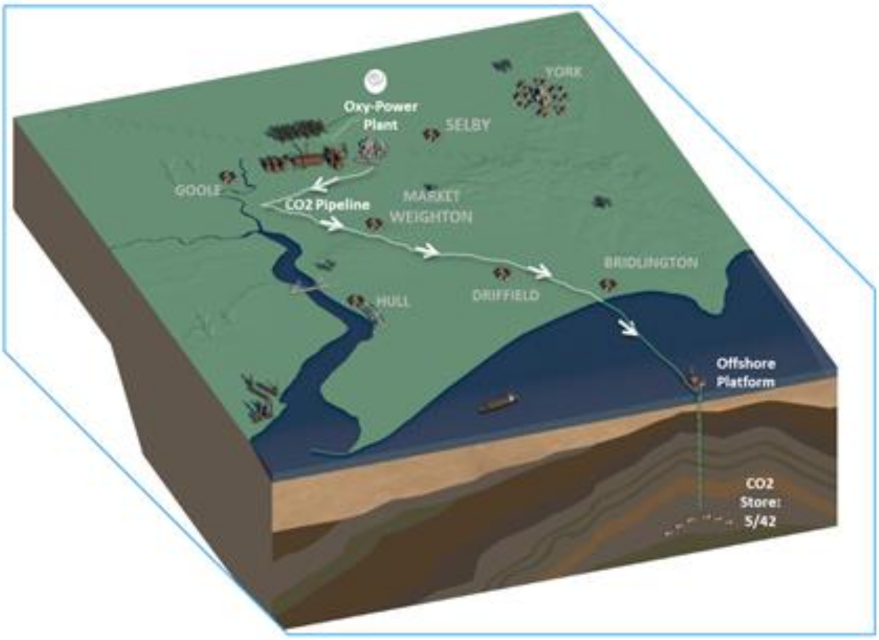
December 2015

K02 Full Chain Basis of Design

Key Knowledge Deliverable, Technical – Full Chain



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Key Words

Key Word	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
Interconnections	Links for supply between existing Drax and Oxy Power Plant (OPP) facilities
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
Maintenance	Preserve the utility of plant/equipment by cleaning or replacing degraded components on a regular schedule or as discovered during routine inspections
White Rose	The White Rose Carbon Capture and Storage project

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Executive Summary

The Full Chain Basis of Design was generated as part of the Front End Engineering Design (FEED) contract with the Department of Energy and Climate Change (DECC) for the White Rose Project (White Rose). 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 is an integrated Full Chain Carbon Capture and Storage (CCS) Project comprising 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 take the carbon dioxide (CO_2) from the OPP and transport it by pipeline for permanent storage under the Southern North Sea. The OPP captures around 90% of the CO_2 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 high level description of the Full Chain Basis of Design (BoD).

The report should be read in conjunction with the following KKD documents:

- K27 – Oxy Power Plant Process Description;
- K29 - Transport Process Description; and
- K30 - 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 take the CO_2 from the OPP and transport it by pipeline for permanent storage under the southern North Sea.

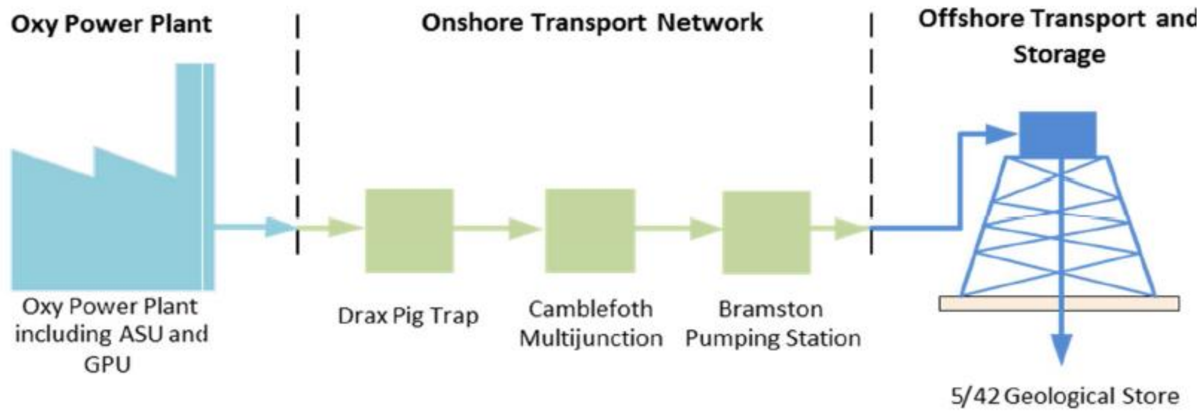
The OPP is a new ultra-supercritical power plant with oxy-fuel technology of up to 448 MWe gross output that will capture around 90% of CO_2 emissions and has the future potential to co-fire biomass.

