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Project Title:
Small-Scale Flexible Advanced Ultra-Supercritical Coal-Fired Power Plant with Integrated Carbon Capture

Pre-FEED Contract:
Coal-Based Power Plants of the Future – Performance Results Report

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1. AUSC Carbon Capture Plant Process Flow Summary

1.1 Coal-fired Power Plant Process Flow Description

The concept for the “Small-Scale Flexible Advanced Ultra-Supercritical Coal-Fired Power Plant” is a pulverized coal power plant with superheat (SH) temperature/reheat (RH) temperature/SH outlet pressure of 1202°F/1238°F/4800 psia (650°C/670°C/330 bar) steam conditions, capable of flexible and low-load operation, consistent with the stated goals of the Department of Energy’s (DOE’s) Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) initiative.

The major components of the plant include a pulverized coal-fired boiler in a close-coupled configuration; air quality control system (AQCS) consisting of an ultra-low NOx firing system, selective catalytic reduction (SCR) system for NOx control, dry scrubber/fabric filter for particulate matter (PM)/SO2/Hg/HCl control; an amine-based post combustion carbon capture system; and a synchronous steam turbine/generator.

A Process Flow Diagram of the overall plant (Concept 1) is shown in Figure 1. Table 1 lists the major streams including mass flow, pressure and temperature. Note that the Process Flow Diagram shows only the steam extractions for the carbon capture system for simplicity and clarity of the diagram. The steam turbine, boiler/AQCS and carbon capture sub-systems are described in more detail in the following sections.

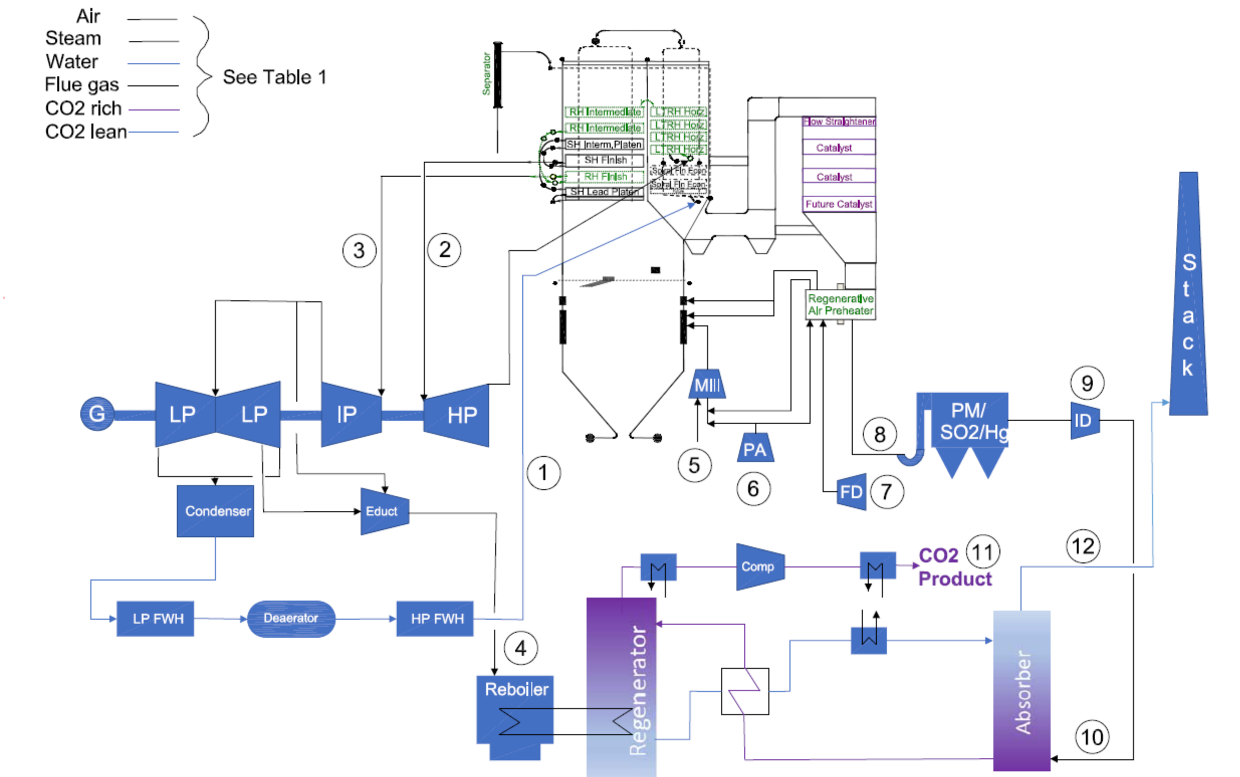

Figure 1 Small, Flexible AUSC Coal Power Plant Process Flow Diagram (Concept 1)

TABLE 1				
STREAM No.	STREAM	MASS FLOW t/hr	TEMPERATURE °C	PRESSURE
1	Feed Water	799	332.4	376 bar
2	Main Steam	799	653	340.8 bar
3	Reheat	618.228	671.2	63.54 bar
4	Steam to Reboiler	218.4	147	3.8 bar
5	Coal Flow	119	15	100.8 KPa
6	Primary Air	231	15	100.8 KPa
7	Forced Draft Air	624.6	15	100.8 KPa
8	Boiler Fluegas	1032	120	97.3 KPa
9	Fluegas to ID Fan	1075	70	94.1 KPa
10	Fluegas to CCP	1075	80	100.8 KPa
11	CO2 Product	193.5	40	120 bar
12	Fluegas to Stack	822.1	40	100.8 Kpa

Table 1 Small, Flexible AUSC Coal Power Plant Major Streams (Concept 1) at VWO load

2 Performance Summary

Table 2-1 below shows the expected plant efficiency range at full load and a summary of the emissions control, including CO_2 emissions control.

Performance Summary for AUSC coal plant:

AUSC carbon capture efficiency of 90% → 193.5 metric tons/hr CO_2 captured
Net plant efficiency of AUSC coal plant → 33.8% with carbon capture

Table 2-1 Expected Plant Performance and Emissions

Parameter	Concept 1
Size MW gross/net	300 / 209
Ramp rate up/down MW/min	15
Cold/Warm start time hours	4 / 2
	Firing PRB coal
Full load net HR MMBtu/MWH	9.908
Full Load Plant net efficiency %	33.8
50% Load Plant net efficiency %	33.1
SO_2 lb/MWh-gross	1.00
NO_x lb/MWh-gross	0.70
PM (Filterable) lb/MWh-gross	0.09
Hg lb/MWh-gross	$3x10^{-6}$
HCl lb/MWh-gross	0.010
CO_2 Capture Rate %	>90%

2.1 Coal-fired Power Plant Heat Balance Diagram (Concept 1)

The AUSC Boiler is designed to generate steam defined by the Turbine Heat Balance shown in Figure 2-1. Note that the CO2 control strategy is facilitated by steam extractions for use by the Carbon Capture Plant's reboiler:

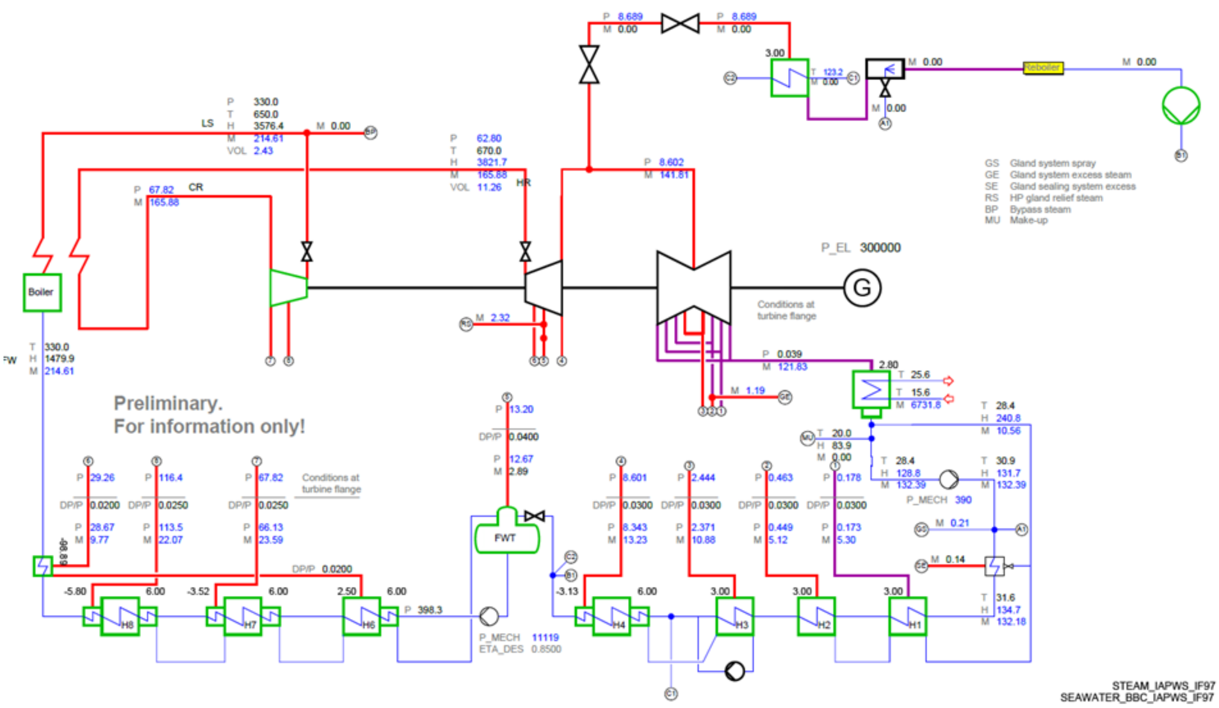

Figure 2-1 Small, Flexible AUSC Coal Power Plant Heat Balance Diagram (Concept 1) at TMCR load

