] [49]	Reference material provided a range from 515 to 720 psi for this parameter. Parameter value represents a Shell gasifier case. Other cases are represented by the range.
Inlet Gas Temperature, °C (°F)	37.2 (99)	36.1–37.2 (97–99)	[47]	Parameter value represents a Shell gasifier case. Other cases are represented by the range.
CO_2 Capture Efficiency, %	93.6		[47]	
Hydrogen Recovery to Treated Gas, %	99.4		[47]	
CO_2 Outlet Pressure, MPa (psia)	0.12 / 0.55 (16.7 / 80.0)		[47]	Produces CO_2 at two pressures.
CO_2 Outlet Temperature, °C (°F)	-11 / -3 (12 / 26)		[47]	Produces CO_2 at two temperatures.
Acid Gas Outlet Pressure, MPa (psia)	0.18 (26.7)		[47]	
Acid Gas Outlet Temperature, °C (°F)	26.7 (80)		[47]	
Treated Gas Outlet Pressure, MPa (psia)	2.9 (419)	2.8–4.0 (413–587)	[47]	Parameter value represents a Shell gasifier case. Other cases are represented by the range.
Treated Gas Outlet Temperature, °C (°F)	18 (65)		[47]	
MDEA				
Inlet Gas Pressure, MPa (psia)	3.3 (473)		[50]	
Inlet Gas Temperature, °C (°F)	37 (98)		[50]	
H_2S Concentration in Acid Gas, wt%	18.8		[50]	
CO_2 Slip to Treated Gas, %	86.3		[50]	
Treated Gas Outlet Pressure, MPa (psia)	3.2 (468)		[50]	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Treated Gas Outlet Temperature, °C (°F)	44 (112)		[50]	
Acid Gas Outlet Pressure, psia	3.2 (468)		[50]	
Acid Gas Outlet Temperature, °C (°F)	44 (112)		[50]	
Cansolv (PC)				
Inlet Gas Pressure, MPa (psia)	0.1 (14.8)		[51]	
Inlet Gas Temperature, °C (°F)	56.7 (134)		[51]	
CO_2 Capture Efficiency, %	90		[51]	
CO_2 Outlet Pressure, MPa (psia)	0.20 (28.9)		[51]	
CO_2 Outlet Temperature, °C (°F)	30 (86)		[51]	
Treated Gas Outlet Pressure, MPa (psia)	0.1 (14.8)		[51]	
Treated Gas Outlet Temperature, °C (°F)	31 (87)		[51]	
LP Steam Pressure, MPa (psia)	0.51 (73.5)		[51]	
Cansolv (NGCC)				
Inlet Gas Pressure, MPa (psia)	0.1 (14.8)		[51]	
Inlet Gas Temperature, °C (°F)	111 (231)		[51]	
CO_2 Capture Efficiency, %	90		[51]	
CO_2 Outlet Pressure, MPa (psia)	0.20 (28.9)		[51]	
CO_2 Outlet Temperature, °C (°F)	30.0 (86)		[51]	
Treated Gas Outlet Pressure, MPa (psia)	0.10 (14.8)		[51]	
Treated Gas Outlet Temperature, °C (°F)	30.6 (87)		[51]	

Equipment and Parameter	Parameter Value	Range	Source	Notes
LP Steam Pressure, MPa (psia)	0.51 (73.5)		[51]	
Sulfinol-M				
Inlet Gas Pressure, MPa (psia)	3.4 (492)		[52]	
Inlet Gas Temperature, °C (°F)	37 (98)		[52]	
H_2S Concentration in Acid Gas, wt%	30.5		[52]	
CO_2 Slip to Treated Gas, %	60		[52]	
Treated Gas Outlet Pressure, MPa (psia)	3.4 (487)		[52]	
Treated Gas Outlet Temperature, °C (°F)	44 (112)		[52]	
Acid Gas Outlet Pressure, MPa (psia)	3.4 (487)		[52]	
Acid Gas Outlet Temperature, °C (°F)	44 (112)		[52]	

The CO_2 compression system unit operation data is given in Exhibit 4-12.

Exhibit 4-12. CO_2 Compression System Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
CO_2 Compression System				
Intercooler Approach Temperature, °C (°F)	13.9 (25)	13.9–39.4 (25–71)	[53]	Number of degrees the exit temperature is above the inlet cooling water temperature. The parameter value is representative of the first two intercoolers. The range covers all intercoolers.
CO_2 Compressor Stage Pressure Ratio	See Range	1.5–2.3	[53] [54]	The pressure ratio differs depending on the stage, target compressor train outlet pressure, stage one inlet pressure, and the number of compression stages required. The range given encompasses all the potential stage pressure ratios modeled.

Equipment and Parameter	Parameter Value	Range	Source	Notes
CO_2 Compressor Outlet Pressure, MPa (psia)	15.3 (2,215)		Engineering Judgment	
CO_2 Dryer Pressure Drop, %	4.5		Engineering Judgment	
CO_2 Dryer Type				TEG
CO_2 Dryer Outlet Moisture Content, ppmv	500		Engineering Judgment	

4.6 ANCILLARY SYSTEMS

Exhibit 4-13 through Exhibit 4-16 contain specifications for ancillary process systems common to many types of cycles.

Exhibit 4-13. Process Parameters for Determining Auxiliary Loads in PC Cases

Equipment and Parameter	Parameter Value	Range	Source	Notes
Ash Handling				
Reference Ash Handling Auxiliary Load, kW/tph Ash	26.8		Engineering Judgment	The ash handling auxiliary load is determined by multiplying the reference auxiliary load by the combined flowrate of bottom and fly ash.
Baghouse				
Reference Auxiliary Load, kW/(lb/hr fly ash removed)	0.002197		Engineering Judgment	Baghouse auxiliary load is based on fly ash flow rate and this reference auxiliary load.
Coal Handling and Conveying				
Reference Auxiliary Load, hp/tph coal	1.27		Engineering Judgment	Coal handling and conveying auxiliary loads are based on the reference auxiliary load, and the flowrate of coal. The reference auxiliary load is based on the reclaim rate and the flow design margin.
Cooling Tower Fans				
Fan Mechanical Efficiency, %	75		Engineering Judgment	Cooling tower fan auxiliary loads depend on cooling water temperature, circulating air to water ratio, fan air flow, fan mechanical efficiency, and fan discharge pressure.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Fan Discharge Pressure, psi	14.7		Engineering Judgment	
Flue Gas Desulfurizer				
Reference Auxiliary Load, kW/(lb SO_2/hr)	0.145		Engineering Judgment	The FGD auxiliary load is dependent on the FGD type, flow rate of SO_2 into the FGD, and this reference auxiliary load.
Ground Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Ground water pump auxiliary loads depend on raw water makeup flowrate, pump efficiency, and pump operating head.
Pump Operating Head, psi	100		Engineering Judgment	
Pulverizers				
Reference Auxiliary Load, kW/tph coal	13.6		Engineering Judgment	Pulverizer auxiliary loads depend on coal size and reference auxiliary load.
SCR				
Pump Mechanical Efficiency, %	80		Engineering Judgment	SCR auxiliary load is dependent upon SCR pumps mechanical efficiency, SCR ammonia flowrate, and ammonia pump head.
Ammonia Pump Head, ft H_2O	250		Engineering Judgment	
Sorbent Handling & Reagent Preparation				
Reference Auxiliary Load, kW/tph limestone	43.7		Engineering Judgment	Sorbent handling and reagent preparation auxiliary loads depend on limestone flowrate and this reference auxiliary load.
Steam Turbine				
Fixed Auxiliary Load, kWe	500		Engineering Judgment	This is an engineering judgment for a steam turbine auxiliary load. This fixed auxiliary load is used across all Bituminous PC models.
Miscellaneous Balance of Plant				

