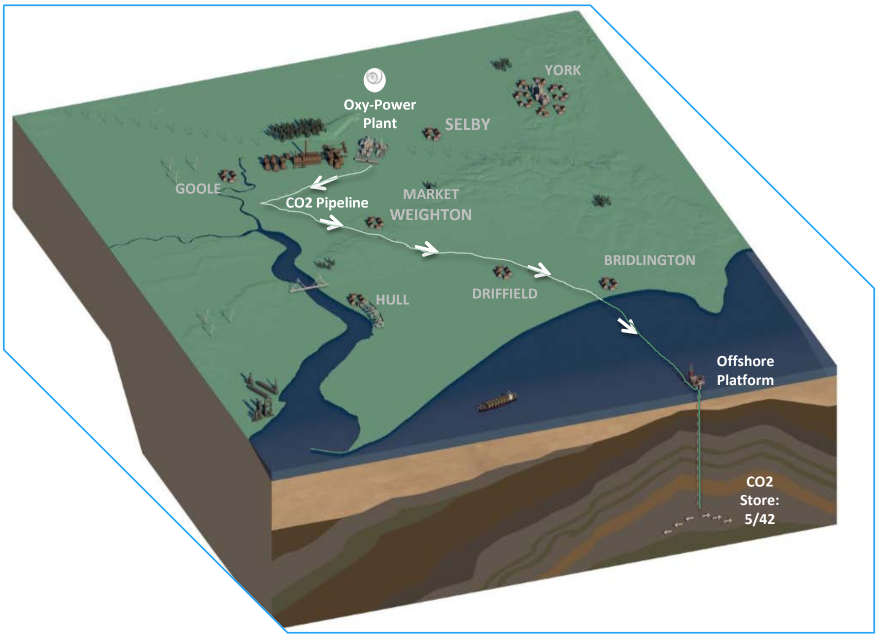
November 2015

K23: Full Chain Heat & Material Balances

Category: Technical: Full Chain



Contents

Chapter	Title	Page
Executive Summary		i
1	Introduction	1
2	Heat & Material Balances	2
3	Glossary	18

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Glossary or Key Words

Key Work	Meaning or Explanation
Carbon Dioxide	A greenhouse gas produced during the combustion process
Carbon Capture and Storage	A technology which reduces carbon emissions from the combustion based power generation process and stores it in a suitable location
Coal	The fossil fuel used in the combustion process for White Rose
Dense Phase	Fluid state that has a viscosity close to a gas while having a density closer to a liquid Achieved by maintaining the temperature of a gas within a particular range and compressing it above a critical pressure
Full Chain	A complete CCS system from power generation through CO_2 capture, compression, transport to injection and permanent storage
Heat and Mass Balance	Heat and mass balance/heat and materials balance is a document produced by process design engineers while designing a process plant. A heat and mass balance sheet represents every process stream on the corresponding process flow diagram in terms of the process conditions.
Key Knowledge	Information that may be useful if not vital to understanding how some enterprise may be successfully undertaken
Storage	Containment in suitable pervious rock formations located under impervious rock formations usually under the sea bed
Transport	Removing processed CO_2 by pipeline from the capture and process unit to storage
Operation	Utilising plant/equipment to produce/provide the designed output commodity/service
Operating Mode	The method of operation of the OPP, which can operate in air or oxy-firing mode
Oxy Boiler	The boiler within the OPP capable of producing full load in either the air or oxy-fired mode of operation
Oxy-firing	The use of oxygen (instead of air) in the combustion process
Oxyfuel	The technology where combustion of fuel takes place with oxygen replacing air as the oxidant for the process, with resultant flue gas being high in CO_2
Oxy Power Plant	A power plant using oxyfuel technology
Process Flow Diagram	Process Flow Diagram (PFD) is a drawing which describes the process flow for a processing plant. PFD is used to capture the main process equipment and main process streams in a single drawing.
White Rose	The White Rose Carbon Capture and Storage project

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Figures

Figure 1.1: Full Chain Schematic Diagram 1
Figure 2.1: Full Chain Block Flow Diagram and Overall Stream Summary 3

Tables

Table 2.1: Water Steam Cycle system 4
Table 2.2: Air, Oxygen, CO_2 and Flue gas system 5
Table 2.3: Auxiliary Steam system 6
Table 2.4: Main Cooling Water system 7
Table 2.5: Raw and Demineralised Water system 8
Table 2.6: Waste Water system 9
Table 2.7: Light Fuel Oil system 10
Table 2.8: Electrostatic Precipitator system 11
Table 2.9: De-ashing system 12
Table 2.10: Flue Gas Desulphurisation system 13
Table 2.11: Gas Processing Unit system 14
Table 2.12: Selective Catalyst Reducer system 15
Table 2.13: Air Separation Plant 16
Table 2.14: Transport & Storage System 17

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Executive Summary

The Full Chain Heat and Mass Balances were generated as part of the Front End Engineering Design (FEED) contract with the Department of Energy and Climate Change (DECC) for White Rose, an integrated full-chain Carbon Capture and Storage (CCS) Project. This document is one of a series of Key Knowledge Deliverables (KKD) from White Rose to be issued by DECC for public information.