2.2 AUSC Boiler and AQCS systems Performance

The AUSC Boiler Expected Performance is shown in Figure 2-2. The predicted Boiler efficiency on HHV basis is 87.5%.

The boiler concept is an innovative close-coupled arrangement. The horizontal high temperature convective surfaces have SH and RH header outlets at the front wall instead of the top of the boiler, yielding shorter high energy piping runs than a typical arrangement. Elimination of the tunnel between the furnace exit vertical plane and low temperature convective pas results in a more compact boiler footprint.

The furnace front, rear and side walls along with the first pass front wall, first and second pass division wall and side walls are all up flow fluid cooled. Only the roof and second pass rear wall and the first circuits after the separator are steam cooled. This innovative arrangement addresses differential expansion between wall sections allowing faster start-up and higher load ramp rates.

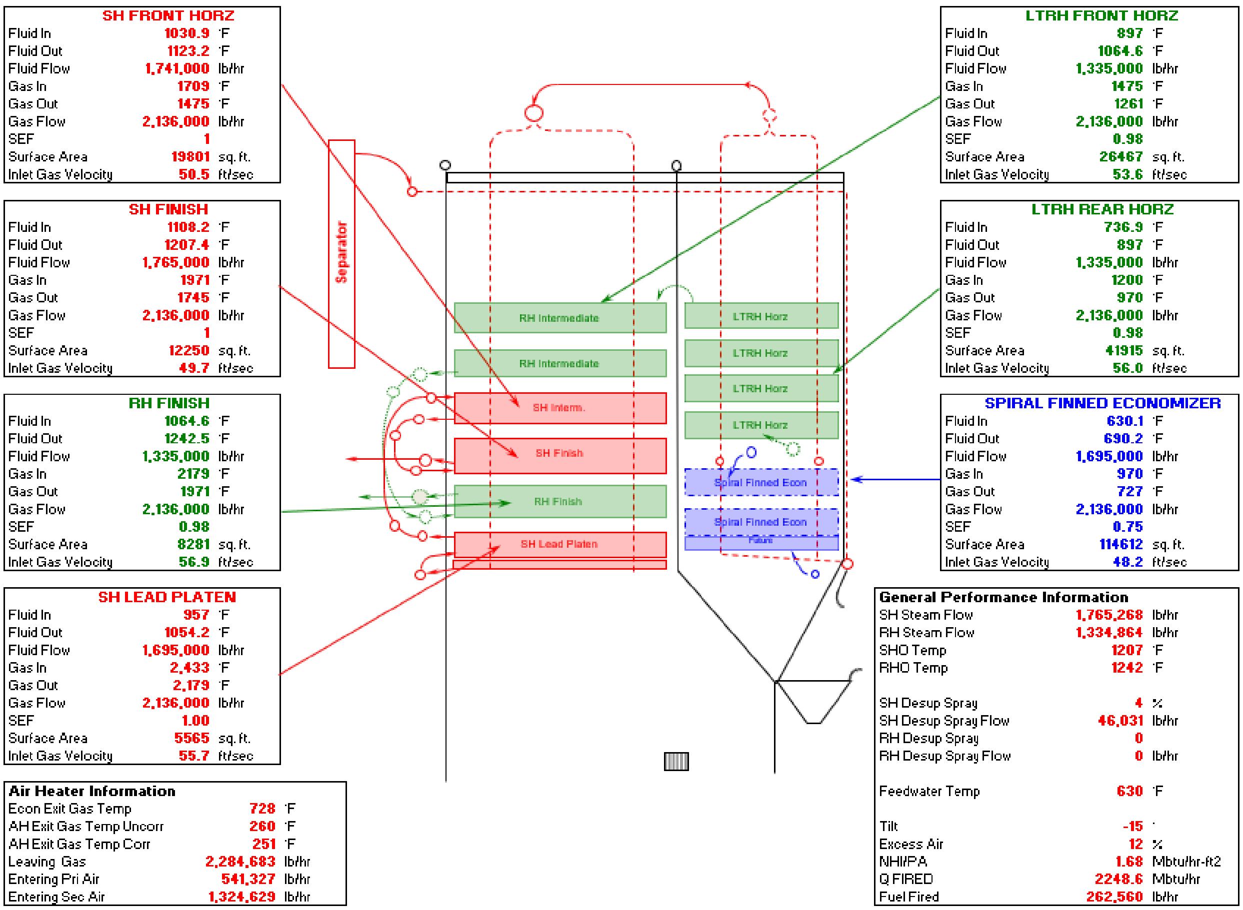

Figure 2-2 AUSC Boiler Expected Performance at VWO (103%) Load

GE Power Inc.'s most recent development is the TFS XP™ Ultra Low NOx Firing System. This system represents over 45 years of progressively developed global and local staging techniques designed to minimize O_2 availability during the critical early phases of combustion when the volatile (fuel) nitrogen species are formed. A key feature of this firing system is the tri-level OFA design consisting of "close coupled" overfire air (CCOFA) and two(2) levels of separated overfire air (SOFA). Moving the upper most SOFA windboxes from the traditional "corner" location to the furnace walls in a "counter" fireball orientation completed the design by providing superior mixing, minimum gas-side energy imbalance (GSEI) and control of CO emissions while operating at minimum NOx emissions levels.

The TFS XP™ firing system has some additional important features including;

- Dynamic classifiers for improved mill performance (fineness and capacity)
- Concentric firing to maintain "oxidizing" conditions along the furnace walls in the firing zone, and
- Enhanced ignition coal nozzle tips for more rapid release of fuel nitrogen, improved coal combustion (lower UBC HL) and low load flame stability

The Boiler Auxiliary Equipment include Coal Mills, PA, FD and ID fans, SSC (submerged scraper conveyer), and APH (air preheater).

The air preheater design will be optimized to gain the maximum heat recovery that allows for an overall reduced heat rate.

The generated flue gas is cleaned by the Air Quality Control Systems (AQCS) by removing particulate and SO2, NOx and other acidic gases, prior to discharge to the downstream Carbon Capture System (CCS) or to the atmosphere when the CCS is bypassed.

The conditions in Coal First Pre-Feed Study Project with request for high performance, low water consumption, zero liquid discharge, modular design and wide turn down ratio are ideal for the SCR and NID-FF technologies.

The SCR system is a well proved post combustion technology for converting by-product NO_x to atmospheric N_2 at reduction efficiencies of +90%. The process involves injecting ammonia (anhydrous, aqueous or as urea) into the flue gas stream of an appropriate temperature and then passing the flue gas through a reactor vessel containing catalyst. An economizer gas bypass system will be used to control SCR inlet gas temperature. The reactor box is a standard multi-layer design with inlet turning vanes, flow straighteners, ash moving devices and integrated catalyst module removal system.

The NID-FF system uses compact reactors combined with Fabric Filters (FF) as dust collector. The reagent handling is possible to be located flexibly in the vicinity of the NID-FF unit and the same for ash handling system.