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 (CPL), a consortium of GE, BOC (a member of the Linde Group) 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, as shown in 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: Key Elements of the Full Chain



Source: CPL

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 Limited (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.

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Figure 1.2: White Rose CCS Project Artist Impression

Source: CPL

CPL is a new company formed by the consortium partners to develop, implement and operate the White Rose CCS Project. Alstom will have responsibility for construction of the power plant together with the CO_2 Gas Processing Unit (GPU) and BOC will have responsibility for the construction of the Air Separation Unit (ASU) that supplies oxygen combustion.

For the T&S elements of the project, NGC will construct and operate the CO_2 transport pipeline and, with partners, the permanent CO_2 undersea storage facilities at a North Sea site.

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

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Figure 1.3: Geographical Overview of the Transportation System

Source: NGC

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 T&S network in the UK's most energy intensive region thereby facilitating decarbonisation and attracting new investment.

1.2 Purpose of the Document

The purpose of this document is to provide an overview of the Basis of Design (BoD) for the Full CCS Chain.

The report should be read in conjunction with the following KKD documents:

- K27 – Oxy Power Plant Process Description;
- K29 – Transport Process Description; and
- K30 – Storage Process Description.

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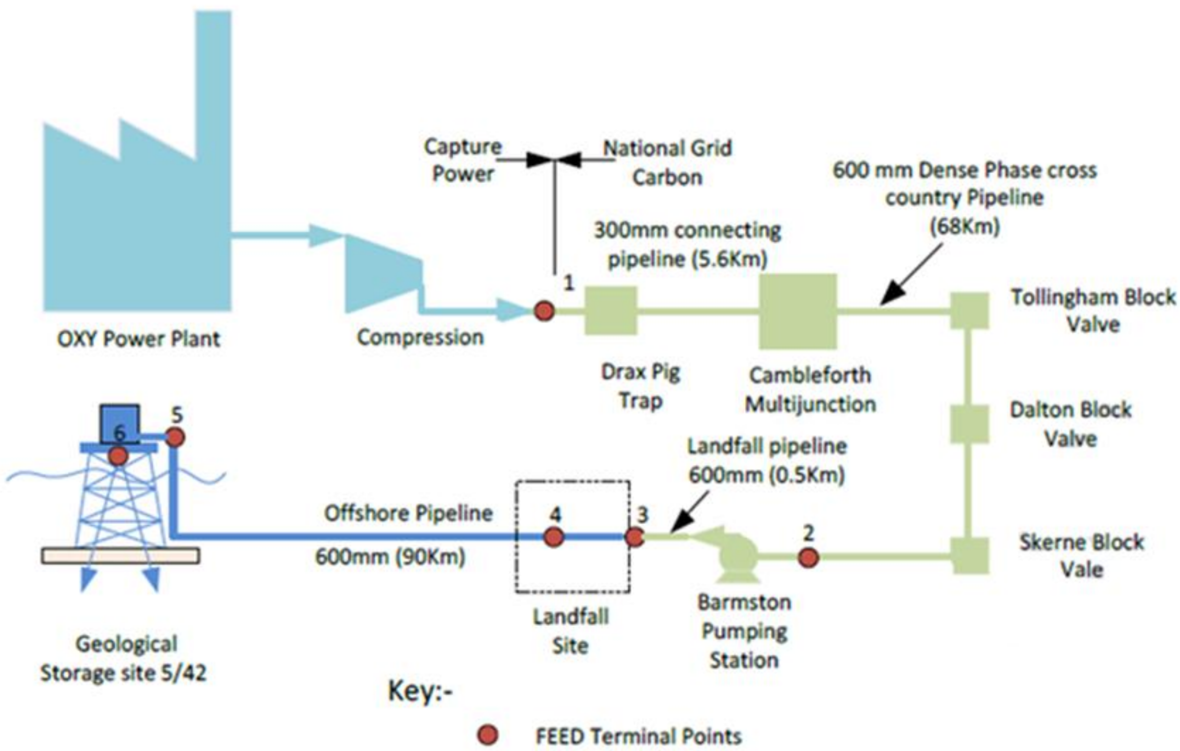
2 Full Chain Integration