White Rose comprises a new coal-fired ultra-supercritical Oxy Power Plant (OPP) of up to 448 MWe (gross) and a Transport and Storage (T&S) network that will transfer the carbon dioxide from the OPP by pipeline for permanent storage under the southern North Sea. The OPP captures around 90% of the carbon dioxide emissions and has the option to co-fire biomass.

Delivery of the project is through Capture Power Limited (CPL), an industrial consortium formed by General Electric (GE), BOC and Drax, and National Grid Carbon Limited (NGC), a wholly owned subsidiary of National Grid.

This report provides the Process Flow Diagrams covering the Full CCS Chain.

This document should be read in conjunction with the following documents:

- K.22 - Full Chain Process Flow Diagrams;
- K.24 - Full Chain Equipment List;
- K.27 - OPP - Process Description;
- K.29 - Transport - Process Description;
- K.30 - Storage - Process Description; and
- K.35 - Onshore Pipeline Route Plans Report.

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

1 Introduction

The White Rose Carbon Capture and Storage (CCS) Project (White Rose) is an integrated full-chain CCS project comprising a new coal-fired Oxy Power Plant (OPP) and a Transport and Storage (T&S) network that will transfer the carbon dioxide from the OPP by pipeline for permanent storage under the southern North Sea.

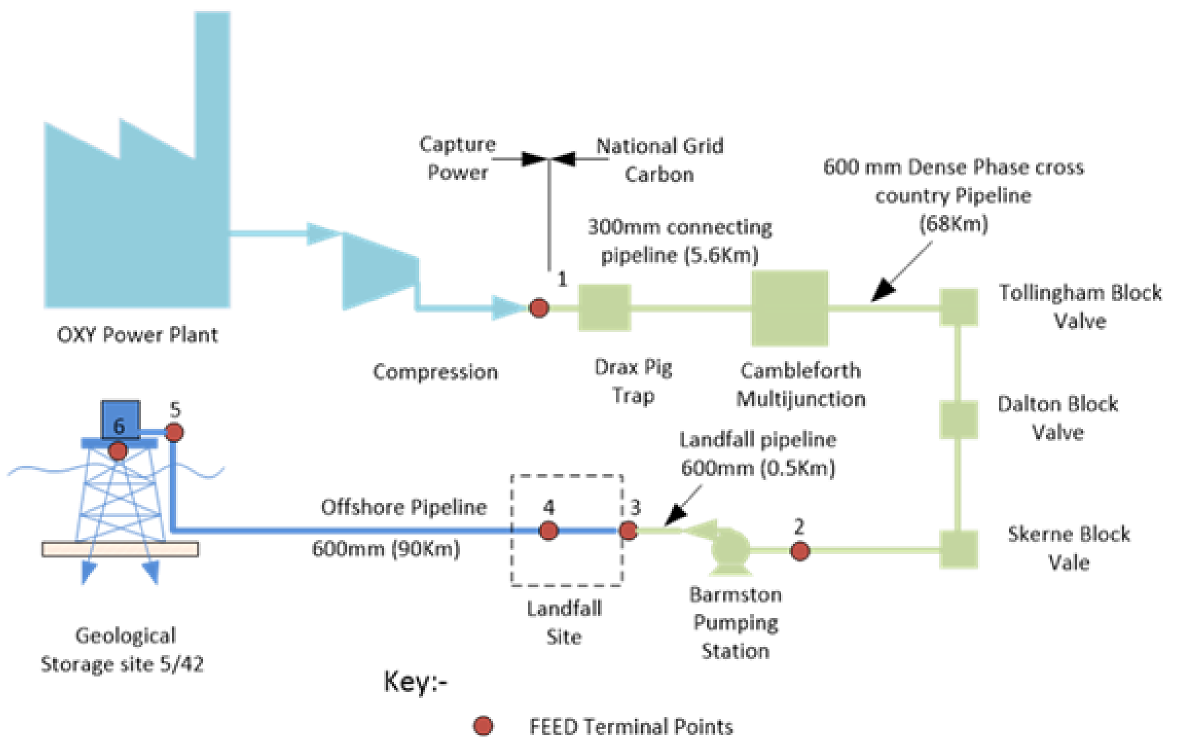
The OPP is a new ultra-supercritical power plant with oxyfuel technology of up to 448 MWe gross output that will capture around 90% of carbon dioxide emissions and also have the option to co-fire biomass.