Equipment and Parameter	Parameter Value	Range	Source	Notes
Fixed Auxiliary Load, kWe	2,250		Engineering Judgment	This fixed auxiliary load is used across all Bituminous PC models.
Transformer Losses				
18/345 kV Efficiency	0.997		Engineering Judgment	Transformer loss auxiliary loads depend upon total plant auxiliary load and transformer efficiencies.
345/13.8 kV Efficiency	0.997		Engineering Judgment	
18/4.16 kV Efficiency	0.995		Engineering Judgment	
4160/480 V Efficiency	0.995		Engineering Judgment	

Exhibit 4-14. Process Parameters for Determining Auxiliary Loads in NGCC Cases

Equipment and Parameter	Parameter Value	Range	Source	Notes
Cooling Tower Fans				
Fan Mechanical Efficiency, %	75		Engineering Judgment	Cooling tower fan auxiliary loads depend on cooling water temperature, circulating air to water ratio, fan air flow, fan mechanical efficiency, and fan discharge pressure.
Fan Discharge Pressure, psi	14.7		Engineering Judgment	
Ground Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Ground water pump auxiliary loads depend on raw water makeup flowrate, pump efficiency, and pump operating head.
Pump Operating Head, psi	100		Engineering Judgment	
SCR				
Pump Mechanical Efficiency, %	80		Engineering Judgment	SCR auxiliary load is dependent upon SCR pumps mechanical efficiency, SCR ammonia flowrate, and ammonia pump head.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Ammonia Pump Head, ft H_2O	252		Engineering Judgment	
Steam Turbine				
Fixed Auxiliary Load, kWe	200		Engineering Judgment	This is an engineering judgment for a steam turbine auxiliary load. This fixed auxiliary load is used across all Bituminous NGCC cases.
Combustion Turbine				
Fixed Auxiliary Load, kWe	1,020		Engineering Judgment	This is an engineering judgment based on the 2017 F-class turbine output. This fixed auxiliary load is used across all Bituminous NGCC cases.
Miscellaneous Balance of Plant				
Fixed Auxiliary Load, kWe	570		Engineering Judgment	This is an engineering judgment based on the gross output of the plant. This fixed auxiliary load is used across all Bituminous NGCC cases.
Transformer Losses				
18/345 kV Efficiency	0.997		Engineering Judgment	Transformer loss auxiliary loads depend upon total plant auxiliary load and transformer efficiencies.
345/13.8 kV Efficiency	0.997		Engineering Judgment	
18/4.16 kV Efficiency	0.995		Engineering Judgment	
4160/480 V Efficiency	0.995		Engineering Judgment	

Exhibit 4-15. Process Parameters for Determining Auxiliary Loads in IGCC Cases

Equipment and Parameter	Parameter Value	Range	Source	Notes
ASU				
Fixed Auxiliary Load, kWe	1,000		Engineering Judgment	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Claus Plant/TGTU Hydrogenation Reactor Auxiliaries				
Fixed Auxiliary Load, kWe	250		Engineering Judgment	
Coal Handling and Conveying				
Flow Design Margin	1.1		Engineering Judgment	Coal handling and conveying auxiliary loads are based on the reclaim operating hours, coal feed rate and flow design margin. 10% design margin over maximum normal flow rate.
Reclaim Operating Hours (hr/day)	16		Engineering Judgment	
Cooling Tower Fans				
Fan Mechanical Efficiency, %	75		Engineering Judgment	Cooling tower fan auxiliary loads depend on cooling water temperature, circulating air to water ratio, fan air flow, fan mechanical efficiency, and fan discharge pressure.
Fan Discharge Pressure, psi	14.7		Engineering Judgment	
Ground Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Ground water pump auxiliary loads depend on raw water makeup flowrate, pump efficiency, and pump operating head.
Pump Operating Head, psi	100		Engineering Judgment	
Steam Turbine				
Fixed Auxiliary Load, kWe	200		Engineering Judgment	This is an engineering judgment for a steam turbine auxiliary load. This fixed auxiliary load is used across all Bituminous IGCC models.
Combustion Turbine				
Fixed Auxiliary Load, kWe	1,000		Engineering Judgment	This is an engineering judgment based on the F-class turbine output. This fixed auxiliary load is used across all Bituminous IGCC models.
Miscellaneous Balance of Plant				
Fixed Auxiliary Load, kWe	3,000		Engineering Judgment	This fixed auxiliary load is used across all Bituminous IGCC models.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Transformer Losses				
24/345 kV Efficiency	0.997		Engineering Judgment	Transformer loss auxiliary loads depend upon total plant auxiliary load and transformer efficiencies.
345/13.8 kV Efficiency	0.997		Engineering Judgment	
24/4.16 kV Efficiency	0.995		Engineering Judgment	
4160/480 V Efficiency	0.995		Engineering Judgment	

Exhibit 4-16 provides the process parameters associated with cooling water systems. Note that the values listed here apply to all Bituminous Baseline cases.