The Full Chain and its component parts (see Figure 2.1) are designed to be operated such that the target of two million tonnes of CO_2 per year can be safely stored.

Figure 2.1: Full Chain Overall Schematic



Source: NGC

Figure 2.1 markers (FEED Terminal Points) are as follows:

- Marker 1: Outlet from OPP/Terminal Point (TP)-13;
- Marker 2: Inlet to Pumping Facility;
- Marker 3: Outlet from Pumping Facility;
- Marker 4: Landfall, the termination point of the Onshore Pipeline and the start of the Offshore Pipeline;
- Marker 5: Start of “Top-Side” (junction of Riser pipes and the platform facility pipework); and
- Marker 6: Well Head/Injection Point.

2.1 Project Location

2.1.1 Oxy Power Plant Location

The OPP will be situated on land on and adjacent to DPL’s existing Coal and Biomass Fired Station (Selby, Yorkshire) and within the DPL landholding. The Site is located north of the M62 motorway approximately mid-way between the cities of Leeds and Hull.

The OPP site area is approx. 27.4 hectares and extends northwards to include an area used for topsoil storage (currently partly vegetated with grasses) and part of an area of semi-natural grassland.

Figure 2.2 below gives a geographical overview of the OPP location.

Figure 2.2: OPP Site Location

Source: CPL

Existing site elevation varies between 2.00 and 7.00 m with an average existing ground elevation of 3.5 m AOD (Above Ordnance Datum).

To protect the OPP from a 1 in 200-year tidal flood level (including an allowance for climate change and a 1 in 5 year river flood event) the OPP will be built on a raised platform with a minimum floor level 0.6 m above this level at a height of 5.1 m AOD.

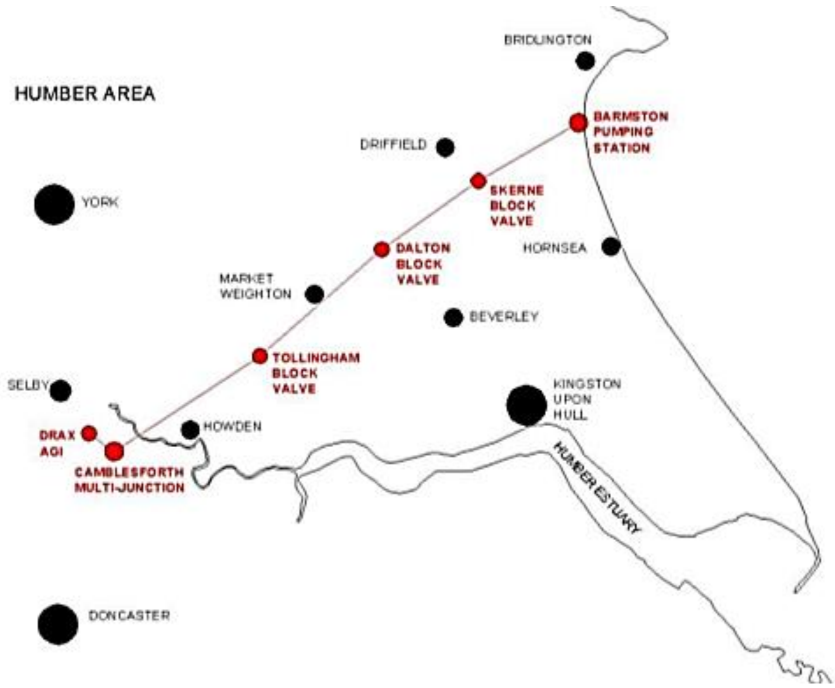
2.1.2 Onshore Transportation Site Location