One of the first large scale demonstration plants of its type in the world, White Rose aims to prove CCS technology at commercial scale as a competitive form of low-carbon power generation and as an important technology in tackling climate change. The OPP will generate enough low carbon electricity to supply the equivalent needs of over 630,000 homes.

White Rose is being developed by Capture Power Limited, a consortium of GE, BOC and Drax. The project will also establish a CO_2 transportation and storage network in the region through the Yorkshire and Humber CCS pipeline being developed by National Grid Carbon Ltd (NGC).

The Full Chain and its component parts (see Figure 1.1) are designed to be operated such that the target of two million tonnes of CO_2 per year can be safely stored.

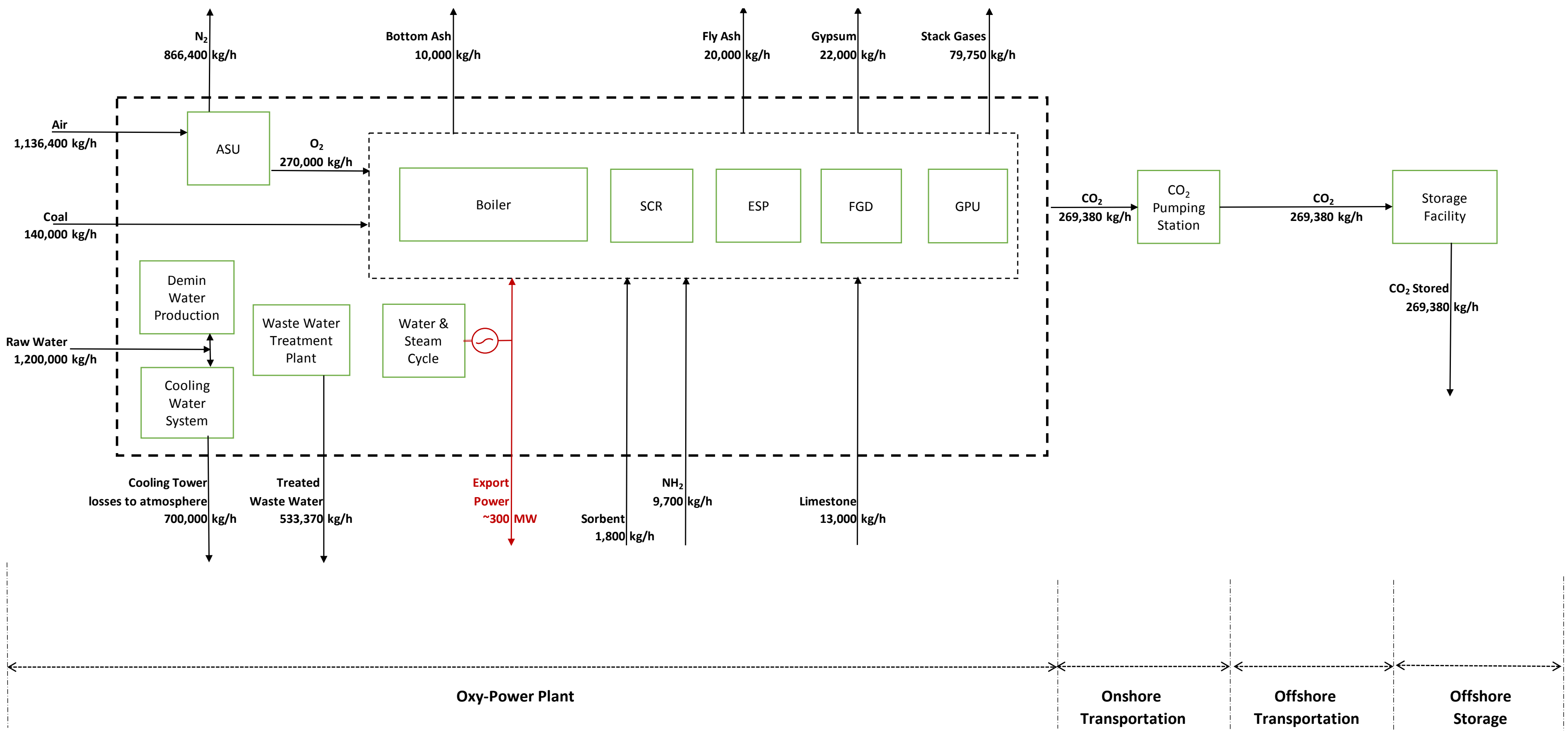
Figure 1.1: Full Chain Schematic Diagram