Exhibit 4-16. Process Parameters for Cooling Water Systems

Equipment and Parameter	Parameter Value	Range	Source	Notes
Wet Cooling Tower				
Cooling Water Range, °C (°F)	11 (20)		[55, pp. 9-95]	
Evaporative Losses, % of Circulating Water Flow	0.8		[55, pp. 9-95]	Percent of circulating water flow per 10°F of temperature range.
Drift Losses, % of Circulating Water Flow	0.001		[55, pp. 9-95]	
Cycles of Concentration	4		[55, pp. 9-95]	The cycles of concentration are a measure of water quality, and a mid-range value was assumed.
Blowdown Losses			[55, pp. 9-95]	Blowdown losses are equal to [Evaporative Losses/(Cycles of Concentration-1)].
Air Cooled Condenser				
Fan Power Ratio	3.5	3–4	[56, pp. 3-23]	Ratio of dry cooling tower power requirement relative to a wet cooling tower design of the same heat duty.
Circulating Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Cooling water pump auxiliary load is based on pump mechanical efficiency, cooling water flowrates, and cooling water pump operating head.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Cooling Water Pump Operating Head, ft	85		Engineering Judgment	

5 Process Parameters for Modeling Low-Rank Applications

The process parameters used for Aspen modeling and spreadsheet modeling of the Low-Rank Baseline [1] are documented in the following subsections. Parameters associated with the Bituminous Baseline [2] are provided in Section 4. For each parameter associated with a unit operation, a single value is provided. If parameter values differ across baseline models, a single value is provided, along with a range of values. The parameter value represents an average case, which is specified in the "Notes" column, while the range represents the range of values used across models. When no entry appears in the range column, it does not imply that a range of values is not possible.

When available, a reference source is provided for the design parameter and range. In many cases, the source is engineering judgment. Additional explanation is provided in the "Notes" column, as warranted.

As of the publication of this reference document (2019), the most recent version of the Bituminous Baseline is Revision 4, published in 2019. [2] However, the most recent versions of the Low-Rank Baseline cases date back to 2011 or earlier. [1] As such, it is expected that there will be differences in parameter values between the Bituminous (Section 4) and Low-Rank (Section 5) cases for the same sub-system parameter. These differences may be attributed to any number of factors, including improvements in system performance, new approaches to a common system, updated data, and many other reasons. It is expected that planned future updates for the Low-Rank cases will bring these two reports into closer agreement.

5.1 MOTOR EFFICIENCIES

Electric motors are used to drive pumps and compressors in many applications. The motor efficiency is a function of motor sizes as documented in Exhibit 5-1. The generator efficiency is also provided in Exhibit 5-1.

Exhibit 5-1. Electric Motor and Generator Efficiencies

Equipment and Parameter	Parameter Value	Range	Source	Notes
Electric Motor Efficiency, %	<1,000 kW: 95 <10,000 kW: 96.5 >10,000 kW: 97		Engineering Judgment	
Generator Efficiency, %	98.5	98.5–99	Engineering Judgment	The parameter value represents the generator efficiency in PC cases, while the range is inclusive of all cases.

The net efficiency of an electric pump, compressor, fan, etc. can be determined by multiplying the equipment efficiency by the motor efficiency.

5.2 COAL COMBUSTION SYSTEMS

The process parameters listed in Exhibit 5-2 through Exhibit 5-4 are for pulverized coal (PC) and circulating fluidized bed (CFB) combustion systems. Parameter values for PC cases are listed first. Technology-specific and fuel-specific distinctions are identified where applicable. Exhibit 5-2 provides process parameters for coal combustion systems.

Exhibit 5-2. Process Parameters for Coal Combustion Systems

Equipment and Parameter	Parameter Value	Range	Source	Notes
Boiler (PC/CFB)				
Heat Loss, %	1.0 / 1.0		[9, p. 11] [10, pp. 23-7]	Radiative losses, as a percentage of energy output.
Air Infiltration, %	2 / 2		[10, pp. 10-16]	Infiltration air percentage is based on theoretical (stoichiometric) air.
Excess Air, vol%	2.7 / 3.2		[10, pp. 10-15]	Design parameter is on a dry basis upstream of the air heater.
Combustion Air Preheater (PC/CFB)				
Air Leakage, %	5.5 / 5.5		[10, pp. 20-13]	Air leakage is 5.5% of total combustion air flow and divided between primary and secondary air based on a ratio of pressure differences between the fan outlet and the air heater outlet.
Flue Gas Exit Temperature, °C (°F)	143 (289) / 127 (261)		Engineering Judgment	CFB case assumes in-bed limestone injection. The minimum flue gas temperature is dictated by the flue gas acid dew point.
Primary Air Fan (PC/CFB)				
Polytropic Efficiency, %	75 / 75		[10]	Backward curved blade type.
Pressure Rise, kPa (psi)	10.0 (1.444) / 10.5 (1.516)	7.5-–10.0 (1.095–1.444) / -	[10, pp. 25-12] / [10, pp. 17-12]	Pressure rise is based on the inlet pressure and set to accommodate a total pressure drop of 1.744 psi across the furnace (including the air preheater). The PC parameter value represents a supercritical, non-capture, PRB case. Other PC cases are represented by the range provided.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Portion of Total Combustion Air, %	40 / 60		Engineering Judgment	
Forced Draft Fan (PC/CFB)				
Polytropic Efficiency, %	75 / 75		[10]	Backward curved blade type.
Pressure Rise, kPa (psi)	3.8 (0.556) / 4.2 (0.614)	3.8–7.2 (0.556–1.0408) / -	[10, pp. 25-12]	The PC parameter value represents a supercritical, non-capture, PRB case. Other PC cases are represented by the range provided.
Portion of Total Combustion Air, %	60 / 40		Engineering Judgment	
Induced Draft Fan (PC/CFB)				
Polytropic Efficiency, %	75 / 75		[10]	Backward curved blade type.
Pressure Rise, kPa (psi)	6.9 (1.0) / 6.2 (0.9)		[10, pp. 25-12]	Pressure ratio is adjusted to provide one inch of H_2O above ambient pressure at the stack base.

Steam cycle conditions for combustion-based subcritical and supercritical coal units in NETL systems studies are based on a market survey that was conducted in 2005. [13] The conditions chosen at the steam turbine throttle valve are representative of currently available commercial offerings and are shown in Exhibit 5-3. There is no consensus regarding the boundary between supercritical and USC steam conditions. A literature review conducted in 2007 did not provide definitive USC steam conditions; however, based on the review, the conditions shown in Exhibit 5-3 were chosen. [14] Study-specific requirements can override the baseline steam conditions. A range of conditions used in past systems studies is also shown in Exhibit 5-3.

Similarly, a vendor survey was used to establish the steam conditions for the bottoming cycle of NGCC systems. Steam conditions for the bottoming cycle of IGCC plants were established based on typical vendor offerings. The conditions and ranges are documented in Exhibit 5-3.