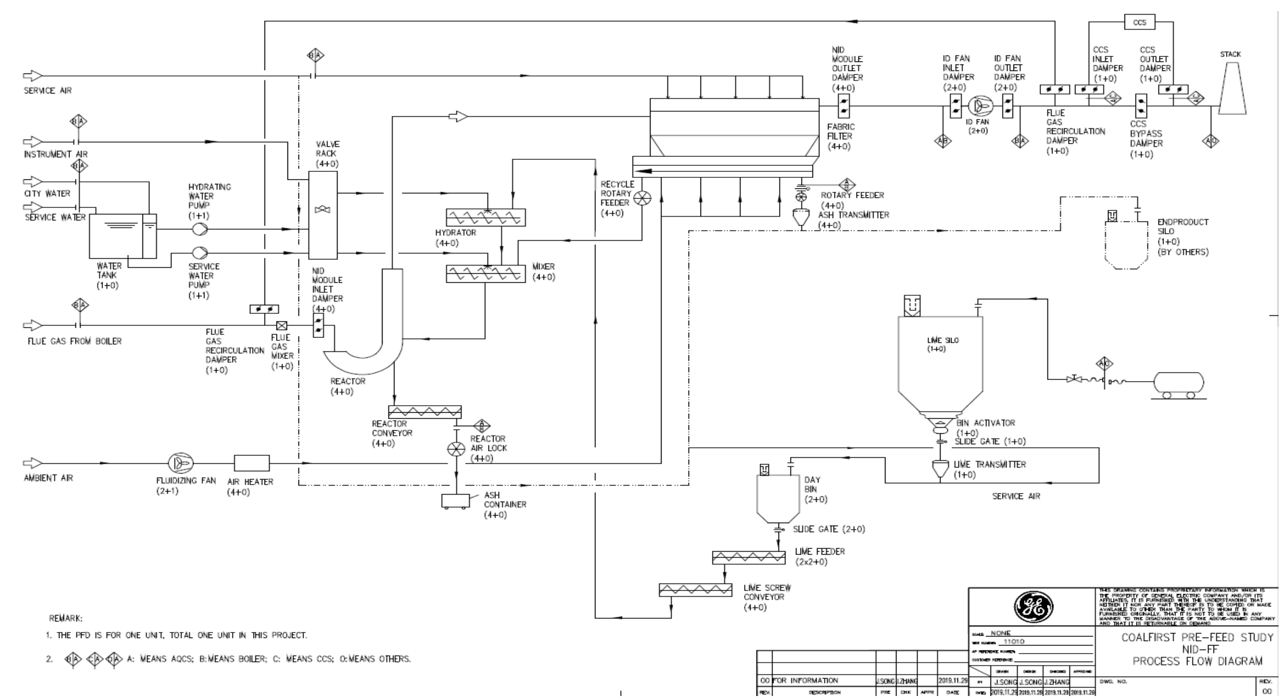

Figure 2-3 NID™ system Process Flow Diagram

2.2.1 Performance Summary Data for the AQCS NIDS

	Unit of measure (UOM)	
	Coal	Rosebud
Boiler load	% MCR	VWO
Flue gas flowrate	kg/h	1,032,417
Flue gas flowrate	Nm3/h	789,924
Flue gas flowrate	m3/h	1,159,967
Gas temperature	ºC	120
Design barometric pressure	Pa	100,801
Static pressure	Pa(g)	-3,483
Total Pressure	Pa	97,319
Gas composition:		
CO2	ppmv, Wet	138,686
N2	ppmv, Wet	714,362
H2O	ppmv, Wet	113,586
O2	ppmv, Wet	32,629
SO2	ppmv, Wet	735
SO3	ppmv, Wet	0.79
Density	kg/Nm3	1.307
	kg/m3	0.890
Dust load (volumetric)	mg/Nm3, 6% O2 dry	9756.4
Dust load (mass)	kg/h	7,888

2.2.2 Flue gas emission for NID-FF design

Pollutant	mg/Nm3, dry, 6%O2	Remarks
SO_2	41	≥ 98% removal efficiency
PM (Filterable)	10	
Hg	$5x10^{-4}$	
HCl	0.35	

TURN-DOWN RATIO
5:1 turndown ratio with full environmental compliance.

LOAD CHANGE RATE
Greater than or equal to 4% ramp rate (up to 30% Heat Input from natural gas can be used).

LIME QUALITY
The quick lime provided as a reagent to the process shall have the following minimum quality characteristics:

- ⩾90 active CaO as per ASTM C 25.
- Particle size: 100% < 3mm, 80% < 0.8mm.
- Chemical activity such that the contact with water leads to a temperature increase > 40°C in 3 minutes as per ASTM C 110
- Density when stored in silo:

Min	900 kg/m^3
Typical	1 000 kg/m^3
Max	1 300 kg/m^3

PROCESS WATER QUALITY
The Process Water provided to the process shall follow water quality characteristics below at the terminal point:

Description	Unit	Mixer Water	Hydrator Water
Total dissolved solids	g/l	< 20	< 1
Total suspended solids	g/l	< 10	< 10
Sulphate, SO_4^{2-}	mg/l	< 500	< 200
Chloride, Cl^-	mg/l	< 1000	< 100
Carbonate $HCO_3^- + CO_3^{2-}$	mg/l	< 1000	< 500
pH		>6.5	>6.5
Particle size	mm	< 0.3	< 0.3
Temperature	°C	15 – 35	15 – 35
Pressure	bar (g)	⩾2	⩾2

CLOSED COOLING WATER QUALITY
The Closed Cooling Water provided to the process shall follow water quality characteristics below at the terminal point:

Description	Unit	Value
Water source		Demineralized water
pH at 25°C		8 – 9
Conductivity at 25°C	µs/cm	< 10
Temperature	°C	< 35
Pressure	barg	5-7

EMERGENCY SHOWER WATER
Emergency water system with showers is to be installed with appropriate water quality based on local safety requirements, to be chosen by the customer as suitable for showers (presumably drinking water).
Water pressure required at terminal point, minimum 2 bar(g)

COMPRESSED AIR QUALITY
The Compressed Air provided to the process shall have the following quality characteristics at the terminal point:

Instrument Air

Pressure		kPa(e)	700
Particulate	ISO8573.1 Class 1	µm	⩽ 0.5
Dew point	ISO8573.1 Class 2	°C	⩽ -40
Oil content	ISO8573.1 Class 2	mg/m^3	⩽ 0.1

Process Air

Pressure		kPa(e)	700
Particle	ISO8573.1 Class 2	µm	⩽ 5
Dew point	ISO8573.1 Class 4	°C	⩽ 3 or min. ambient temperature
Oil content	ISO8573.1 Class 3	mg/m^3	⩽ 1

ELECTRICAL POWER SUPPLY

Electric power at the terminal point shall have the following specification.

Low voltage power supply	Voltage – Frequency – Phase	480 V – 60 Hz – 3 phase
	Fluctuation of voltage	Within ±10%
Medium voltage power supply	Voltage – Frequency – Phase	6.0 kV – 60 Hz – 3 phase
	Fluctuation of voltage	Within ±10%
For Instruments	240V, 60Hz 3 Phase or 24V DC	
For PLC	240V, 60Hz 3 Phase or 24V DC	

ELECTRICAL EQUIPMENT PROTECTION SPECIFICATION

Electrical equipment and instrument in electric and electronic rooms IP31

Electrical equipment and instrument in process area IP54

Electrical equipment and instrument outdoors IP55

GAS PRESSURE FOR MECHANICAL DESIGN

The following gas pressure was chosen as the design basis for the NID-FF installation.

Description	Unit	Normal	Excursion
Under pressure in flue gas path, for mechanical design	Pa	– 6,500	– 8,700

2.2.3 Consumption Data

Following consumption numbers are expected for one boiler unit:

Boiler load		VWO	TMCR	70% TMCR	50% TMCR	35% TMCR	20% MCR
Quick lime	kg/h	3503	3409	2412	1710	1222	675
Powdered Activated Carbon (PAC)	kg/h	50	48	36	30	23	22
Mixer water	m^3/h	24.7	24.0	15.9	12.4	10.8	9.0
Hydrating water	m^3/h	2.2	2.1	1.5	1.1	0.8	0.4
Closed cooling water	m^3/h		10			5	
End product from NID	t/h	14.9	14.4	10.3	7.5	5.4	3.2

Service air (Max.)	Nm^3/h	2,074	2,074	1,556	1,037	1,037	1,037
Service air (Normal operation)	Nm^3/h	1,018	941	598	720	378	295
Instrument air	Nm^3/h	60					

2.2.4 Pressure Drop Data

Following pressure drop numbers are expected for design conditions:

Boiler load	Unit	VWO	TMCR	70% TMCR	50% TMCR	35% TMCR	20% MCR
Pressure drop across NID-FF (flange-to-flange)	Pa	3000	2900	2800	3400	2700	2500

2.2.5 Power Consumption Data

Following auxiliary power consumption numbers are expected for design conditions

Boiler load	Unit	VWO					
Power Consumption of NID-FF system	kW	350					
Power Consumption of PA, FD, ID fans, misc. fans, HP mills, feeders, vaporizer, SSC and APH	kW	7,056					

3 AUSC Carbon Capture Plant

The simplistic version of the proposed carbon capture system Process Flow Diagram (PFD) is shown in Figure 3-1. A typical post combustion carbon capture system (CCS) consists of two main blocks, as follows:

- The CO_2 Absorber, in which the CO_2 from the power plant flue gas is absorbed into a solvent via fast chemical reaction, and
- A regenerator system where the CO_2 absorbed in the solvent is released, and then the sorbent is sent back to the absorber for further absorption.