2 Heat & Material Balances

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Figure 2.1: Full Chain Block Flow Diagram and Overall Stream Summary



The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.1: Water Steam Cycle system

Stream Numbers	Units	11-A	11-B	11-C	11-D	11-E	11-F	11-G	11-H	11-I	11-J	11-K
Phase		Gas	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Gas	Gas	Gas
Fluid description		LP Steam Turbine exhaust	Condensate water Extraction	Condensate to LP Heaters	Cold Condensate to ASU Heat Integration	Hot Condensate from ASU Heat Integration	Hot Condensate at FWT inlet	Feedwater at FWT Outlet	Feedwater at Boiler Inlet	Steam at HP Turbine Inlet	Cold Reheat Steam at HP Turbine Outlet	Hot Reheat Steam at IP Turbine Inlet
Pressure	bar a	~ 0	10	40	40	30	22	22	310	260	52	50
Temperature	°C	30	30	30	30	150	170	220	300	600	350	620
Mass Flow	kg/s	200	210	140	70	70	290	315	315	315	260	260
Enthalpy	kJ/kg	2300	120	130	130	630	720	930	1350	3500	3000	3700
Density	kg/m^3	0.03	996	997	997	920	900	840	780	74	20	12
Main components		Steam	Water	Water	Water	Water	Water	Water	Water	Steam	Steam	Steam

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.2 Steam and Water Cycle system

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.2: Air, Oxygen, CO_2 and Flue gas system

Stream Numbers	Units	12-A	12-B	12-C	12-D	12-E	12-F	12-G	12-H	12-J	12-K	12-L	Air Mode 12-C Note 1	Air Mode 12-M Note 1
Phase		Solid	Gas	Gas + Solid	Gas	Gas	Gas	Gas	Gas	Gas	Gas	Liquid	Gas+ Solid	Gas
Fluid description		Coal to coal mills Notes 2 & 3	Oxygen from ASU	flue gas to ESP (Oxy mode)	Flue gas from ID Fan	Flue gas from FGD	GPU Vent to Stack Note 4	Flue gas to DCC	Flue gas to GPU	secondary air / oxidant	primary air / oxidant	CO_2 Note 5	Flue gas to ESP (Air Mode)	Flue gas to Stack (Air Mode)
Pressure	bar g	close to atmospheric	0.3	close to atmospheric	close to atmospheric	close to atmospheric	close to atmospheric	close to atmospheric	close to atmospheric	close to atmospheric	close to atmospheric	105 Note 6 (135 max)	close to atmospheric	close to atmospheric
Temperature	°C	ambient	25	160	160	70	65	70	25	60	30	20	130	52
Mass Flow	kg/h	140 000	270 000	1 480 000	1 490 000	1 550 000	79 750	864 870	355 240	720 000	380 000	269 380	1 507 400	1 560 000
Density	kg/m^3	992	1.7 (estimated)	1.0 (rounded)	1.1 (rounded)	1.3 (rounded)	1.45 (rounded)	1.3 (rounded)	1.65 (rounded)	1.3 (rounded)	1.7 (rounded)	892	0.9 (rounded)	1.07 (rounded)
Main components		Coal	Oxygen O_2 (96.3%) Ar (3.3%) N_2 (0.4%)	Flue Gas CO_2 (62%) H_2O (24%) N_2 (7.5%) O_2 (3.5%) Ar (2.5%) SOx (0.4%) Ash/Inerts (0.1%)	Flue Gas CO_2 (61.6%) H_2O (23.5%) N_2 (8.4%) O_2 (3.7%) Ar (2.6%) SO_x (0.2%)	Flue Gas CO_2 (56.7%) H_2O (29.9%) N_2 (7.7%) O_2 (3.3%) Ar (2.4%)	Flue Gas CO_2 (25.7%) H_2O (0.2%) N_2 (43.7%) O_2 (18.2%) Ar (12.2%)	Flue Gas CO_2 (56.7%) H_2O (29.9%) N_2 (7.7%) O_2 (3.3%) Ar (2.4%)	Flue Gas CO_2 (77%) H_2O (3.1%) N_2 (11.7%) O_2 (4.9%) Ar (3.3%)	Flue Gas CO_2 (46.5 H_2O (23.5%) N_2 (6.4%) O_2 (21%) Ar (2.6%)	Flue Gas CO_2 (63.4%) H_2O (2.6%) N_2 (9.7%) O_2 (21%) Ar (3.3%)	Liquid CO_2 CO_2 (99.9%) H_2O (<50 ppmv) O_2 (<10 ppmv)	Flue Gas CO_2 (13.3%) H_2O (8.4%) N_2 (74%) O_2 (4%) SO_x (0.2%) Ash/Inerts (0.1%)	Flue Gas CO_2 (12.3%) H_2O (13.5%) N_2 (70%) O_2 (4%) Others (0.1%)