Exhibit 5-3. Process Parameters for Steam Turbines and Feedwater Systems

Equipment and Parameter	Parameter Value	Range	Source	Notes
Supercritical Single Reheat Steam Cycle (3,515 psia/1100°F/1100°F) (550 MWe)				
Inlet Pressure, MPa (psia)	24.2 (3,515)		[10, pp. 26-7]	
Max Steam Temperature, °C (°F)	593 (1,100)		Engineering Judgment	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Reheat Steam Temperature, °C (°F)	593 (1,100)		Engineering Judgment	
HP Exhaust Pressure, MPa (psia)	4.9 (711)		[10, pp. 2-16]	
IP Inlet Pressure, MPa (psia)	4.5 (656)		Engineering Judgment	
IP Exhaust Pressure, MPa (psia)	1.0 (138)	0.5–1.0 (75–138)	Engineering Judgment	Parameter value represents non-capture cases. The range is representative of all cases.
HP Isentropic Efficiency, %	90.3		Engineering Judgment	
IP Isentropic Efficiency, %	94.0		Engineering Judgment	
LP Isentropic Efficiency, %	92.5		Engineering Judgment	Additional increase over subcritical as the exhaust losses are applied to total power production (LP, IP, and HP).
Exhaust Losses, %	0.778		[57]	Exhaust losses are a function of annular velocity.
Ultra-supercritical Single Reheat Steam Cycle (4,015 psia/1200°F/1200°F) (550 MWe)				
Inlet Pressure, MPa (psia)	27.7 (4,015)		[10, pp. 2-18]	
Max Steam Temperature, °C (°F)	649 (1,200)		Engineering Judgment	
Reheat Steam Temperature, °C (°F)	649 (1,200)		Engineering Judgment	
HP Exhaust Pressure, MPa (psia)	8.3 (1,200)		Engineering Judgment	
IP Inlet Pressure, MPa (psia)	7.8 (1,128)		Engineering Judgment	
IP Exhaust Pressure, MPa (psia)	0.6 (90)	0.5–0.6 (75–90)	Engineering Judgment	Parameter value represents non-capture cases. The range is representative of all cases.
HP Isentropic Efficiency, %	90.3		Engineering Judgment	Ultra-supercritical efficiency assumed to be the same as supercritical efficiency.
IP Isentropic Efficiency, %	94.0		Engineering Judgment	Ultra-supercritical efficiency assumed to be the same as supercritical efficiency.

Equipment and Parameter	Parameter Value	Range	Source	Notes
LP Isentropic Efficiency, %	92.5		Engineering Judgment	Ultra-supercritical efficiency assumed to be the same as supercritical efficiency. Additional increase over supercritical as the exhaust losses are applied to total power production (LP, IP, and HP).
Exhaust Losses, %	0.778		[57]	Exhaust losses are a function of annular velocity. Modeled as a percentage of gross power.
Surface Condenser				
Operating Pressure, MPa (psia) [in. Hg]	0.0048 (0.698) [1.4]		[10, pp. 2-16]	Operating pressure depends on cooling water temperature.
Terminal Temperature Difference, °C (°F)	12.2 (22)	11.7–12.8 (22–23)	[17]	Terminal temperature difference is higher than typical to account for lack of a summer design condition. Parameter value represents PRB cases. All cases are represented by the range.
Condensate Pumps				
Discharge Pressure, MPa (psia)	1.7 (250)	(125–250)	[10, pp. 2-18]	
Efficiency, %	80		Engineering Judgment	
Deaerator				
Operating Pressure, MPa (psia)	0.9 (134)	0.3–0.9 (44–134)	Engineering Judgment	Parameter value represents non-capture, supercritical cases. The range provided represents all cases.
Operating Temperature, °C (°F)	176 (349)	152–194 (273–349)	Engineering Judgment	The deaerator maintains a saturated liquid product stream. Therefore, the temperature is a product of pressure. Parameter value represents non-capture, supercritical cases. The range provided represents all cases.
Boiler Feed Water Pump Turbine				
Inlet Pressure, MPa (psia)	0.9 (135)	0.5–0.9 (74–135)	[10, pp. 2-16]	Parameter value represents PC supercritical cases. The range provided represents all cases.
Exhaust Pressure, MPa (psia)	0.014 (2.0)		[10, pp. 2-16]	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Isentropic Efficiency, %	80		Engineering Judgment	
Boiler Feed Water Pump – Supercritical Steam Cycle (3,515 psia/1100°F/1100°F)				
Discharge Pressure, MPa (psia)	29.0 (4,200)		[10, pp. 2-16]	
Efficiency, %	80		Engineering Judgment	
Boiler Feed Water Pump – Ultra-supercritical Steam Cycle (4,015 psia/1200°F/1200°F)				
Discharge Pressure, MPa (psia)	32.4 (4,700)		Engineering Judgment	
Efficiency, %	80		Engineering Judgment	
LP Feed Water Heaters				
Cold/Hot End Temperature Approach, °C (°F)	5.56 (10)		[10, pp. 2-16]	
Pressure Drop, kPa (psi)	34.5 (5)		Engineering Judgment	
IP Feed Water Heater				
Cold/Hot End temperature approach, °C (°F)	5.56 (10)		[10, pp. 2-16]	
Pressure drop, kPa (psi)	34.5 (5)		Engineering Judgment	
HP Feed Water Heater				
Cold/Hot End Temperature Approach, °C (°F)	5.56 (10)		[10, pp. 2-16]	
Pressure Drop, kPa (psi)	34.5 (5)		Engineering Judgment	
Feed Water Superheater				
Pressure Drop, MPa, (psi)	0.69 (100)		Engineering Judgment	

Exhibit 5-4. Process Parameters for Environmental Systems Associated with Coal Combustion

Equipment and Parameter	Parameter Value	Range	Source	Notes
SCR				
Catalyst	Titanium/ Vanadium Oxide		[10, pp. 34-5]	
NOx Reduction, %	65		[10, pp. 29-3]	The SCR efficiency value is fixed for all cases. Assumed NOx production rate of 0.2 lb/MMBtu.
Ammonia Slip, ppmv	2		Engineering Judgment	
SNCR				
NOx Reduction, %	46		[10, pp. 29-23]	Assumed NOx inlet concentration of 0.13 lb/MMBtu.
Ammonia Slip, ppmv	2		[58, p. 2]	Reference material suggests a typical range of 2-10 ppmv for this parameter.
Baghouse (PC/CFB)				
Pressure Drop, kPa (psi)	1.4 (0.2) / 1.4 (0.2)		[10, pp. 33-10]	
Particulate Removal Efficiency, %	99.88 / 99.91	99.88–99.95 / 99.91–99.93	[10, pp. 32-10]	Range depends on inlet solids loading (including solids from dry FGD applications). PC parameter value represents a supercritical, non-capture, PRB case. CFB parameter value represents PRB cases. The respective ranges represent all cases.
Activated Carbon Injection				
Carbon Feed Rate, kg/MMacm (lb/MMacf)	16 (1.0)	16–24 (1–1.5)	[10, pp. 32-11]	Parameter value represents PRB cases. All cases are represented by the range.
Hg Removal Efficiency, %	92	90–92	[10, pp. 32-11]	Combined co-benefit capture and ACI. Parameter value represents PRB cases. All cases are represented by the range provided.
Dry FGD Absorber Module				
SO_2 Removal Efficiency, %	93		[10, pp. 35-12]	Used with low sulfur PRB and lignite coals.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Exit Temperature, °C (°F)	82 (180)		[10, pp. 32-9]	
Pressure Drop, kPa (psi)	2.7 (0.397)		Engineering Judgment	
Limestone Slurry Feed Pumps				
Discharge Pressure, MPa (psia)	0.10 (15)		[10, pp. 35-10]	
Efficiency, %	65		Engineering Judgment	
In-Bed Limestone Injection				
SO_2 Removal Efficiency, %	94		Engineering Judgment	

5.3 COMBINED CYCLE SYSTEMS

The steam turbine system unit operation data is given in Exhibit 5-5.