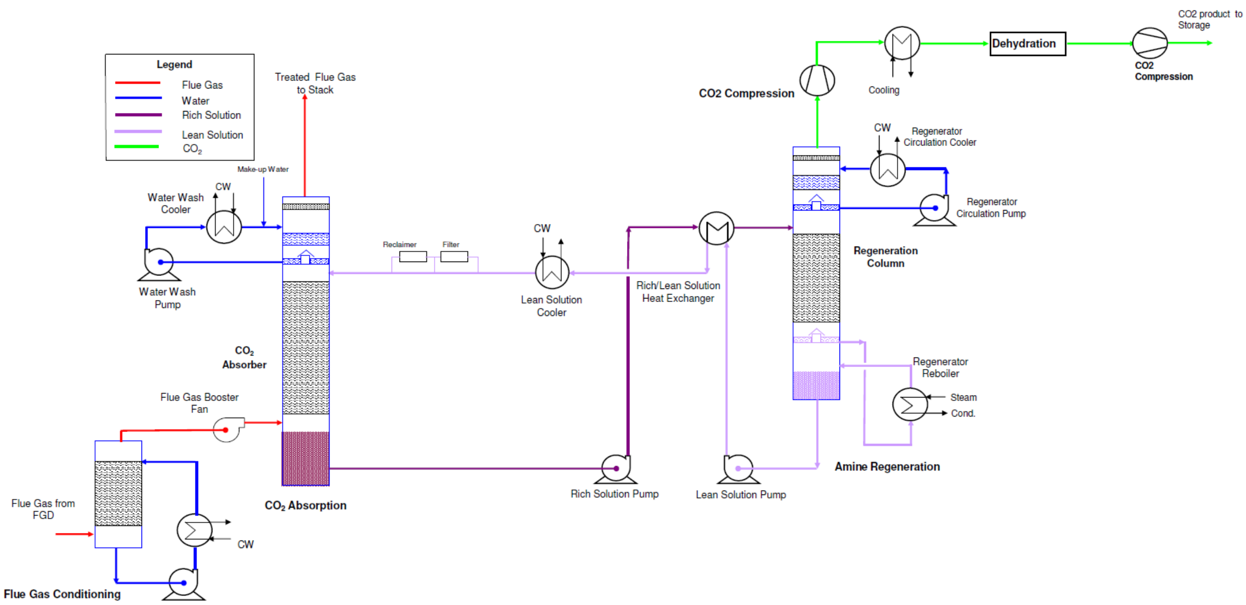

Figure 3-1 Process Flow Diagram of the proposed carbon capture technology

The CCP is located downstream of the traditional AQCS plant section with the specific target to reduce the CO2 emissions of the host power plant. The proposed CCP concept utilizes a proven Advanced Amine Process (AAP), comprising a proprietary amine-based solvent in a proprietary flow scheme for flue gas applications. The AAP technology applied is based on smaller scale AAP pilot plant experience as well as a reference design for large scale post-CCPs, but downscaled to process the flue gas from target host plant capacity.

The main CCP plant performance target is 90 % CO2 capture from the pre-treated flue gas of up-stream AQCS components, while producing a CO2 product with specified quality in terms of composition and battery limit conditions - pressure and temperature - for further utilization.

These targets are accomplished with the objectives to achieve minimized energy and utility consumptions, primarily steam and electrical power, but also cooling water and chemical consumptions, primarily amine make-up. Additional CCP plant integration options with the host power plant water/steam cycle could further improve the overall operations expenditures (OPEX) on cost of additional capital expenditures (CAPEX). Generally, amines-based processes are proven technologies for decades in the oil and gas industry. In this application, the process has been optimized to combustion flue gas under atmospheric pressure and power plant operations.

The main emission target for the CCP is a 90% reduction of CO_2 emissions for the AUSC coal plant in Concept 1 and for both the AUSC coal plant and the gas turbine/heat recovery boiler system in Concept 2. A validated solvent and emission management is utilized to keep the emissions generated from the CCP below tolerable limits, typically defined for amines and ammonia.

The individual CCP equipment design is considering a well-balanced techno-economical solution (CAPEX/OPEX-ratio) to achieve the performance targets, like CO_2 capture, CO_2 product quality and emissions, while keeping the OPEX on a low level. This comprises the following components:

- Flue gas conditioning system for an optimized CO_2 absorption performance
- Improved absorber design maximizing the CO_2 loading in the rich solvent
- Advanced regeneration concept minimizing steam consumption and CO_2 product compression power demand
- High efficiency heat exchanger network maximizing heat recovery from the hot lean solvent from the regenerator
- Advanced solvent management
- Efficient CO_2 product compression & dehydration system to accommodate CO_2 pipeline conditions

All equipment of the CCP is designed to meet these targets. The interplay of its different components is harmonized for operation within the required operating range. Figure 3-2 shows the specific advantages and features of the AAP technology outlined in the bullets above.

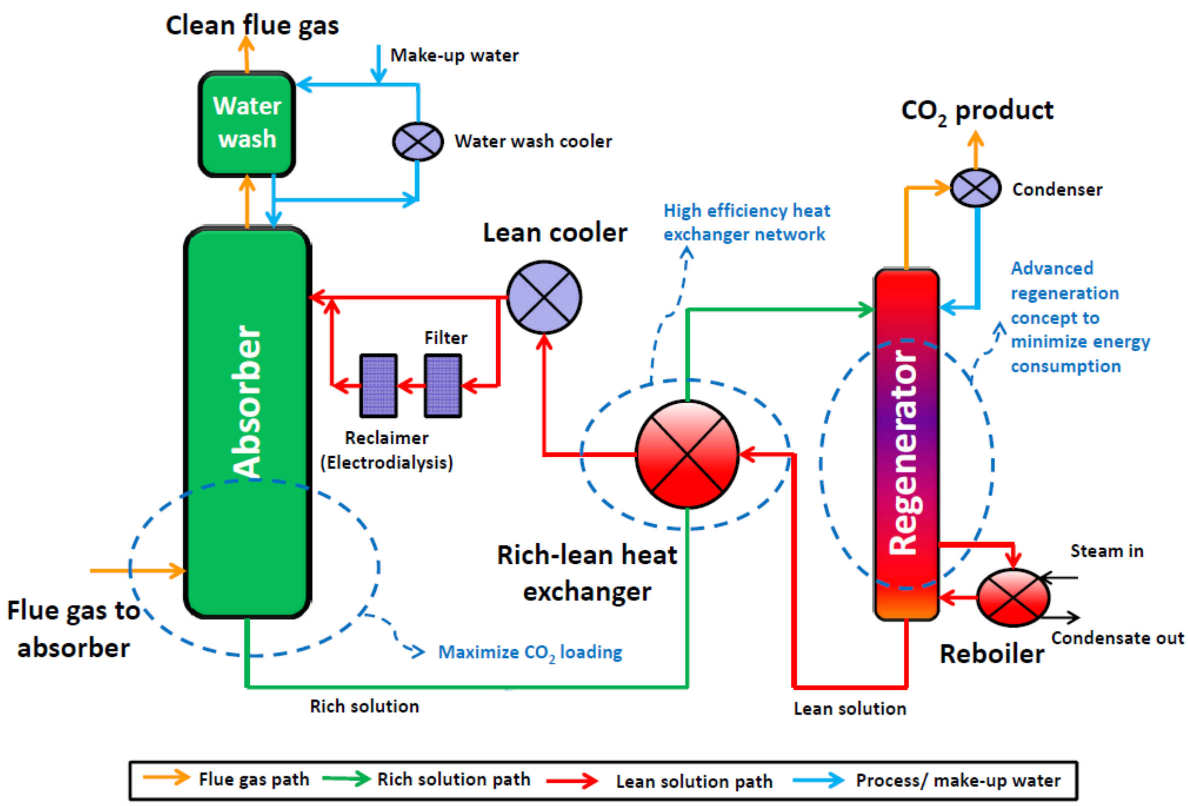

Figure 3-2 Features and Advantages of the Advanced Amine Process

3.1 Performance Summary

The scope of this Performance Summary Report is to summarize:

- CO_2 capture efficiency
- CO_2 product flow and quality
- energy and utility consumption figures
- chemical consumption figures
- expected emissions
- expected effluents
- solid wastes

of the CCP for the governing design case (BMCR/VWO case of the host AUSC coal plant) of **case 1**, defining the CCP design plant capacity.