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.3 Air, Oxygen, CO_2 and Flue gas system

Notes:

1. The H&MBs is this document are for oxy mode operation. However, for comparison, stream 12-C (the flue gas ex the boiler SCR to the ESP) is provided for both oxy mode and air mode. In addition stream 12-M, flue gas flow to the stack in air mode is also provided for information. During oxy mode this flow will normally be zero other than during unit start-up and shut down which are performed in air mode.
2. The H&MB is based on Kellingley Coal
3. Coal is provided to the mills and conveyed from there by the primary air / oxidant stream to the boiler. Further details of the arrangement of the coal mills and boiler firing system are given in K27 – OPP Process Description.
4. Further details of trace compositions of pollutants is stream 12-F are provided in K26 – Full chain Effluent and Emissions Summary..
5. The full pipeline entry specification for CO_2 is detailed in K02 – Full Chain Basis of Design..
6. CO_2 discharge pressure from OPP will vary depending on pressure in storage formation (expected to rise as CO_2 is injected) and flowrate (pressure drop) in pipeline.

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.3: Auxiliary Steam system

Stream Numbers	Units	13-A	13-B	13-C	13-D
Phase		Gas	Gas	Gas	Gas
Fluid description		Steam from Auxiliary Boiler (Start-up only)	Steam from boiler and turbine bleeding	Steam to consumers	Steam to ASU
Pressure	bar a	15	15 / 20	20	20
Temperature	°C	300	300	300	200
Mass Flow	kg/s	15	30	30	6
Density	kg/m^3	6	6 / 8	8	3
Main components		Steam	Steam	Steam	Steam

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.4 Auxiliary Steam system

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.4: Main Cooling Water system

Stream Numbers	Units	14-A	14-B	14-C	14-D	14-E	14-F	14-G	14-H	14-I	14-J
Phase		Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Fluid description		Cold main cooling water	Hot main cooling water	MCW to ASU	MCW from ASU	MCW to GPU	MCW from GPU	MCW to CCW	MCW from CCW	MCW to condenser	MCW from condenser
Pressure	bar g	3	2	3	2	3	2	3	2	3	2
Temperature	°C	19	29	19	29	19	27	19	27	19	30
Mass Flow	kg/h	57 000 000	57 000 000	2 500 000	2 500 000	18 000 000	18 000 000	2 000 000	2 000 000	34 500 000	34 500 000
Density	Kg/m^3	998	996	998	996	998	996	998	996	998	996
Main components		Water	Water	Water	Water	Water	Water	Water	Water	Water	Water

Stream Numbers	Units	14-K	14-L	14-M
Phase		Liquid	Liquid	Liquid
Fluid description		vapour losses	blowdown	make up
Pressure	bar g	atmosphere	1	1
Temperature	°C	atmosphere	19	19
Mass Flow	kg/h	700 000	500 000	1 200 000
Density	Kg/m^3	0.5	998	998
Main components		Water	Water	Water

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.5 Main Cooling Water system

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.5: Raw and Demineralised Water system

Stream Numbers	Units	15-A	15-B	15-C	15-D
Phase		Liquid	Liquid	Liquid	Liquid
Fluid description		Raw water inlet	pre-treated water	demineralized water	backwash water
Pressure	bar g	1	1	3	1
Temperature	°C	15	15	15	15
Mass Flow	kg/h	1 200 000 (typical) 1 700 000 (max)	1 100 000	20 000 (typical) 40 000 (max)	3 000 (typical)
Density	kg/m^3	1000	1000	1000	1000
Main components		Water	Water	Water	Water

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.6 Raw and Demineralised Water system

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.6: Waste Water system

Stream Numbers	Units	16-A	16-B	16-C	16-D	16-E
Phase		Liquid	Liquid	Liquid	Liquid	Liquid
Fluid description		Cooling tower blowdown	Treated water & rain water discharge to TP8a	Strom basin (north of Carr Dyke) discharge	Strom basin (south of Carr Dyke) discharge to TP8b	sanitary effluent
Pressure	bar g	1	1	1	2	2
Temperature	°C	15	15	15	15	15
Mass Flow	kg/h	400 000	1 500 000 (max) Note 1	900 000 (max)	130 000 (max)	10 0000
Density	kg/m^3	1000	1000	1000	1000	1000
Main components		Water	Water	Water	Water	Water + Sludge

Refer to K22: Full Chain - Process Flow Diagram – Figures 2.7 & 2.8 Waste Water system

Note 1: Stream 16-B is a combination of treated water from the Waste Water Treatment Plant and rain water from the storm basin which collects water from the site drainage system north of Carr Dyke. The flow of 16-C is variable and dependant on the amount of rainfall, with the storm basin sized to limit the flow to a maximum of 900,000 kg/h. The flow from the Waste Water Treatment Plant is also variable but a typical value of ~ 535,000 kg/h is provided in the overall mass balance in Figure 2-1.

