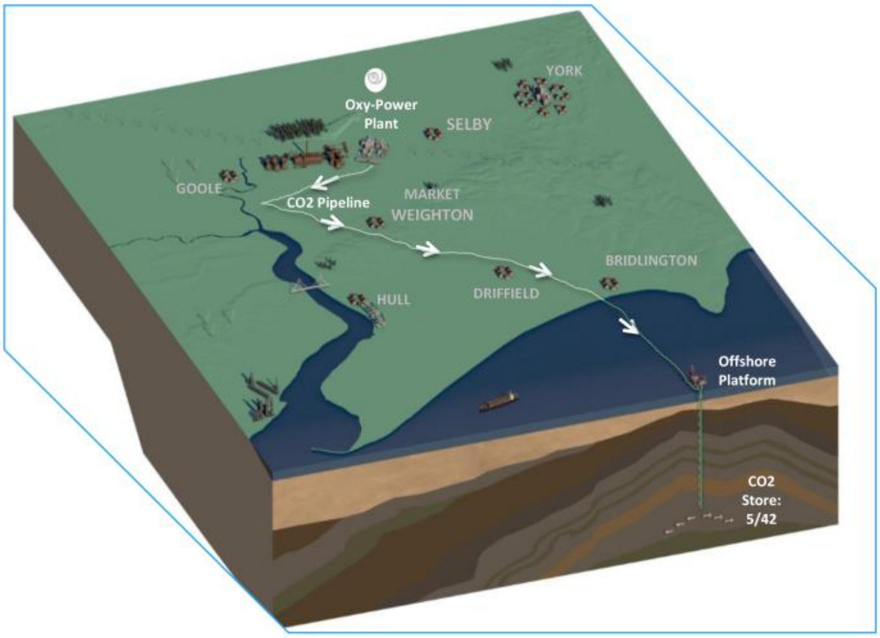
November 2015

K26: Full Chain Effluent Summary

Technical: Full Chain



CAPTURE POWER · drax · BOC A Member of The Linde Group · GE · nationalgrid

Contents

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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, main process streams, process/design conditions in these items of equipment and the basic process control scheme in a single drawing.
White Rose	The White Rose Carbon Capture and Storage project

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Figures

Tables

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Executive Summary

The Full Chain Effluent Summary was 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 a summary description of the effluents and emission, as required by the operating permit for the OPP, and also covering the Full Chain.

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

- K.22 - Full Chain Process Flow Diagrams;
- K.23 - Full Chain Heat and Material Balances;
- K.24 - Full Chain Equipment List;
- K.27 - OPP - Process Description;
- K.29 - Transport - Process Description; and
- K.30 - Storage - Process Description.

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1 Introduction

1.1 Background

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.