Exhibit 5-5. Steam Turbine System Unit Operation Data

Unit Operation	Design Parameter	Range	Source	Notes
Single Reheat Subcritical Steam Turbine (NGCC: 2415 psia/1050°F/1050°F / IGCC: 1800 psia/1050°F/1050°F)				
Max Steam Temperature, °C (°F)	566 (1,050) / 566 (1,050)	- / 532–566 (990–1,050)	[15, pp. 1-14]	Syngas cases vary based on combustion turbine outlet temperature. CO_2 capture cases are lower than non-capture cases. Syngas parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
Reheat Steam Temperature, °C (°F)	565.5 (1,050) / 566 (1,050)	- / 532–566 (990–1,050)	Engineering Judgment	Syngas cases vary based on combustion turbine outlet temperature. CO_2 capture cases are lower than non-capture cases. Syngas parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
HP Inlet Pressure, MPa (psia)	16.7 (2,415) / 12.1 (1,760)		[15, pp. 1-14]	

Unit Operation	Design Parameter	Range	Source	Notes
HP Exhaust Pressure, MPa (psia)	2.7 (390) / 3.5 (501)		Engineering Judgment	Includes HP governing and HP turbine stages.
IP Inlet Pressure, MPa (psia)	2.5 (360) / 3.2 (458)		Engineering Judgment	
IP Exhaust Pressure, MPa (psia)	0.52 (75) / 0.45 (65)		Engineering Judgment	
LP Inlet Pressure, MPa (psia)	0.52 (75) / 0.45 (65)		Engineering Judgment	
HP Isentropic Efficiency, %	85.0 / 80	- / 80–89	Engineering Judgment	Syngas parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
IP Isentropic Efficiency, %	91.1 / 93		Engineering Judgment	
LP Isentropic Efficiency, %	92.7 / 93		Engineering Judgment	
Exhaust Losses, %	1.5 / -		Engineering Judgment	Modeled as a percentage of gross power.
Blowdown, % of feedwater flow	1 / 1-1.6		Engineering Judgment	NGCC cases have LP, IP, and HP blowdown of 1%. Syngas cases have an IP blowdown of 1% and an HP blowdown of 1.6%.

Process parameters for environmental systems associated with NGCC cases are presented in Exhibit 5-6.

Exhibit 5-6. Process Parameters for Environmental Systems Associated with NGCC Systems

Equipment and Parameter	Parameter Value	Range	Source	Notes
SCR				
Catalyst	Titanium/ Vanadium Oxide		[10, pp. 34-5]	
NOx Reduction, %	90		Engineering Judgment	SCR efficiency is fixed at 90% for all cases.
Ammonia Slip, ppmv	2		Engineering Judgment	

5.4 GASIFICATION AND ASSOCIATED SYNGAS SYSTEMS

The syngas processing, sour water, and mercury removal systems unit operation data is given in Exhibit 5-7.

Exhibit 5-7. Syngas Processing Systems Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
Single-Stage Syngas Recycle Compressor				
Discharge Pressure, MPa (psia)	4.2 (615)		[23]	
Isentropic Efficiency, %	75		[23]	
Syngas Scrubbing Tower				
Pressure Drop, kPa (psi)	68.9 (10)		Engineering Judgment	
Water Pressure, MPa (psia)	4.3 (625)	4.1–4.3 (595–630)	Engineering Judgment	Above inlet gas stream pressure. Parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
Sour Water Stripper				
Inlet Temperature, °C (°F)	50 (122)	49–148 (121–298)	Engineering Judgment	Parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
Acid Gas Pressure, MPa (psia)	0.4 (65)		[34]	
Effluent Pressure, MPa (psia)	0.8 (115)		Engineering Judgment	
Ammonia Separation, %	80	70–80	Engineering Judgment	Parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
Water Recovery, %	99.8	99.4–99.8	Engineering Judgment	Parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
Steam Pressure, MPa (psia)	0.45 (65)		Engineering Judgment	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Sour CO-Shift[a]				
High Temperature Shift (HTS) Catalyst			Engineering Judgment	Iron-chromium oxide catalysts.
Low Temperature Shift (LTS) Catalyst			Engineering Judgment	Copper-zinc oxide-aluminum oxide catalysts.
Steam to CO Ratio (lbmol/lbmol)	1.74	1.74–2.2	Engineering Judgment	Steam injection rate is varied to control for ratio. If moisture content of syngas exceeds requirement, no additional controls are taken. Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
CO Conversion, %	97.5	97.0–98.0	Engineering Judgment	Temperature approach to equilibrium (CO conversion rate) is varied to control carbon capture rate at 90 percent. Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Inlet Temperature to LTS Reactors, °C (°F)	204 (400)		Engineering Judgment	
HTS Pressure Drop, MPa (psi)	0.07 (10)		Engineering Judgment	
LTS Pressure Drop, MPa (psi)	0.05 (7.1)		Engineering Judgment	
COS/HCN Hydrolysis Reactor[b]				
Catalyst			[36]	Activated alumina-based catalysts.
Pressure Drop, MPa (psi)	0.07 (10)		[36]	
COS Conversion efficiency, %	99.5		[36]	This value is associated with a catalyst volume of 60 m^3 and an approach to equilibrium of 24°F (-4.4°C).
Inlet Temperature Above Dew Point, °C (°F)[c]	13.9 (25)		[36]	

[a] Used in CO_2 capture plants
[b] Used in non-CO_2 capture plants

[c] A COS Hydrolysis vendor suggested that the conversion rate would increase with decreasing temperatures, with the minimum inlet temperature suggested at 250°F. However, the conversion rate would decrease with decreasing water composition.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Low Temperature Gas Cooling Heat Exchangers				
Pressure Drop, MPa (psi)	0.03 (5.0)	0.03–0.07 (5.0–10.0)	Engineering Judgment	Parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
Outlet Temperature, °C (°F)	35 (95)		Engineering Judgment	
Ammonia Removal, %	100		Engineering Judgment	
Mercury Removal Bed				
Adsorbent Type			[41]	Sulfur-impregnated activated carbon.
Operating Temperature, °C (°F)	35 (95)		[41]	
Pressure Drop, MPa (psi)	0.07 (10)		[41]	
Removal Efficiency, %	95		[41]	

The sulfur processing system unit operation data is given in Exhibit 5-8.