Out of scope of this Performance Summary Report are:

- performance figures for any turndown operation of the CCP
- plant integration optimizations for the host power plant and CCP, offering potential for reduced energy and utility consumption figures.

3.2 CO2 Capture Efficiency

The CCP is designed to capture at least 90 % of the CO2 contained in the specified flue gas outlet stream from the AQCS. For the design case (BMCR/VWO case) of **case 1**, the total flue gas outlet stream from the AQCS plant section will be routed to the CCP. The relevant design flue gas stream from AQCS plant section is a wet flue gas flow of 1.075 t/h, respectively 836.7 kNm^3/h. This stream contains a CO2 concentration of 13.09 vol-%, wet, which results in a CO2 flow of 215.0 t/h in the total flue gas to the CCP unit.

90 % of this CO2 contained in the total flue gas stream will be captured in the CCP unit and compressed to the required pressure of 120 bar(abs) for Enhanced Oil Recovery (EOR) utilisation. Thus, the maximum CO2 capture plant capacity for subject power plant is 193.5 t/h, respectively 4,644 t/day of CO2 product, which is captured from 100 % of flue gas flow.

3.3 CO2 Product Flow and Quality

Typically, the CO2 product stream will be delivered to the CCP boundary at a pressure between 100 and 150 bar(abs), depending on site specific conditions like distance to storage site. For the CO2 capture study, the CO2 product pressure of 120 bar(abs) is assumed for the purpose of this study as specified. The battery limit for the CCP pertaining to the CO2 Product route is assumed at CO2 compressor outlet flange, respectively its aftercooler.

The expected CO2 product stream characteristics are provided in the following tabulation.

Description	**Units**	
CO2 product mass flow at CCP design plant capacity	t/h	193.5
CO2 product temperature (at CCP battery limit)	°C	40
CO2 product pressure	bar(abs)	120
Composition		
CO_2	vol-%, wet	> 99.5
N_2 (including Ar)	ppm-mol, wet	balance (< 5,000)
H_2O	ppm-mol, wet	< 50
O_2	ppm-mol, wet	< 100
Amine, degradation products, TEG	ppm-mol, wet	traces

Table 3-1: CO2 product characteristics of the CCP

3.4 Low Pressure Steam

Energy in the form of steam is needed within the AAP technology regeneration system to:

- Release the CO2 in the Amine Regenerator and produce the desired CO2 product stream
- Regenerate the CO2-"rich" amine solution from the CO2 Absorber in order to produce a reagent for reuse.

LP Steam has been foreseen to provide this thermal energy to the Amine Regenerator Reboiler.

The estimated value for steam consumption is shown in table below and is based on the shown assumed steam pressure and temperature. For the CO2 capture study, a saturated steam temperature at the CCP battery limit of 147 °C was assumed.

Estimated steam demand for the CCP of the CO2 capture study:

(subject to confirmation by detailed process design)

Description	**Units**	
Steam pressure at battery limit to CCP *1)	bar(abs)	min. 3.8
Steam temperature at battery limit to CCP *1)	°C	147

Note 1:

Steam conditioning/de-superheating is assumed to be outside of CCP scope.

The condensate from the regeneration reboiler is returned to the host power plant's steam/water cycle to generate steam again. The required condensate pressure of 7.0 bar(abs) at the CCP battery limit is assumed.

3.5 Electrical Power

The CCP's electrical demand may be provided by a single medium voltage electrical feed to the CCP's electrical power distribution. The electrical distribution strategy to provide the most economical electrical power to the individual CCP components will be developed in a later stage. The electrical power distribution equipment may include, but is not limited to switchgear, substations, power transformers, Motor Control Centers (MCCs), power distribution transformers, power distribution panels.

The CO2 compressor outlet pressure, respectively the required pressure of the CO2 product at CCP battery limit influences significantly the electrical power consumption of the CCP. This pressure is assumed for the purpose of this study and needs to be defined by site-specific condition of distance to storage site and will need a more detailed calculation in a later stage.

Estimated electrical power consumption for the CCP of the CO2 capture study:

(subject to confirmation by detailed process design)

Description	Units	
Average demand at CCP design plant capacity	MW	26.5
CCP electrical power per year (at 5,000 full load operating hours per year)	MWh	132,500

All small and large size machinery, e.g. CO2 Compressor, are assumed electrical motor driven. No steam turbine is considered as driver of any machine.

3.6 Cooling Water

For the CO2 capture study, the availability of cooling water is assumed. The cooling water is assumed to be provided from host power plant. The CO2 capture study in hand and its performance/consumptions calculations have been done for the specified Cooling Water (CW) supply temperature of 15.6 °C.

Note, the CCP performance is depending on available cooling water supply temperature.

The cooling water conditions are assumed as following:

Parameter	Unit	Total
CW supply temperature	°C	15.6
CW return temperature	°C	25.6
CW supply pressure	bar(abs)	5.0
CW return pressure	bar(abs)	3.5

The cooling water utilization for the AAP CCP is mainly for cooling of the following process heat loads:

- flue gas conditioning
- CO_2 Absorber system
- Water Wash at CO_2 Absorber
- Water Wash at Amine Regenerator
- CO_2 Compression system.

The estimated cooling water amount required for the AAP CCP plant considering an assumed 10 °C temperature increase is shown in the following tabulation.

Estimated cooling water demand for the CCP of the CO_2 capture study:

(subject to confirmation by detailed process design)

Description	Units	
Average demand at CCP design plant capacity	m^3/s	5.3
	m^3/h	19,200
Cooling water supply temperature (design)	°C	15.6
Overall cooling water temperature increase in CCP	°C	10
Cooling water supply pressure (design)	bar(abs)	5.0
Cooling water allowable pressure drop over the CCP	bar	1.5

3.7 Demineralized Water

The CCP, with the inclusion of the Water Wash System at the top of the CO_2 Absorber, is designed to be nearly water neutral, e.g. any water make-up requirements or waste water treatment requirements have been minimized. During periods of ambient conditions with higher temperature and start-up periods, a small amount of demineralized water may be additionally required. In addition, the ED Reclamation unit and the Water Wash System of the CO_2 Absorber require some demineralized water feed. Further, process water for gearbox cooling and equipment seals is anticipated but is <u>not</u> included in the estimate demineralized water consumption figure below.

There is considerable flexibility with regard to the demineralized water flow rate and quality that can be accepted by the AAP of the CCP. The optimization for a minimum demineralized water consumption will be evaluated in a later stage.

For the CO2 capture study, the demineralized water as specified in following tabulation is considered as make-up for the CCP.

Parameter	Value
Chlorides - limits chloride corrosion-related problems	< 2 ppmw
Total dissolved solids - limits ash build-up and foaming problems	< 50 ppmw
Total hardness - limits calcium and magnesium scale problems	< 2 ppmw
Sodium/potassium - limits heat stable salts	< 10 ppmw
Iron - limits iron scale and build-up and fouling	< 1 ppmw

Demineralized water is mainly consumed in following services:

- CO2 Absorber
- Amine Reclamation unit.

Estimated demineralized water demand for the CCP of the CO2 capture study:

(subject to confirmation by detailed process design)

Description	Units	
Average demand at CCP design plant capacity	t/h	3.0
CCP demand per year (at 5,000 full load operating hours per year)	t/year	15,000
Amount for first fill	m^3	1.500

3.8 Nitrogen

Nitrogen is consumed in following services:

- storage tanks, for blanketing
- drain drums, for blanketing.

Estimated demand of nitrogen for the CCP of the CO2 capture study:

(subject to confirmation by detailed process design)

Description	Units	
Average demand at CCP design plant capacity	Nm^3/h	3.0
CCP demand per year (at 5,000 full load operating hours per year)	$kNm^3/year$	15.1

3.9 Instrument Air

Instrument air is consumed in following services:

- CO2 Compression and Amine Reclaimer Unit
- other instruments and control valves.

Estimated demand of instrument air for the CCP of the CO2 capture study:

(subject to confirmation by detailed process design)

Description	Units	
Average demand at CCP design plant capacity	Nm^3/h	430
CCP demand per year (at 5,000 full load operating hours per year)	kNm^3/year	2,150

3.10 Amine Solution

GE Power's AAP technology uses UCARSOL™ FGC-3000 as the solvent, a proprietary advanced amine solvent supplied by DOW, the largest supplier of specialty chemicals in the world.

Amine solution is lost from the process mainly in two ways:
- in the flue gas leaving the CO2 Absorber
- in the waste water stream from the Amine Reclaimer.