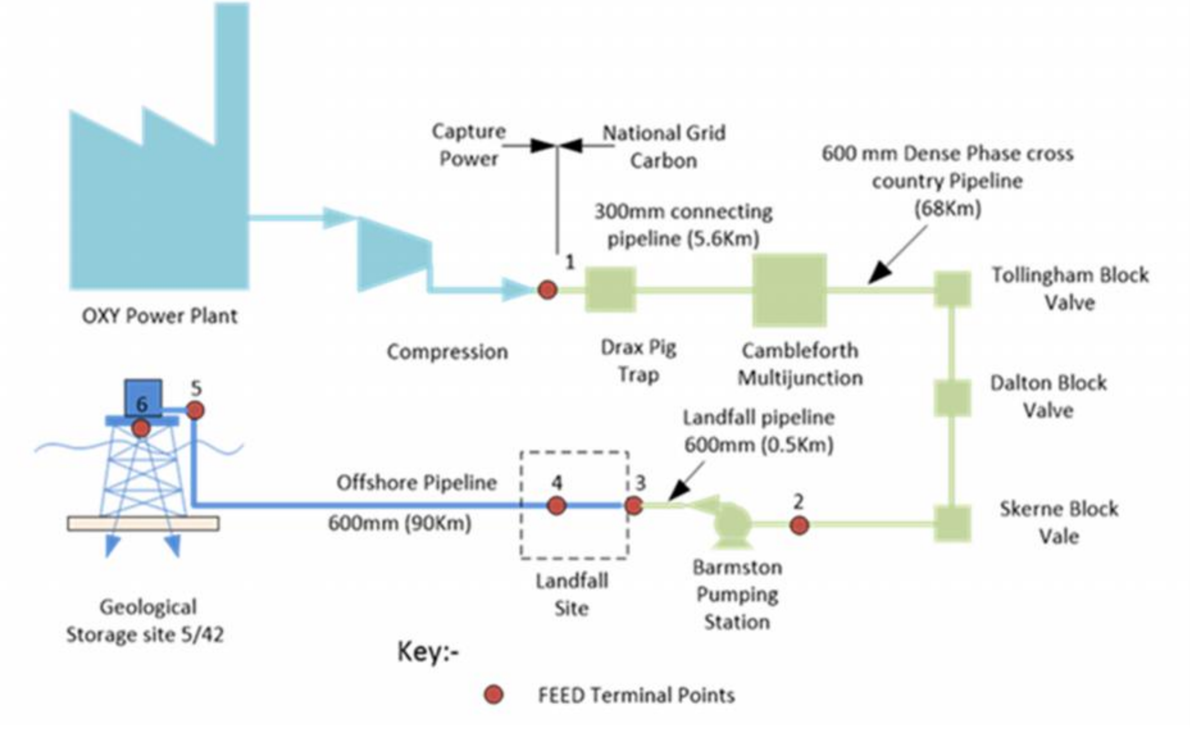
The OPP is a new ultra-supercritical power plant with oxyfuel technology of up to 448 MWe gross output that will capture around 90% of carbon dioxide emissions and also have the option to co-fire biomass.

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



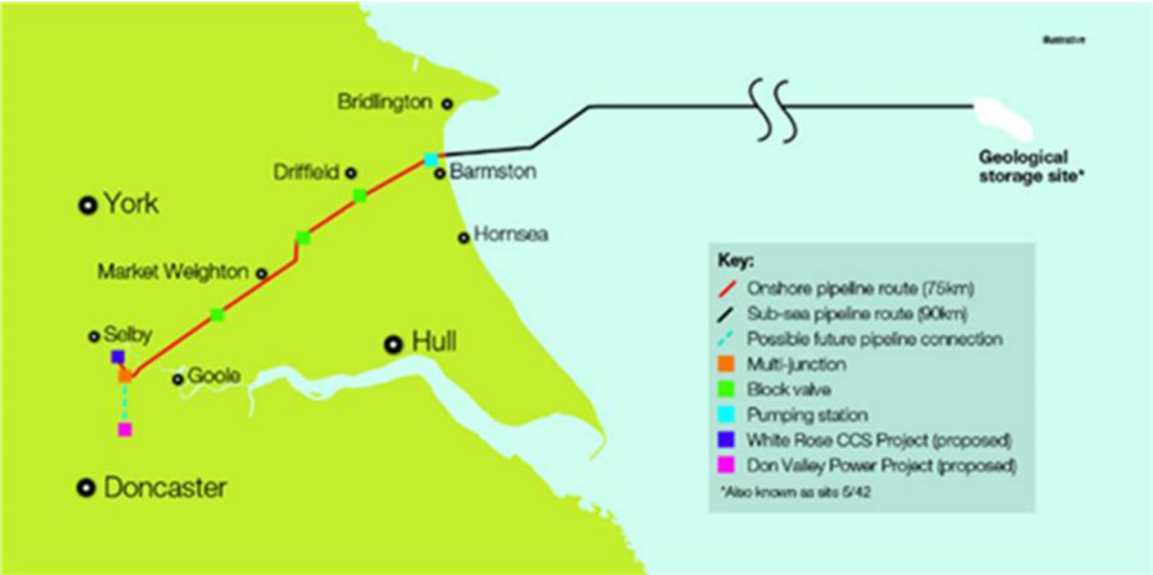
The standalone OPP will be located to the northeast of the existing Drax Power Station site near Selby, North Yorkshire (see Figure 1.2) within the Drax Power Ltd (DPL) landholding and benefits from fuel import and power transmission infrastructure currently in place. The plant will generate electricity for export to the Electricity Transmission Network while capturing approximately 2 million tonnes of CO_2 per year, some 90% of all CO_2 emissions produced by the plant. The CO_2 will be transported by pipeline for permanent undersea storage beneath the North Sea.