Exhibit 5-8. Sulfur Processing Systems Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
Overall Claus Plant				
Sulfur recovery, %	98.6	95.7–98.8	[43]	Per pass through system. Syngas parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
Claus Reaction Furnace				
Furnace Temperature, °C (°F)	1,316 (2,400)		[44]	Parameter value is minimum required for ammonia destruction.
Pressure Drop, kPa (psi)	3.4 (0.5)		Engineering Judgment	
Heat Loss, MMBtu/lb-H_2S	80		Engineering Judgment	Oxygen rate is varied to control heat loss from reactor.

Equipment and Parameter	Parameter Value	Range	Source	Notes
H_2S:SO_2 Ratio in Exhaust	1.8	1.3–1.9	Engineering Judgment	Reactor bypass is varied to control for a 1.8 ratio at the inlet to the tail gas hydrolysis reactor. Syngas parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
Inlet H_2S Concentration, mol%	26.5	6.8–27.6	[44]	Below an H_2S concentration of 50%, it is usually necessary to use the split-flow version of the process (where only a portion of acid gas is combusted in the burner) to maintain a stable flame in the burner. Below an H_2S concentration of about 15%, a stable flame usually cannot be maintained in the burner, but special design techniques (such as supplemental fuel gas firing) can be employed to extend the range of the process to very lean acid gas streams. Syngas parameter value represents a non-capture, Shell gasifier, PRB case. Other cases are represented by the range.
Claus Waste Heat Boiler				
Outlet Temperature, °C (°F)	343 (650)		[43]	
Steam Pressure, MPa (psia)	3.6 (525)	3.0–3.6 (430–525)	Engineering Judgment	Steam generated. Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Claus Condenser				
Outlet Temperature, °C (°F)	185 (365)	160–785 (320–365)	[43]	Parameter value is the outlet temperature of the first condenser, while the range covers the outlet temperatures of all stages (except for the final condenser).
Steam Pressure, MPa (psia)	3.6 (525)	3.0–3.6 (430–525)	Engineering Judgment	Steam generated. Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Pressure Drop, kPa (psi)	3.4 (0.5)		[43]	Pressure drop per condenser.
Claus Final Condenser				

Equipment and Parameter	Parameter Value	Range	Source	Notes
Exit Temperature, °C (°F)	138 (280)		Engineering Judgment	
Generated Steam Pressure, MPa (psia)	3.8 (550)	3.8–4.2 (550–605)	Engineering Judgment	Steam generated. Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Pressure Drop, kPa (psi)	3.4 (0.5)		Engineering Judgment	
Claus Reheat Exchanger				
Outlet Temperature, °C (°F)	232 (450)	191–216 (375–420)	[43]	Parameter value is the outlet temperature of the first reheat exchanger. The range covers the outlet temperatures of the remaining reheat exchangers.
Pressure Drop, kPa (psi)	3.4 (0.5)	2.1–3.4 (0.3–0.5)	[43]	Pressure drop per reheat exchanger. Parameter value is the pressure drop across the first heat exchanger. The range covers the pressure drop of the remaining heat exchangers.
Claus Reactor				
Catalyst			[44]	Alumina-based with promoting agents.
Exit Temperature, °C (°F)	303 (577)	191–303 (375–577)	Engineering Judgment	Parameter value is the outlet temperature of the first reactor. The range covers the exit temperatures of the remaining reactors.
Pressure Drop, MPa (psi)	2.1 (0.3)	2.1–3.4 (0.3–0.5)	Engineering Judgment	Pressure drop per reactor. Parameter value is the pressure drop across the first reactor. The range covers the pressure drop across the remaining reactors.

The tail gas treatment system unit operation data is given in Exhibit 5-9.

Exhibit 5-9. Tail Gas Treatment Systems Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
TGTU Hydrogenation Reactor				
Catalyst			[45]	Cobalt molybdate on alumina.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Operating Temperature, °C (°F)	288 (550)		[45]	

5.5 ACID GAS REMOVAL SYSTEMS AND CARBON DIOXIDE COMPRESSION

The acid gas removal system unit operation data is given in Exhibit 5-10.

Exhibit 5-10. Acid Gas Removal System Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
Two-Stage Selexol				
Inlet Gas Pressure, MPa (psia)	3.4 (488)	3.4–3.7 (488–530)	[32]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Inlet Gas Temperature, °C (°F)	34 (94)	34–35 (94–95)	[32]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
CO_2 Capture Efficiency, %	90.1	90.1–92.2	[32]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Hydrogen Recovery to Treated Gas, %	99.4	98.0–99.8	[32]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
CO_2 Outlet Pressure, MPa (psia)	1.03 (150)	0.93–1.03 (135–150)	[32]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
CO_2 Outlet Temperature, °C (°F)	16 (60)		[32]	
Acid Gas Outlet Pressure, MPa (psia)	0.16 (24)		[32]	
Acid Gas Outlet Temperature, °C (°F)	48 (119)		[32]	
Treated Gas Outlet Pressure, MPa (psia)	3.2 (470)	3.2–3.3 (470–480)	[32]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Treated Gas Outlet Temperature, °C (°F)	31 (87)		[32]	
MDEA				
Inlet Gas Pressure, MPa (psia)	3.8 (545)		[50]	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Inlet Gas Temperature, °C (°F)	33 (92)		[50]	
H_2S Concentration in Acid Gas, wt%	5.4		[50]	
CO_2 Slip to Treated Gas, %	85.0		[50]	
Treated Gas Outlet Pressure, MPa (psia)	3.6 (522)		[50]	
Treated Gas Outlet Temperature, °C (°F)	51 (124)		[50]	
Acid Gas Outlet Pressure, MPa (psia)	0.4 (60)		[50]	
Acid Gas Outlet Temperature, °C (°F)	51 (124)		[50]	
Amine (PC/CFB)				
Inlet Gas Pressure, kPa (psia)	90.3 (13.1) / 90.3 (13.1)	90.3–95.8 (13.1–13.9) / 90.3–95.8 (13.1–13.9)	[59]	Parameter value represents PRB cases. Other cases are represented by the range.
Inlet Gas Temperature, °C (°F)	92.2 (198) / 136 (277)		[59]	
CO_2 Capture Efficiency, %	90 / 90		[59]	
CO_2 Outlet Pressure, MPa (psia)	0.16 (23.5) / 0.16 (23.5)		[59]	
CO_2 Outlet Temperature, °C (°F)	20.6 (69) / 20.6 (69)		[59]	
Treated Gas Outlet Pressure, MPa (psia)	0.09 (13.1) / 0.09 (13.1)	13.1–13.9 / (13.1–13.9)	[59]	Parameter value represents PRB cases. Other cases are represented by the range.
Treated Gas Outlet Temperature, °C (°F)	31.7 (89) / 3 31.7 (89)		[59]	
Amine (NGCC)				
Inlet Gas Pressure, kPa (psia)	89.6 (13.0)		[59]	
Inlet Gas Temperature, °C (°F)	142 (288)		[59]	
CO_2 Capture Efficiency, %	90.7			
CO_2 Outlet Pressure, MPa (psia)	0.16 (23.5)		[59]	