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.7: Light Fuel Oil system

Stream Numbers	Units	17-A	17-B	17-C
Phase		Liquid	Liquid	Liquid
Fluid description		LFO unloading	LFO to boiler	LFO to auxiliaries
Pressure	bar g	2	20	-
Temperature	°C	-	18	18
Mass Flow	t/h	35 000	max flow : 25 000 normal flow : 0	max flow : 10 000 normal flow : 0
Density	kg/m^3	850	850	850
Main components		Fuel Oil	Fuel Oil	Fuel Oil

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.9 Light Fuel Oil system

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.8: Electrostatic Precipitator system

Stream Numbers	Units	18-A	18-B	18-C
Phase		Gas + Solid	Gas	Solid
Fluid description		ESP inlet	ESP outlet	Ash discharge
Pressure	Bar g	close to atmospheric	close to atmospheric	-
Temperature	°C	160	160	160
Mass Flow	kg/h	1 480 000	1 490 000	20 000
Density	kg/m^3	1 (rounded)	1 (rounded)	800
Main components		Flue Gas CO_2 (62%) H_2O (24%) N_2 (7.5%) O_2 (3.5%) Ar (2.5%) SO_x (0.4%) Ash/Inerts (0.1%)	Flue Gas CO_2 (61.6%) H_2O (23.5%) N_2 (8.4%) O_2 (3.7%) Ar (2.6%) SO_x (0.2%)	Ash

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.10 Electrostatic Precipitator system

Note: purge gas flow into ESP not shown in H&MB

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.9: De-ashing system

Stream Numbers	Units	19-A	19-B	19-C	19-D
Phase		Solid	Solid	Solid	Solid
Fluid description		Bottom ash production	Bottom ash emptying rate	Fly ash production	Fly ash emptying rate
Pressure	Bar g	-	-	-	-
Temperature	°C	60	60	160	150
Mass Flow	kg/h	10 000 Note 1	max flow: TBA	20 000	max flow: 100 000
Density	kg/m^3	920	800	800	800
Main components		Ash Water	Ash	Ash	Ash

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.11 De-ashing system

Note 1: Bottom ash contains ~ 35% water

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.10: Flue Gas Desulphurisation system

Stream Numbers	Units	20-A	20-B	20-C	20-D
Phase		Gas	Gas	Solid	Solid
Fluid description		FGD flue gas inlet	FGD flue gas outlet	limestone	Gypsum
Pressure	Bar g	close to atmospheric	close to atmospheric	-	-
Temperature	°C	160	70	ambient	ambient
Mass Flow	kg/h	1 490 000	1 550 000	13 000	22 000
Density	kg/m^3	1.1 (rounded)	1.3 (rounded)	1400	1050
Main components		Flue Gas CO_2 (61.6%) H_2O (23.5%) N_2 (8.4%) O_2 (3.7%) Ar (2.6%) SO_x (0.2%)	Flue Gas CO_2 (56.7%) H_2O (29.9%) N_2 (7.7%) O_2 (3.3%) Ar (2.4%)	Limestone	Gypsum

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.12 Flue Gas Desulphurisation system

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.11: Gas Processing Unit system

Stream Numbers	Units	21-A	21-B	21-C	21-D
Phase		Gas	Gas	Gas	Liquid
Fluid description		Flue gas to DCC	Flue gas to DCC	GPU Vent to Stack	CO_2
Pressure	bar g	close to atmospheric	close to atmospheric	close to atmospheric	105 Note 1 (135 max)
Temperature	°C	70	70	65	20
Mass Flow	kg/h	864 870	864 870	79 750	269 380
Density	kg/m^3	1.3 (rounded)	1.3 (rounded)	1.45 (rounded)	892
Main components		Flue Gas CO_2 (56.7%) H_2O (29.9%) N_2 (7.7%) O_2 (3.3%) Ar (2.4%)	Flue Gas CO_2 (56.7%) H_2O (29.9%) N_2 (7.7%) O_2 (3.3%) Ar (2.4%)	Flue Gas CO_2 (25.7%) H_2O (0.2%) N_2 (43.7%) O_2 (18.2%) Ar (12.2%)	Liquid CO_2 CO_2 (99.9%) H_2O (<50 ppmv) O_2 (<10 ppmv)

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.13 Gas Processing Unit system

Note1: CO_2 discharge pressure from OPP will vary depending on pressure in storage formation (expected to rise as CO_2 is injected) and flowrate (pressure drop) in pipeline.