Figure 1.2: White Rose CCS Project Artist Impression

The power plant technology, known as oxy-fuel combustion, burns fuel in a modified combustion environment with the resulting combustion gases having a high CO_2 concentration. This allows the CO_2 produced to be captured without the need for additional chemical separation, before being transported for storage.

Figure 1.3 below gives a geographical overview of the proposed CO_2 transportation system.

Figure 1.3: Geographical overview of the transportation facility



White Rose will benefit the UK and continued development of CCS technology by:

- Demonstrating oxy-fuel CCS technology as a cost effective and viable low-carbon technology;
- Reducing CO_2 emissions in order to meet future environmental legislation and combat climate change;
- Improving the UK's security of electricity supply by providing a new, flexible and reliable coal-based low-carbon electricity generation option;
- Generating enough low-carbon electricity to supply the energy needs of the equivalent of over 630,000 households; and
- Acting as an anchor project for the development of a CO_2 transportation and storage network in the UK's most energy intensive region thereby facilitating decarbonisation and attracting new investment.

1.2 Purpose of the Document

This document provides a summary of the Full Chain effluents and emissions and include emissions to air, water and solid waste to landfill.

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2 Discharges from the OPP

2.1 OPP Emissions to Air

There are two points of emissions to air from the OPP, exhaust from the main stack and from the auxiliary boiler stack.

2.1.1 OPP Main Stack

The OPP is provided with a 120 m height stack.

The OPP has two modes of operation;

- oxy-mode which represents the normal operating conditions for the Project;
- air-mode which represents the operational conditions during start-up, shut down and when the T&S system is not available.

The full load emissions to air for each case are shown below:

Table 2.1: OPP Stack emissions in oxy mode and air mode

Emissions	Unit	Air-Mode BMCR	Oxy-Mode BMCR
Sulphur Dioxide	g/s	50.830	0.606
Nitrogen Dioxide	g/s	45.830	1.260
Particulates Matter (PM10)	g/s	3.477	0.250
Carbon monoxide	g/s	83.61	15.00
Hydrogen chloride	g/s	1.769	0.001
Hydrogen fluoride (as F)	g/s	0.110	0.001
Arsenic and compounds (as As)	g/s	0.016	0.008
Cadmium and its compounds (as Cd)	g/s	0.001	0.0005
Chromium, chromium(II) compounds and chromium(III) compounds as Cr	g/s	0.007	0.003
Chromium(IV) compounds as Cr	g/s	0.001	0.0005
Copper dusts and mists (as Cu)	g/s	0.007	0.004
Lead	g/s	3.008	0.004
Mercury and compounds, except mercury alkyls (as Hg)	g/s	0.001	0.0001
Nickel (total Ni compounds in PM10 factor)	g/s	0.020	0.009
Selenium and compounds except hydrogen selenide (as Se)	g/s	1.773	0.082
Vanadium	g/s	0.178	0.006
Ammonia	g/s	0.233	0.139

In oxy-mode, the same quantity of CO_2 and the same or lower quantities of pollutants are produced, however the total quantity of flue gas produced is significantly lower (~25% of air-firing). In addition the oxy-mode flue gas undergoes additional purification and separation to capture the majority of the CO_2. As a result a much smaller flue gas stream consisting of inert gases (argon and nitrogen), unused oxygen,

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uncaptured CO_2 and any remaining pollutants will be emitted via the stack. The flowrate is about 2.5% of the quantity of flue gas emitted during air-firing.