The advanced amine solvent will be transported to site by tank truck and fed to the Amine Tank in concentrated form with low water content. It will be fed into the unit in its concentrated form, in case the amine concentration in the loop is decreasing. There will be a separate water make-up stream to the amine circulation loop, in case the amine concentration becomes too high.

Concentration of the amine solvent solution that will be stored in the CCP

Two solvent supply tanks, one for the advanced amine solvent and one for additive make-up are considered for the proposed CCP design. The concentration intended to be supplied will be concentrates of higher concentration than used amine concentration (> 60 wt-% amine, balance water).

Estimated amine solvent demand (pure, 100 % concentration) for the CCP of the CO2 capture study:

(subject to confirmation by detailed process design)

Description	Units	
Amount of solvent (100 %) for initial fill	m^3	1,500

3.11 Sodium Hydroxide

Sodium hydroxide (NaOH) is used for two services in the AAP CCP:
- for amine reclamation process to neutralize the amine solution
- for SO2 removal in the Flue Gas Conditioning section to adjust the SO2/NO2 content contained in the incoming flue gas to the optimum level for the AAP optimum operation.

NaOH will be delivered to site by tank truck already in the correct dilution and fed to the Caustic Storage Tank in the storage tank area.

Estimated demand of NaOH (based on NaOH concentration of 30 wt-%) for the CCP of the CO2 capture study:

(subject to confirmation by detailed process design)

Description	Units	
Average demand at CCP design plant capacity	t/h	0.28
CCP demand per year (at 5,000 full load operating hours per year)	t/year	1,400

Demands to be confirmed with Reclaimer package unit vendor. Consumption can be reduced, if the AQCS plant section can be modified for a higher SOX removal.

3.12 Antifoam

In order to effectively control potential occurrence of foaming in the amine solution cycles, the AAP is designed with provisions for antifoam injection in various areas of the system. The AAP technology uses a specific recommended antifoam chemical. The antifoam agent is supplied to site in liquid form already in the right concentration in special storage totes that will be situated in the storage tank area. Spare totes can be stored indoors in a suitable warehouse storage area and delivered to the storage tank area as required.

Estimated demand of antifoam for the CCP of the CO2 capture study:

(subject to confirmation by detailed process design)

Description	Units	
CCP demand per year (at 5,000 full load operating hours per year)	t/year	7.0

Note, the demand per full load operating hour is normally <u>no flow</u>, only discontinuous supply in case of potential occurrence of foaming in the amine solution cycles. The maximum peak demand is trace amounts to the system.

3.13 Activated Carbon

In order to keep the solution loops free from particles and traces of organic chemicals and degradation products, the AAP is equipped with an effective filtering system, consisting of an activated carbon filter followed by a mechanical filter. The activated carbon inventory of the filter is expected to be exchanged against fresh activated carbon once per 1.5 years. The activated carbon is supplied to site in storage totes or big bags and filled into the activated carbon filter.

Estimated demand of activated carbon for the CCP of the CO2 capture study:

(subject to confirmation by detailed process design)

Description	Units	
CCP demand per year (at 5,000 full load operating hours per year)	m^3/year	100

Note, the demand per full load operating hour is none. However, the active carbon bed is to be changed on a regular schedule, depending on the flue gas impurity concentrations. The estimate is based on expected exchange against fresh activated carbon once per year.

3.14 Tri-Ethylene Glycol

Tri-Ethylene Glycol (TEG) is consumed in following service:

- CO2 Dehydration unit.

Estimated demand of TEG for the CCP of the CO2 capture study:

(preliminary, subject to confirmation by detailed process design)

Description	Units	
Average demand at CCP design plant capacity	kg/h	2.9
CCP demand per year (at 5,000 full load operating hours per year)	t/year	14.5

3.15 AAP Outlet Flue Gas Emissions

The CCP is designed to treat the flue gas outlet stream from the AQCS plant section of the host power plant for the design case (BMCR/VWO case) of **case 1**, and to remove at least 90 % of the entering CO2. The amine content in the flue gas after the capture plant is expected to be less than 1 ppmv. The flue gas discharge temperature leaving the AAP is approximately 40 °C. The treated flue gas from the AAP plants are assumed to be returned to a tie-in in the duct from the AQCS plant section to the common stack.

The expected treated flue gas characteristics are given in following table. Since the function of the CCP is to capture CO2, the treated flue gas may also contain trace components which have entered the CCP with the inlet flue gas such as SOx, NOx, HCl, HF, NH3, PM.

Description	Units	
AAP outlet flue gas volumetric flow (wet, norm) at CCP design plant capacity	kNm^3/h	663,890
AAP outlet flue gas mass flow (wet) at CCP design plant capacity	t/h	822.1
AAP outlet CO2 mass flow	t/h	21.5
Flue gas temperature	°C	~ 40
Flue gas pressure	bar(g)	atmospheric
Composition (wet)		
H2O	vol-%, wet	6.96
CO2	vol-%, wet	1.65
N2 (including Ar)	vol-%, wet	86.98
O2	vol-%, wet	4.41
Amine	ppmv, wet	< 1
Amine Degradation products	ppmv, wet	traces

Table 3-2: AAP outlet flue gas characteristics of the CCP

3.16 Flue Gas Condensate

The Flue Gas Conditioning section of the CCP will generate two product streams:

- a flue gas condensate stream
- a spent caustic stream.

The flue gas condensate stream is the flue gas condensate stream due to flue gas moisture condensation when the temperature of the flue gas is cooled down in the top section of the flue gas conditioning column. The accumulated condensate contains predominantly water with a trace amount of dissolved gases (like N2, O2, CO2) which are part of the incoming flue gas and get dissolved in the condensate. This Flue gas condensate is sent to the CCP battery limit for further handling and reuse in the host power plant.

The expected flue gas condensate stream characteristics are provided as follows:

Description	Units	
Flue gas condensate mass flow at CCP design plant capacity	t/h	62.0
Temperature	°C	< 50
Pressure	bar(abs)	5.0

3.17 Spent Caustic

The Flue Gas Conditioning section of the CCP will generate two product streams:

- a flue gas condensate stream
- a spent caustic stream.

The spent caustic stream is an aqueous spent caustic stream from caustic scrubbing of the flue gas in the bottom section of the flue gas conditioning column. This stream contains predominantly water with a trace amount of dissolved gases (like N2, O2, CO2) as well as some dissolved sodium salts which are formed during caustic wash of the acid gases (mostly SO2, NO2) from the incoming flue gas. This spent caustic is sent to the CCP battery limit for further handling and reuse in the host plant.

The expected spent caustic stream characteristics are provided as follows:

Description	Units	
Spent caustic mass flow at CCP design plant capacity	t/h	~ 0.19
Temperature	°C	< 50
Pressure	bar(abs)	5.0

3.18 Other Liquid Effluents

Other liquid waste water streams of the CCP are:

- CO2 Dehydration unit effluent
- ED Reclaimer effluent (ED Reclaimer brine)
- backwash water from Amine Pre-Filter
- blow down water from Amine Regenerator Water Wash section
- amine purge.

Some of these waste waters are expected not to be a continuous effluent over the complete operating time, but are provisional streams foreseen for maintaining plant operability/ performance and/or for solvent management as needed, e.g. expected to be required under certain operating conditions only. The continuous and discontinuous waste water streams are estimated to be approximately between 1.5 m^3/h (continuous) and 5.5 m^3/h (discontinuous) for the CCP. The waste water streams can be sent to a Waste Water Treatment unit of the host power plant and which is not in the scope of the CCP for further handling and reuse in the host power plant. Those streams containing major amounts of solvent related components may be sent to a first treatment step for separation of the waste water into a treated water and a more concentrated waste stream containing most of the solvent related components, e.g. concentrate from Reclaimer brine or amine purge. This concentrated waste stream can then be collected and sent to chemical disposal or may potentially be co-combusted in a boiler. The treated water stream may be recycled back to the CCP plant and thereby replace make-up process water.

Further typical plant waste waters like rain sewage, sanitary sewage and fire-fighting sewage are expected.