Equipment and Parameter	Parameter Value	Range	Source	Notes
CO_2 Outlet Temperature, °C (°F)	21 (69)		[59]	
Treated Gas Outlet Pressure, MPa (psia)	0.09 (13.0)	0.09–0.10 / (13.0–13.8)	[59]	Parameter value represents cases with Montana site conditions. Other cases are represented by the range.
Treated Gas Outlet Temperature, °C (°F)	30 (85)		[59]	
Sulfinol-M				
Inlet Gas Pressure, MPa (psia)	3.6 (525)	3.6–3.9 (525–560)	[52]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Inlet Gas Temperature, °C (°F)	37 (98)	35–246 (94–476)	[52]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
H_2S Concentration in Acid Gas, wt%	26.5	16.6–26.5	[52]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
CO_2 Slip to Treated Gas, %	86	85–86	[52]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Treated Gas Outlet Pressure, MPa (psia)	3.6 (522)		[52]	
Treated Gas Outlet Temperature, °C (°F)	42 (108)	42–51 (108–124)	[52]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Acid Gas Outlet Pressure, MPa (psia)	0.4 (60)	0.2–0.4 (24–60)	[52]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.
Acid Gas Outlet Temperature, °C (°F)	40 (104)	40–51 (104–124)	[52]	Parameter value represents a Shell gasifier, PRB case. Other cases are represented by the range.

The CO_2 compression system unit operation data is given in Exhibit 5-11.

Exhibit 5-11. CO_2 Compression System Unit Operation Data

Equipment and Parameter	Parameter Value	Range	Source	Notes
CO_2 Compression System				
Intercooler Approach Temperature, °C (°F)	12.2 (22)	12.2–28.9 (22–52)	Engineering Judgment	Number of degrees the exit temperature is above the inlet cooling water temperature. Parameter value represents the approach temperature of the first intercooler, the range covers the approach temperature of remaining intercoolers.
CO_2 Compressor Stage Pressure Ratio	See Range	1.4–2.2	Engineering Judgment	The pressure ratio differs depending on the stage, target compressor train outlet pressure, stage one inlet pressure, and the number of compression stages required. The range given encompasses all the potential stage pressure ratios modeled.
CO_2 Compressor Outlet Pressure, MPa (psia)	15.3 (2,215)		Engineering Judgment	
CO_2 Dryer Type				TEG
CO_2 Dryer Operating Pressure, MPa (psia)	2.8 (410)		Engineering Judgment	
CO_2 Dryer Moisture Outlet, ppmv	150	0–150	Engineering Judgment	Parameter value represents PC and CFB cases. The range represents all cases.

5.6 ANCILLARY SYSTEMS

Exhibit 5-12 through Exhibit 5-15 contain specifications for ancillary process systems common to many types of cycles.

Exhibit 5-12. Process Parameters for Determining Auxiliary Loads in PC and CFB Cases

Equipment and Parameter	Parameter Value	Range	Source	Notes
Ash Handling				
Reference Ash Handling Auxiliary Load, kW/tph Ash	26.8		Engineering Judgment	The ash handling auxiliary load is determined by multiplying the reference auxiliary load by the combined flowrate of bottom and fly ash.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Baghouse				
Reference Auxiliary Load, kW/(lb/hr fly ash removed)	0.002197		Engineering Judgment	Baghouse auxiliary load is based on fly ash flow rate and this reference auxiliary load.
Circulating Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Cooling water pump auxiliary load is based on pump mechanical efficiency, cooling water flowrates, and cooling water pump operating head.
Cooling Water Pump Operating Head, ft	85		Engineering Judgment	
Coal Handling and Conveying				
Reference Auxiliary Load, kW/tph Coal	1.2		Engineering Judgment	Coal handling and conveying auxiliary loads depend on this reference auxiliary load factor.
Cooling Tower Fans				
Fan Mechanical Efficiency, %	75		Engineering Judgment	Cooling tower fan auxiliary loads depend on cooling water temperature, circulating air to water ratio, fan air flow, fan mechanical efficiency, ambient pressure and fan head.
Fan Head, in. H_2O	0.5		Engineering Judgment	
Flue Gas Desulfurizer				
Reference Auxiliary Load, kW/(lb SO_2/hr)	0.27		Engineering Judgment	The FGD auxiliary load is dependent on the flow rate of SO_2 into the FGD, and this reference auxiliary load.
Ground Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Ground water pump auxiliary loads depend on raw water makeup flowrate, pump efficiency, and pump operating head.
Pump Operating Head, psi	100		Engineering Judgment	
Pulverizers – PC Cases				
Reference Auxiliary Load, kW/tph coal	13.6		Engineering Judgment	Pulverizer auxiliary loads depend on coal size and reference auxiliary load.

Equipment and Parameter	Parameter Value	Range	Source	Notes
Pulverizers – CFB Cases				
Reference Auxiliary Load, kWh/ton coal	0.43		Engineering Judgment	Pulverizer auxiliary loads depend on coal size and reference auxiliary load.
SCR				
Pump Mechanical Efficiency, %	80		Engineering Judgment	SCR auxiliary load is dependent upon SCR pumps mechanical efficiency, SCR ammonia flowrate, and ammonia pump head.
Ammonia Pump Head, ft H_2O	250		Engineering Judgment	
Sorbent Handling & Reagent Preparation – PC Cases				
Reference Auxiliary Load, kW/(lb lime +recycled solids/hr)	0.00083		[10, pp. 35-17]	Sorbent handling and reagent preparation auxiliary loads depend on sorbent feed rate and recycle rate as well as the reference auxiliary load.
Sorbent Handling & Reagent Preparation – CFB Cases				
Reference Auxiliary Load, kW/tph coal	4.01		[10, pp. 35-17]	Sorbent handling and reagent preparation auxiliary loads depend on the limestone flowrate, limestone conveyors and milling, as well as the reference auxiliary load.
Steam Turbine				
Fixed Auxiliary Load, kWe	400		Engineering Judgment	This is an engineering judgment for a steam turbine auxiliary load. This fixed auxiliary load is used across all Low-Rank PC and CFB cases.
Miscellaneous Balance of Plant				
Fixed Auxiliary Load, kWe	2,000		Engineering Judgment	This fixed auxiliary load is used across all Low-Rank PC and CFB cases.
Transformer Losses				
24/345 kV Efficiency	0.997		Engineering Judgment	Transformer loss auxiliary loads depend upon total plant auxiliary load and transformer efficiencies.
24/4.16 kV Efficiency	0.995		Engineering Judgment	
4160/480 V Efficiency	0.995		Engineering Judgment	