The mass flow rates of emission compounds (SOx, NOx, etc.) to the atmosphere in oxy mode are significantly lower than in the air mode, primarily due to the enhanced removal associated with a large portion of the flue gas being recirculated through the Air Quality Control Systems (AQCS). The emissions modelling, submitted for Environmental Statement in the DCO, has confirmed, despite the potential adverse impacts on the dispersion characteristics of the exhaust plume as a result of lower volume flow rate, that the impact of emissions in oxy mode is lower than in air mode (further details can be found in the White Rose DCO Application ES Volume 2 Chapter A - Emissions to Atmosphere Technical Report at http://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010048/2.%20Post-Submission/Application%20Documents/Environmental%20Statement/6.3.1%20ES%20Volume%202%20Chapter%20A%20-%20Emissions%20to%20Atmosphere%20Technical%20Report.pdf).

However the metrics currently applied for emissions in Europe still link the limit values for the main pollutants (NOx, SOx, CO and particulates) to flue gas volumes (mg/Nm^3) and will therefore need to be reconsidered for the lower stack flowrates for CCS in general and oxy combustion in particular. For White Rose, while the assessed impacts are lower for oxy-mode, if the emissions are expressed on a volume basis (mg/nm^3), as in the EU Industrial Emissions Directive (IED), they would appear higher.

Stack emissions during air mode operation will be in compliance with the IED 2010/75/EU limits shown in the table below.

Table 2.2: Stack Emissions in Air Mode

Stack emissions[1]	Unit	EU Directive Value
SO_2	mg/nm^3, 6% O_2 dry	150
NO_X	mg/nm^3, 6% O_2 dry	150
Particulates Matter (PM)	mg/nm^3, 6% O_2 dry	10

Therefore, to provide a meaningful metric, it is proposed that emission limits for the plant in oxy-mode should be expressed on an energy input basis, as milligrams per Mega-Joule (mg/MJ). This basis allows for an easy correlation and comparison with the air mode emissions. This is currently under discussion with the Environment Agency (EA) through the Environmental Permit application process. The application was first received by the EA in April 2015 and they have set out a provisional timetable for completion which indicates a decision in March 2016.

2.1.2 Auxiliary Boiler

The auxiliary boiler is provided with a 50 m height stack. Emissions must comply with the limits in Table 2.3.

1 Current European directive max acceptable – min to full load

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Table 2.3: Auxiliary Boiler Stack Emissions Limits

Stack emissions[2]	Unit	EU Directive Value
SO_2	mg/nm^3, 3% O_2 dry	175
NO_X	mg/nm^3, 3% O_2 dry	300
Particulates Matter (PM)	mg/nm^3, 3% O_2 dry	15

The auxiliary boiler will be in operation during a cold start-up of the OPP, and could operate for a maximum of 72 hours per start up. Based on the size of the auxiliary boiler (50 MW) emissions to air are calculated as:

Table 2.4: Auxiliary Boiler Emissions to Air

Emissions	Unit	Full Load
Sulphur Dioxide	g/s	2.265
Nitrogen Dioxide	g/s	2.985
Particulates Matter (PM10)	g/s	1.500
Carbon monoxide	g/s	2.235

2.1.3 Flue Gas Desulphurisation Unit

A gaseous stream is emitted from the Flue Gas Desulphurisation (FGD) unit's sulphide oxidation tank. This contains some CO_2 generated in the FGD's sulphur removal process and as such is not covered under the EP.

2.2 Liquid Effluents

There are separate liquid effluent discharge points from the OPP to the north and the south of Carr Dyke.