3.19 Solid Wastes

Two main solid waste streams are generated in the CCP, both resulting from amine filtration. The insoluble contaminants can usually be removed by mechanical filtration. Soluble contaminants that are surface-active can be removed to a certain extent by activated carbon filtration. This results in following waste streams:

- spent (loaded) Activated Carbon Bed.
- potentially filter cake from the Pre-Filter if further

4. Design Basis

4.1 General Information

	Parameter	Value
1.1	Plant	AUSC Coal Plant
1.2	Location	Greenfield, Midwestern
1.3	Plant owner	not applicable
1.4	Power Plant power production, MWe gross (w/o CCS) per Power Unit	300
1.5	Power Plant power production, MWe net (w/o CCS) per Power Unit	
1.6	Number of Power Units to be equipped with Carbon Capture Unit(s)	1 (concept 1); 1 + GT (concept 2)
1.7	Number of Carbon Capture units per Power Unit	1 (concept 1); 1 for AUSC + 1 for GT (concept 2)
1.8	Total number of Carbon Capture units for all Power Units together	1 (concept 1) 1 for AUSC + 1 for GT (concept 2)
1.9	Type of fuel (coal, natural gas, etc.)	coal (concept 1); coal + natural gas (concept 2)
1.10	SCR installed (Yes/No)	assumed for AUSC flue gas: • SCR, which reduces NOx, upstream of air preheater • NID, which reduces SO2, SO3 and particulates (dust)
1.11	Particulate collection installed (ESP, fabric filter, etc.)	
1.12	SO3 control installed (lime injection, WESP, etc.)	
1.13	SO2 control installed (WFGD, etc.)	
1.14	CO_2 capture efficiency	90 %
1.15	Average full load operating hours per year (for yearly consumptions/productions calculations)	5000
1.16	Plant availability in hours per year	8000
1.17	Specific local design requirements e.g. piling, EHS, seismicity, etc.?	n.a.
1.18	Potential plant integration e.g. DCS, control room, switch room, etc. or standalone plant	no separate DCS, control room, switch room, etc. for CCS plant

4.2 Units of Measure

	Parameter	Units
	Temperature	°C
	Pressure	bara
	Vacuum pressure	mbara
	Weight (mass)	kg
	Volume, liquids	m^3
	Volume, gases,	actual m^3
	Volume, gases, norm	Nm^3 [at 0 °C and 1013 mbara]
	Flow, liquids	m^3/h, kg/h
	Flow, gases	m^3/h, kg/h
	Flow, solids	kg/h
	Flow, steam	kg/h
	Heat	kJ
	Power	MW, kW

4.3 Flue Gas to Carbon Capture Plant (CCP) - per Power Plant unit

<u>For Coal FIRST:</u>

- to be provided for both, Concept 1 (Base Concept) and Concept 2 (with GT) for each load point requested to be investigated
- Note: Data to be provided at interface point/battery limit (BL) to Carbon Capture Plant (CCP).

	Parameter	**Units**	**Design Value**
3.1a	Description of interface point (BL connection point) proposed by Customer	- downstream of AQCS for power plant (concept 1 and 2) and Flue Gas Blower - 103 % of guarantee rate, VWO – design case	
3.2a	Gas flow rate to Carbon Capture Plant	kg/h wet	1,075,084
3.3a	Gas flow rate to Carbon Capture Plant	Nm^3/h wet	836,724
3.4a	Temperature at interface point	°C	80

3.5a	Pressure at interface point	bara	1.000
3.6a	Composition		
	O_2	vol %, wet	3.5
	N_2	vol %, wet	69
	Argon	vol %, wet	---
	H_2O	vol %, wet	14.4
	CO_2	vol %, wet	13.1
	SO_2	ppmv wet	14
	SO_3	ppmv wet	0.3
	NO	ppmv wet	50
	NO_2	ppmv wet	<2
	NH_3	ppmv wet	<2
	HCl	ppmv wet	<1
	HF	ppmv wet	<1
	Total Particulate Matter	mg/Nm3 wet	10

	Parameter	Units	Design Value
3.1b	Description of interface point (BL connection point) proposed by Customer	- downstream of HRSG for gas turbine (concept 2, only)	
3.2b	Gas flow rate to Carbon Capture Plant	kg/h wet	1,057,680
3.3b	Gas flow rate to Carbon Capture Plant	Nm³/h wet	841,509
3.4b	Temperature at interface point	°C	162.3
3.5b	Pressure at interface point	bara	1.013
3.6b	Composition		
	O_2	vol %, wet	10.92
	N_2	vol %, wet	72.87
	Argon	vol %, wet	0.87
	H_2O	vol %, wet	10.90
	CO_2	vol %, wet	4.44
	SO_2	ppmv wet	0
	SO_3	ppmv wet	0

	NO	ppmv wet	50
	NO_2	ppmv wet	<2
	NH_3	ppmv wet	0
	HCl	ppmv wet	0
	HF	ppmv wet	0
	Total Particulate Matter	mg/Nm3 wet	0

4.4 Treated Flue Gas from Carbon Capture plant (per Power plant Unit)

	Parameter	Units	Design Value
4.1	Description of interface point (BH connection point) proposed by Customer	- downstream of CCP emission control system for power plant (concept 1 and 2) - downstream of CCP emission control system for gas turbine (concept 2, only)	
4.2	Pressure at interface point	bara	1.000
4.3	Composition/emissions (in case max. allowed limits are defined)		
	Amines	mg/Nm^3 dry	no special requirements
	NH3	mg/Nm^3 dry	no special requirements
	Amine degradation products	mg/Nm^3 dry	no special requirements
	Other?	mg/Nm^3 dry	

4.5 CO_2 Product Specification

	Parameter	Units	Design Value
5.1	Use of CO_2 product (saline aquifer, EOR, utilization, other?)	Enhanced Oil Recovery (EOR)	
5.2	Description of interface point (BH connection point) proposed by Customer	downstream of CO2 compression and aftercooling (concept 1 and 2)	
5.3	Temperature at interface point	°C	40
5.4	Pressure at interface point	bara	120
5.5	Requested composition		
	CO_2	vol %, dry	min. 99.0

	N_2	ppm-mol, wet	N2 and Ar together < 10,000
	Argon	ppm-mol, wet	
	H_2O	ppm-mol, wet	max. 50
	O_2	ppm-mol, wet	max. 100
	NH_3	ppm-mol, wet	n.a.
	Amines	ppm-mol, wet	n.a.
	Glycol	ppm-mol, wet	n.a.
	Other?	ppm-mol, wet	n.a.

4.6 Flue Gas Condensate from Carbon Capture plant (per Power Plant)

	Parameter	Units	Min. Value	Max. Value	Design Value
6.1	Description of interface point (BH connection point) proposed by Customer	downstream of condensate pump flow control valve; condensate tank ISBL of power plant			
6.2	Temperature at interface point	°C			< 50
6.3	Pressure at interface point	bara			5.0
6.4	Any composition restrictions?				

4.7 Reserved

4.8 Steam Supply

(If steam is available, provide the following info and properties)

	Parameter	Units	Min. Value	Max. Value	Design Value
8.1	Description of interface point (BH connection points) proposed by Customer	downstream of de-superheating station			
8.2	Temperature at interface point	°C	147	160	approx. 5 °C superheated, i.e. T = Tsat (@ 3.8 bara) 142 °C + 5 °C = 147 °C
8.3	Pressure at interface point	bara	3.8	4.5	3.8 bara @ BL CCP

					(assuming FCV; FI on CCP part)

4.9 Steam Condensate

For Coal FIRST:

- If required condensate return conditions are different for Concept 1 (Base Concept) and Concept 2 (with GT), please provide the conditions for both concepts.

(for condensate return, provide the following info and properties)

	Parameter	Units	Min. Value	Max. Value	Design Value
9.1	Description of interface point (BH connection points) proposed by Customer for condensate	downstream of steam condensate pump flow control valve			
9.2	Temperature at interface point	°C			137
9.3	Pressure at interface point	bara			7.0

4.10 Cooling Water

	Parameter	Units	Min. Value	Max. Value	Design Value
10.1	Description of interface point (BL connection point) proposed by Customer	at battery limit of CCP site			
10.2	Type (sea water, river water, cooling tower, closed loop CW, etc.)	cooling water			
10.3	Temperature - supply at interface point	°C		n.a.	15,6
10.4	Temperature - return (if return temp has a constraint) at interface point	°C			25.6
10.5	Max. allowed overall CW temperature difference between supply and return (if limited)	°C			10
10.6	Supply pressure at interface point	bara			5.0
10.7	Allowable pressure drop between supply and return	bar			1.5
10.8	Available flow rate- if restricted	t/h			n.a.