Exhibit 5-13. Process Parameters for Determining Auxiliary Loads in NGCC Cases

Equipment and Parameter	Parameter Value	Range	Source	Notes
Circulating Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Cooling water pump auxiliary load is based on pump mechanical efficiency, cooling water flowrates, and cooling water pump operating head.
Cooling Water Pump Operating Head, ft	85		Engineering Judgment	
Cooling Tower Fans				
Fan Mechanical Efficiency, %	75		Engineering Judgment	Cooling tower fan auxiliary loads depend on cooling water temperature, circulating air to water ratio, fan air flow, fan mechanical efficiency, and fan head.
Fan Head, in. H_2O	0.5		Engineering Judgment	
Ground Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Ground water pump auxiliary loads depend on raw water makeup flowrate, pump efficiency, and pump operating head.
Pump Operating Head, psi	100		Engineering Judgment	
SCR				
Pump Mechanical Efficiency, %	80		Engineering Judgment	SCR auxiliary load is dependent upon SCR pumps mechanical efficiency, SCR ammonia flowrate, and ammonia pump head.
Ammonia Pump Head, ft H_2O	252		Engineering Judgment	
Steam Turbine				
Fixed Auxiliary Load, kWe	100		Engineering Judgment	This is an engineering judgment for a steam turbine auxiliary load. This fixed auxiliary load is used across all Low-Rank NGCC models.
Combustion Turbine				

Equipment and Parameter	Parameter Value	Range	Source	Notes
Fixed Auxiliary Load, kWe	700		Engineering Judgment	This is an engineering judgment based on the 2001 F-class turbine output. This fixed auxiliary load is used across all Low-Rank NGCC models.
Miscellaneous Balance of Plant				
Fixed Auxiliary Load, kWe	500		Engineering Judgment	This fixed auxiliary load is used across all Low-Rank NGCC models.
Transformer Losses				
24/345 kV Efficiency	0.997		Engineering Judgment	Transformer loss auxiliary loads depend upon total plant auxiliary load and transformer efficiencies.
345/13.8 kV Efficiency	0.997		Engineering Judgment	
24/4.16 kV Efficiency	0.995		Engineering Judgment	
4160/480 V Efficiency	0.995		Engineering Judgment	

Exhibit 5-14. Process Parameters for Determining Auxiliary Loads in IGCC Cases

Equipment and Parameter	Parameter Value	Range	Source	Notes
ASU				
Fixed Auxiliary Load, kWe	1,000		Engineering Judgment	
Claus Plant/TGTU Hydrogenation Reactor Auxiliaries				
Fixed Auxiliary Load, kWe	250		Engineering Judgment	
Coal Handling and Conveying				
Flow Design Margin	1.1		Engineering Judgment	Coal handling and conveying auxiliary loads are based on the reclaim operating hours, coal feed rate and flow design margin. 10% design margin over maximum normal flow rate.
Reclaim Operating Hours (hr/day)	16		Engineering Judgment	

Equipment and Parameter	Parameter Value	Range	Source	Notes
Coal Milling				
Reference Auxiliary Load, kW/tph coal	9.33		Engineering Judgment	Coal milling auxiliary load depends on this reference auxiliary load and the flowrate of coal.
Cooling Tower Fans				
Fan Mechanical Efficiency, %	75		Engineering Judgment	Cooling tower fan auxiliary loads depend on cooling water temperature, circulating air to water ratio, fan air flow, fan mechanical efficiency, and fan head.
Fan Head, in. H_2O	0.5		Engineering Judgment	
Ground Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Ground water pump auxiliary loads depend on raw water makeup flowrate, pump efficiency, and pump operating head.
Pump Operating Head, psi	100		Engineering Judgment	
Steam Turbine				
Fixed Auxiliary Load, kWe	100		Engineering Judgment	This is an engineering judgment for a steam turbine auxiliary load. This fixed auxiliary load is used across all Low-Rank IGCC models.
Combustion Turbine				
Auxiliary Load, kWe	1,000		Engineering Judgment	This is an engineering judgment based on the 2001 F-class turbine output. This fixed auxiliary load is used across all Low-Rank IGCC models.
Miscellaneous Balance of Plant				
Auxiliary Load, kWe	3,000		Engineering Judgment	This fixed auxiliary load is used across all Low-Rank IGCC models.
Transformer Losses				
24/345 kV Efficiency	0.997		Engineering Judgment	Transformer loss auxiliary loads depend upon total plant auxiliary load and transformer efficiencies.

Equipment and Parameter	Parameter Value	Range	Source	Notes
345/13.8 kV Efficiency	0.997		Engineering Judgment	
24/4.16 kV Efficiency	0.995		Engineering Judgment	
4160/480 V Efficiency	0.995		Engineering Judgment	

Exhibit 5-15 provides process parameters associated with cooling water systems. These values apply to all Low-Rank cases.

Exhibit 5-15. Process Parameters for Cooling Water Systems

Equipment and Parameter	Parameter Value	Range	Source	Notes
Wet Cooling Tower				
Cooling Water Range, °C (°F)	11 (20)		[55, pp. 9-95]	
Evaporative Losses, % of Circulating Water Flow	0.8		[55, pp. 9-95]	
Drift Losses, % of Circulating Water Flow	0.001		[55, pp. 9-95]	
Cycles of Concentration	4		[55, pp. 9-95]	The cycles of concentration are a measure of water quality, and a mid-range value was assumed.
Blowdown Losses				Blowdown losses are equal to: [Evaporative Losses/(Cycles of Concentration-1)]
Air Cooled Condenser				
Fan Power Ratio	3.5	3–4	[56, pp. 3-23]	Ratio of dry cooling tower power requirement relative to a wet cooling tower design of the same heat duty.
Circulating Water Pumps				
Pump Mechanical Efficiency, %	80		Engineering Judgment	Cooling water pump auxiliary load is based on pump mechanical efficiency, cooling water flowrates, and cooling water pump operating head.
Cooling Water Pump Operating Head, ft	85		Engineering Judgment	

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