2.2.1 Terminal Point 8a (north of Carr Dyke)

This discharge combines effluent streams from the following areas of the OPP:

- Raw Water Pre-Treatment;
- Cooling Tower; and
- Waste Water Treatment Plant;

as well as rain water (after oil separation) collected from the north side of Carr Dyke. In order to control the water flow discharge according to the permit the clean rain water is collected and stored in the North storm basin, before being discharged to the river Ouse along with the effluent streams to the interface point with Drax in compliance with Drax's existing Environmental Permit.

The Environmental Permit allows the following:

2 Current European directive max acceptable – min to full load

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Table 2.5: Characteristics of Effluents Discharged from OPP

Parameter	Units	Continuous
Flow	m^3/h	468 (normal) / 650 (max) effluent 1,650 (max – including rainwater return)
pH	-	6 to 9
Temperature	°C	Max 30
Total Ammonia (as Nitrogen)	mg/l	0.5
Cadmium (Cd)	mg/l	0.01
Mercury (Hg)	mg/l	0.005

2.2.2 Terminal Point 8b (south of Carr Dyke)

Clean rain water (after oil separation) from the South of the Care Dyke is collected and stored in the South storm basin, before being discharged to the Carr Dyke.

Flowrate: Min. 0 m^3/h, Max. 130 m^3/h.

2.3 Solid Waste

The following solid waste and by product streams are produced by the OPP.

Table 2.6: OPP Solid Wastes

Solid Waste	Production rate	Comment
Furnace Bottom Ash	Nominal 10.9 t/h (35% moisture) Max. 20.3 t/h wet (35% moisture	Non-hazardous. Exported for sale as building aggregate
Fly Ash	Nominal 19.6 t/h Max. 36.6. t/h	Non-hazardous. Anticipated that majority will be sold for cement production with remainder being sent for disposal on Barlow Mound
Gypsum	Nominal 22.5 t/h	Classed by EA as a by-product (not waste). Exported for production of plaster board
Sludge from waste water treatment plant	Approx. 18 m^3/day (dryness ~ 30 to 40%)	Hazardous waste (principally due to alkalinity) Taken by truck for offsite treatment and disposal
Activated Carbon – mercury removal	90 t/year	Stable non-reactive hazardous waste Taken off site for potential recovery
Desiccant – flue gas driers	55 t (every two years)	Non -hazardous waste Taken off site for potential recovery
SCR catalyst	~180 t (every 5 years)	Harmful to health when in contact with vanadium pentoxide dust.
Ultra-Filtration Membranes	1 set (every three years) Approx. 2x10 modules	Non- hazardous. Membranes cannot be recycled - taken off site for disposal

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Reverse Osmosis Membranes	1 set (every three years) Approx. 2x10 modules	Non- hazardous. Membranes cannot be recycled - taken off site for disposal
Cartridge Filters	~5 sets of each type (every year)	Non- hazardous. Filters cannot be recycled - taken off site for disposal
Ion Exchange Resins	~15 m^3 (every 5 years)	Non- hazardous. Resins cannot be recycled - taken off site for disposal

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3 Discharge from the Transport and Storage System

3.1 Transport System Effluents & Emissions

There are no effluent or emission streams from the Transport System.

3.2 Offshore Storage Effluents & Emissions

The only source of emissions from the offshore platform is the exhaust gases from the diesel generators, which operate continuously delivering power to the platform. The demand on the generators varies depending on whether personnel are on the platform; the platform is expected to be occupied for one seven day week every seven weeks, for eight hours a day.

The estimated emissions can be summarised as follow

Table 3.1: Diesel Generator Combustion Emissions

Equipment	Fuel Demand (l/hr)	Duty (kW)	Annual Operation (hr/yr)	CO_2	NO_x	SO_x	CO (t/yr)	VOCs	PM_{10}	CO_2e
Diesel Generator (unmanned)	12.0	34.4	8396	263.80	7.09	0.47	1.53	0.56	0.50	263.80
Diesel Generator (manned)	40.6	140.0	364	38.81	1.04	0.07	0.22	0.08	0.07	38.81
Wash water Injection Package (maintenance)	29.0	100.0	504	38.40	1.03	0.07	0.22	0.08	0.07	38.40
Crane (manned)	55.0	200.0	364	52.59	1.41	0.09	0.30	0.11	0.10	52.59

3.3 Solid Waste

During normal operation, solid wastes come from the following sources:

- domestic waste from personnel;
- batteries;
- oily rags or other swabbing material;
- filter cartridges;
- medical;
- non-hazardous; and
- hazardous.