4.11 Electric Power

	Parameter	Units	Design Value
11.1	Description of interface point (BH connection point) proposed by Customer	at battery limit of CCP site	
11.2	Voltage	V	
11.3	Amperage	A	

4.12 Site/Climate conditions

	Parameter	Units	Min. Value	Max. Value	Design Value
12.1	Barometric pressure	bara			1.01
12.2	Ambient temperature	°C		n.a.	15
12.3	Relative humidity	%			60

4.13 Storage requirements

	Parameter	Design Value
13.1	Storage requirements in days for chemicals?	30

4.14 Plot space

	Parameter	Units	Min. Value	Max. Value	Design Value
14.1	Plot space will be estimated for AAP plant, inside battery limits including all required process equipment as well as storage tanks and loading/unloading facilities (subject to confirmation by detailed process design); Scope (ISBL facilities)/Terminal points according to definition in Carbon Capture Ready study. The space requirement is estimated under the assumption, that the available plot space area is located close to the tie-ins into the flue gas duct downstream the FGD and suitably shaped to allow a reasonable	m^2			no limitation - greenfield

	arrangement of the CCP equipment as typical for chemical plants; e.g. adjacent rectangular shaped area(s) of reasonable widths and lengths				

The following Exhibits 1-5 were taken from the original RFP for this Coal FIRST project.

Exhibit 1: Site characteristics

Parameter	Value
Location	Greenfield, Midwestern U.S.
Topography	Level
Size (Pulverized Coal), acres	300
Transportation	Rail or Highway
Ash Disposal	Off-Site
Water	50% Municipal and 50% Ground Water

Exhibit 2: Site ambient conditions

Parameter	Value
Elevation, (ft)	0
Barometric Pressure, MPa (psia)	0.101 (14.696)
Average Ambient Dry Bulb Temperature, °C (°F)	15 (59)

Average Ambient Wet Bulb Temperature, °C (°F)	10.8 (51.5)
Design Ambient Relative Humidity, %	60
Cooling Water Temperature, °C (°F)[A]	15.6 (60)
Air composition based on published psychrometric data, mass %	
N_2	72.429
O_2	25.352
Ar	1.761
H_2O	0.382
CO_2	0.076
Total	100.00

The cooling water temperature is the cooling tower cooling water exit temperature. This is set to 8.5°F above ambient wet bulb conditions in ISO cases.

Exhibit 3: Design coal – Sub-Bituminous

Rank/Seam	**Sub-Bituminous/Montana Rosebud**	
Proximate Analysis (weight %)[A]		
	As Received	**Dry**
Moisture	25.77	0.00
Ash	8.19	11.04
Volatile Matter	30.34	40.87
Fixed Carbon	35.70	48.09
Total	100.00	100.00
Sulfur	0.73	0.98
HHV, kJ/kg (Btu/lb)	19,920 (8,564)	26,787 (11,516)
LHV, kJ/kg (Btu/lb)	19,195 (8,252)	25,810 (11,096)
Ultimate Analysis (weight %)		
	As Received	**Dry**
Moisture	25.77	0.00
Carbon	50.07	67.45

Hydrogen	3.38	4.56
Nitrogen	0.71	0.96
Chlorine	0.01	0.01
Sulfur	0.73	0.98
Ash	8.19	10.91
Oxygen	11.14	15.01
Total	100.00	100.00

Exhibit 4: Natural gas characteristics

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
Methanethiol[A]	CH_4S	5.75×10^{-6}
	Total	100.00
	LHV	**HHV**
kJ/kg (Btu/lb)	47,454 (20,410)	52,581 (22,600)
MJ/scm (Btu/scf)	34.71 (932)	38.46 (1,032)

[A]The sulfur content of natural gas is primarily composed of added Mercaptan (methanethiol, CH_4S) with trace levels of H_2S. Note: Fuel composition is normalized and heating values are calculated.

Exhibit 5: MATS and NSPS emission limits for PM, HCl, SO_2, NOx, and Hg

Pollutant[A]	PC limits (lb/MWh-gross)
SO_2	1.00
NOx	0.70
PM (Filterable)	0.09
Hg	$3x10^{-6}$
HCl	0.010

5. Inventory of Commercial Equipment

The proposed small-scale flexible advanced ultra-supercritical coal-fired power plant with integrated carbon capture includes the following components:

- Boiler/AQCS island, Vendor: General Electric
    - Once-through AUSC pulverized coal-fired boiler in a close-coupled configuration with SH, RH, Economizer, Waterwalls and Separator
    - Start-up System
    - PA,FD and ID fans
    - Regenerative air preheater
    - SSC (submerged scraper conveyer)
    - Bowl Mills
    - Ultra-Low NOx Tangential Firing System
    - Scanning system
    - Selective Catalytic Reduction system (SCR)
    - Novel Integrated Desulfurization (NID™) dry FGD/fabric filter system
- Steam Turbine Island, Vendor: General Electric
    - HP turbine module
    - IP turbine module
    - LP turbine module
    - Main steam stop & control valve
    - Reheat stream stop & control valves
    - Bearing pedestals
    - Generator
- Balance of Plant by AECOM including:
    - Condenser and condensate pump

    - Deaerator
    - Boiler feed pump
    - Low pressure (LP) and high pressure (HP) feedwater heaters
    - Coal and Ash Handling Systems
    - DCS
    - Electrical Equipment including Transformers and switchgear
    - MCC
    - Civil and Site Infrastructure
    - Waste Water, Cooling Water, Instrument and Service Air and Water
- Integrated Carbon Capture System Block, Vendor: Baker Hughes General Electric
    - Flue Gas Handling System
        - Flue Gas Cooler
        - Flue Gas Cooler Exchanger
        - Axial Booster Fan
    - CO2 Absorption System
        - CO2 Absorber
        - Absorber Water Wash Cooler
        - Lean Solution Cooler
    - Regeneration System
        - Regenerator Column
        - Regenerator Water Wash Cooler
        - Rich/Lean Solution Exchangers
        - Regenerator Reboiler
    - CO2 Compression and Dehydration
        - CO2 Compressor
        - CO2 Dryer Skid
    - Solvent Filtration and Reclamation System
        - Solvent Solution Filter System
        - Solvent Reclaimer Unit
    - Tanks
        - Solvent Storage Tank
        - Auxiliary Storage Tank
        - Chemical Storage Tanks
        - Anti-Foam Tote
        - Solvent Drain Tank
        - Make-up Water Tank
    - Various drums, pumps and heat exchangers

6. Assessment of Available Data for Commercial Equipment

GE and BHGE has design experience for all the equipment listed in section 5. All equipment listed can be selected to operate within the required operating range. Further development needed is noted in section 7. Finalized input data such as final site location, elevation, site conditions, final coal analysis and range, and start-up fuels will need to be determined in a later phase.

7. Equipment Requiring R&D

GE is a leader in the design of pulverized coal fired boilers ranging in capacity from 100,000 lbs/hr at 250 psig to over 7,000,000 lbs/hr and pressures exceeding 5000 psig. Final outlet steam temperatures of up to 1200 F have been attempted in the past. This experience has demonstrated the need for improved materials and the development of an improved boiler design that is robust and flexible.

The plant concept proposed is based on a foundation of established technologies within GE for both boilers and steam turbines. Nevertheless, the application of these technologies in the proposed configuration, for the foreseen steam parameters and at the anticipated scale, represents an innovative step forward for which the following boiler and steam turbine development work is required.

This innovative, small flexible AUSC boiler design presents many challenges. Development work will be needed on the fluid cooled boiler enclosure to incorporate the advanced OFA system and its effects on the heat absorption in the furnace. The boiler design will use a spiral/vertical water wall arrangement in a more compact design to ensure uniform heat absorption, uniform outlet temperature distribution, and uniform thermal expansion that will allow fast startups and rapid load swings. Additional work would be needed to incorporate high-grade materials into the water wall fin welded membranes to address the pressures and temperatures of the AUSC boiler.

Similarly, work is needed on header, terminal tube and interconnecting link design and arrangement. For example, increasing the number of links between heat exchanger sections reduces the OD and thickness of the links and headers making them more flexible during rapid changes in firing rate. The ultra, high temperature finishing steam sections will need to be studied to determine the best means of support for flexibility and any possible “corrosion resistant” arrangements.

Steam Turbine Components Requiring R&D

Component	Development
Turbine Train	– Water steam cycle optimization, including requirement and location of extractions, also covering carbon capture requirements. – Overall performance determination for optimized cycle using finalized steam paths. – Rotor dynamics feasibility for optimized reaction technology blade paths – Thermal expansion determination at elevated temperatures; confirmation of axial bearing location
HP & IP valves	– New valve design at small size with advanced materials, based on standard USC designs. – Redesign of internals with advanced materials. – Lifetime verification.
HP & IP turbines	– Blade path layout for defined steam conditions – Module redesign for small size with advanced materials, including lifetime verification.
Advanced Sealing	– For better sealing efficiency and lower steam excitation forces
Materials	– Extension of MarBN to forged applications

GE is a leader in the development of both cleaner coal technologies and Air Quality Control Systems, and is at the forefront of the development of carbon capture technology advancements. GE has designed and constructed 13 CO_2 Capture and Storage Solutions (CCS) demonstration projects around the world. These technologies are ready for large-scale implementation.