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.12: Selective Catalyst Reducer system

Stream Numbers	Units	23-A	23-B	23-C	23-D	23-E	23-F
Phase		Gas	Gas	Gas	Gas	Liquid	Vapour
Fluid description		Flue Gas to SO_3 Mitigation Injection Grid Note 1	Gas Flow to the Ammonia Injection Grid	Flue Gas To Selective Catalytic Reduction System Note 2	Flue Gas to Boiler Gas-Gas Heater	SO_3 mitigation injection	NH_3 Injection
Pressure	Bar g	1,005	1,005	1,005	1,002	1,01	0,08
Temperature	°C	351,7	351,7	351,7	351,7	11,1	85
Mass Flow	Kg/h	1 309 900	1 311 700	1 321 400	1 321 400	1 800	9 700
Density	kg/m^3	0,56	0,56	0,56	0,56	921	0,98
Main components		CO_2 (62.8%) H_2O (23.3%) N_2 (7.5%) O_2 (3.3%) Ar (2.7%) SO_2 (0.3%) Ash/Inerts (0.1%)	CO_2 (62.8%) H_2O (23.4%) N_2 (7.5%) O_2 (3.3%) Ar (2.6%) SO_2 (0.3%) Ash/Inerts (0.1%)	CO_2 (62.8%) H_2O (23.4%) N_2 (7.5%) O_2 (3.3%) Ar (2.6%) SO_2 (0.3%) Ash/Inerts (0.1%)	CO_2 (62.8%) H_2O (23.4%) N_2 (7.5%) O_2 (3.3%) Ar (2.6%) SO_2 (0.3%) Ash/Inerts (0.1%)	Na_2CO_3 + H_2O	NH_3+Air

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.14 Selective Catalyst Reducer system

Note 1: SO_3 mitigation reduces SO_3 content from 63 kg/h to 9.5 kg/h (compared to 6 340 kg/h for SO_2)

Note 2: SCR reduces NO_X from 388 kg/h to 78 kg/h

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.13: Air Separation Plant

Stream Numbers	Units	GAP125	GAP170	LO258	GO294	GNP448	GN425	GNP483	LO251	GO 295
Phase		Gas	Gas	Liquid	Gas	Gas	Gas	Gas	Liquid	Gas
Fluid description		Air Note 1	Air Note 1	Liquid Oxygen Note 1	Gaseous oxygen to Boiler Note 1	Gaseous nitrogen Note 1	Gaseous nitrogen Note 1	Gaseous nitrogen Note 1	Liquid Oxygen Note 1	Total gaseous oxygen to Boiler Note 2
Pressure	bar g				0.3					0.3
Temperature	°C				25					25
Mass Flow	kg/h	413 000	155 200	Normally zero	135 000	600	277 500	155 100	Normally zero	270 000
Normal Density*	kg/nm^3	1.293	1.293	1.437	1.439	1.253	1.253	1.253	1.437	1.439
Main components		O_2 (20.96%) Ar (0.93%) N_2 (78.11%)	O_2 (20.96%) Ar (0.93%) N_2 (78.11%)	O_2 (97.6%) N_2+Ar balance	O_2 (96.3%) Ar (3.3%) N_2 (0.4%)	O_2 (0.45%) N_2+Ar balance	O_2 (0.50%) N_2+Ar balance	O_2 (0.45%) N_2+Ar balance	O_2 (97.6%) N_2+Ar balance	O_2 (96.3%) Ar (3.3%) N_2 (0.4%)

Refer to K22: Full Chain - Process Flow Diagram – Figures 2.15 & 2.16 for Air Separation Plant

Note 1: Flow for 1 (of 2x50%) ASU within Air Separation Plant

Note 2: Flow from both ASUs (2x 50%) within Air Separation Plant

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Table 2.14: Transport & Storage System