The amount of domestic waste for the offshore platform and onshore sites is estimated as follows:

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Table 3.2: Solid Domestic Waste Summary

Location	Mass (t/person/day)	Frequency (day/yr)	Number of Personnel	Mass per Year (t/yr)
Offshore	0.0025	16	12	0.480
Onshore	0.0025	14	2	0.070

Batteries are a significant source of waste on the offshore platform, when expired they are recycled onshore:

Table 3.3: Summary of Battery Waste on the Offshore Platform

Equipment	Mass (t)	Maintenance Period (yr)	Average Battery Waste per Year (t/yr)
Uninterruptible Power Supply Battery Banks	38	20	1.9
Navigation Aids Battery	0.5	20	0.025
Diesel Generator Starter Batteries	0.6	20	0.03
Crane and Lifeboat Engine Starter Batteries	0.2	20	0.01

Note that the life cycle of nickel cadmium cells is up to twenty years.

Pumps do not use a drains system and instead are situated over a drip tray where spills are mopped up with rags and disposed of according to the waste management procedure.

Other waste, such as filter cartridges and medical waste, is minimal.

Non-hazardous waste is recycled or sent to landfill and hazardous waste is disposed of using a suitable waste management contractor.

No waste is left on the unoccupied site.

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4 Glossary

Abbreviations	Meaning or Explanation
AQCS	Air Quality Control Systems
Carbon Capture	Collection of carbon dioxide (CO_2) from power station combustion process or other facilities and its process ready for transportation
CCS	Carbon Capture and Storage
CEMS	Continuous Emissions Monitoring System
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPL	Capture Power Limited
DECC	UK Government's Department of Energy and Climate Change
EA	Environment Agency
FEED	Front End Engineering Design
FEED Contract	CPL have entered into an agreement with the UK Government's DECC pursuant to which it will carry out, among other things, the engineering, cost estimation and risk assessment required to specify the budget required to develop and operate the White Rose assets
Full Chain	The complete process from the capture of the CO_2 at the emitter plant to its injection into the storage reservoir
hr	Hour
Key Knowledge Deliverable	A series of reports Including this one) issued as public information to describe the flows and processes associated with the overall system. Also referred to as a KKD
kW	Kilowatt
l	Litres
mg	milligram
m^3	Cubic metres
MW	Megawatt
N_2O	Nitrous Oxide
NO_x	Generic term for the mono-nitrogen oxides, and nitric oxide (NO) and nitrogen dioxide (NO_2)
NGC	National Grid Carbon Limited
O_2	Oxygen
Oxy-fuel Combustion	A process that burns fuel in a modified combustion environment with the resulting combustion gases being high in CO_2 concentration. This allows the CO_2 produced to be captured without the need for additional chemical separation, before being compressed into dense phase and transported for storage
pH	pH is a measure of how acidic/basic water is. The range goes from 0 - 14, with 7 being neutral. pHs of less than 7 indicate acidity, whereas a pH of greater than 7 indicates a base.
PM_{10}	Particulate Matter up to 10 micrometres in size; air pollution
SF_6	Sulphur Hexafluoride
SO_x	Generic term for the Sulphur Oxides the two major ones being sulphur dioxide (SO_2) and sulphur trioxide (SO_3)
Storage	Containment in suitable pervious rock formations located under impervious rock formations usually under the sea bed
t	Tonnes

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Transport	Removing processed CO_2 by pipeline from the capture and process unit to storage
VOCs	Volatile organic compounds; are organic chemicals that have a high vapour pressure at ordinary room temperature
yr	Year

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