Stream Numbers	Units	1	2	3	4	5	6	7
Phase		Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Fluid description		Feed Outlet from Drax	Camblesforth Feed Inlet	Combined Feed	Feed Inlet at Feed Inlet	Tolling-ham Outlet	Feed Inlet at Dalton	Dalton Outlet
Pressure (Note 1)	bar g	104.7	103.0	103.0	102.1	102.1	98.5	98.5
Temperature	°C	20.0	18.8	18.8	13.8	13.8	11.4	11.4
Mass Flow (Note 1)	kg/h	305 374	305 374	305 374	305 374	305 374	305 374	305 374
Density	kg/m^3	859	865	865	897	897	908	908
Main components (Note 2)	mol.% CO_2	99.7	99.7	99.7	99.7	99.7	99.7	99.7
Stream Numbers	**Units**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Phase		Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Fluid description		Feed Inlet at Skerne	Skerne Outlet	Inlet to Barmston	CO_2 Pump Suction	CO_2 Pump Discharge (Note 3)	Barmston Meter Outlet	Offshore Reception
Pressure	bar g	102.8	102.8	101.5	101.4	101.4	101.3	98.9
Temperature	°C	10.0	10.0	5.4	5.4	5.4	5.4	3.6
Mass Flow	kg/h	305 374	305 374	305 374	305 374	305 374	305 374	305 374
Density	kg/m^3	920	920	945	945	945	945	953
Main components	mol% CO_2	99.7	99.7	99.7	99.7	99.7	99.7	99.7

Refer to K22: Full Chain - Process Flow Diagram – Figure 2.18 to Figures 2.21 for Transport & Storage System

Note 1: The H&MB & associated pressure profile for the T&S reflect the "design", i.e. maximum, CO_2 flowrate from the OPP. This value is based on the highest CO_2 producing coal along with biomass co-firing plus a 5% margin. The resulting value of 305.374 kg/h gives significant margin over the expected CO_2 flowrate from OPP of 269 380, based on firing Kellingley coal only, as presented in the OPP H&MB.

Note 2: The H&MB & associated pressure profile for the T&S are based on an initial estimated CO_2 composition of 99.7% CO_2. During FEED the CO_2 composition ex the OPP was confirmed as 99.9%. No significant impact on the H&MB is foreseen. The pipeline entry specification has a minimum CO_2 content of 96% (as detailed in K02).

Note 3: For the expected flowrates during the first 5 years of operation, the flow assurance work (see K34 – Flow Assurance) has shown that the booster pumps at the Barmston Pumping Station are not expected to operate as the pressure generated at the OPP will be adequate to ensure sufficient pressure at the offshore platform for injection to storage.

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

3 Glossary

Abbreviations	Meaning or Explanation
Ar	Argon
ASU	Air Separation Unit
bar a	Pressure in bar (1 bar = 100 000 Pa) above complete vacuum
bar g	Pressure in bar (1 bar = 100 000 Pa) above atmospheric pressure
C	Degrees Celsius
CCS	Carbon Capture and Storage
CCW	Closed Circuit Cooling Water
CO_2	Carbon Dioxide
CPL	Capture Power Limited
DCC	Direct Contact Cooler
DECC	The UK Government's Department of Energy and Climate Change
Dense Phase	Fluid state that has a viscosity close to a gas while having a density closer to a liquid. Achieved by maintaining the temperature of a gas within a particular range and compressing it above its critical pressure.
ESP	Electrostatic Precipitator
FEED	Front End Engineering Design
FGD	Flue Gas Desulphurisation
FWT	Feedwater Tank
GE	General Electric
GPU	Gas Processing Unit – processes the flue gases to provide the dense phase carbon dioxide
H&MB	Heat and Mass Balance
HP	High Pressure
H_2O	Water
ID	Induced Draft
IP	Intermediate Pressure
kg/h	Kilogrammes per hour
kg/m^3	Kilogrammes per cubic meter
kg/s	Kilogrammes per second
kJ/kg	Kilojoules per kilogramme
KKD	Key Knowledge Deliverable
km	Kilometre
LFO	Light Fuel Oil
LP	Low Pressure
MCW	Main Cooling Water
mm	millimetre
$NaCO_3$	Sodium Carbonate
NGC	National Grid Carbon Limited
NH_3	Ammonia
N_2	Nitrogen

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.

Abbreviations	Meaning or Explanation
OPP	Oxy Power Plant
O_2	Oxygen
PFD	Process Flow Diagram
PIG	Pipeline Inspection Gauge: a unit, which is inserted into the pipeline, to clean and/or monitor the inner bore surface of the pipe.
ppmv	Parts per million by volume
SCR	Selective Catalytic Reducer
SO_3	Sulphur Trioxide
SO_x	Sulphur Oxides
t/h	Tonnes per hour
T&S	Transportation and Storage
TP	Terminal Point
WR	White Rose

The contents of this report draw on work partly funded under the European Union's European Energy Programme for Recovery. The European Union is not responsible for any use that may be made of the information contained within this document.