The 300 mm nominal diameter (ND) (12”) pipeline between Drax Above Ground Installation (AGI) (located adjacent to the OPP) and the proposed Multi-Junction, near Camblesforth is approximately 6 km in length. The pipeline from Camblesforth Multi-Junction to Barmston Pumping Facility will be 600 mm ND (24”), approximately 69 km in length, with block valve installations located near Tollingham, Dalton and Skerne. The route and installation layouts are defined in the Development Consent Order (DCO) application submitted to the Planning Inspectorate.

Barmston Pumping Facility is located approximately 1 km north of Barmston, primarily positioned to maintain separation distance from Barmston, align with the onshore and offshore constraints and to minimise visual impact through the use of Hamilton Hill as a backdrop. Barmston Pumping Facility is less than a kilometre away from the proposed landfall location.

Figure 2.3 below gives a geographical overview of the onshore transportation system.

Figure 2.3: Overview of Onshore Transportation System Location

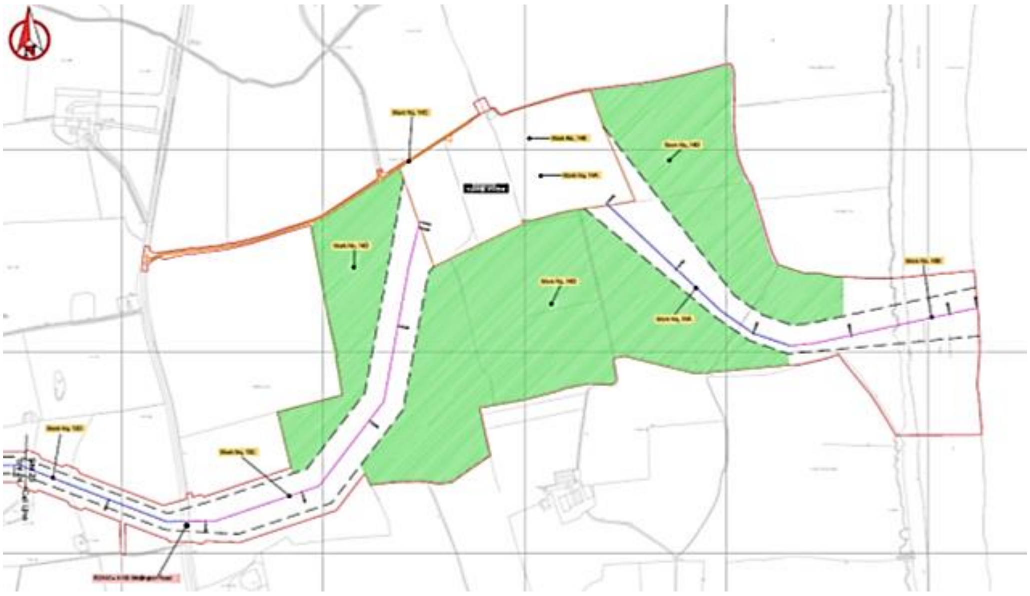


Source: NGC

2.1.3 Barmston Pumping Facility

The pumping facility is located to the north of Barmston, approximately 1 km inland from the Holderness Coast and 10 km south of Bridlington. The location is shown below in Figure 2.4.

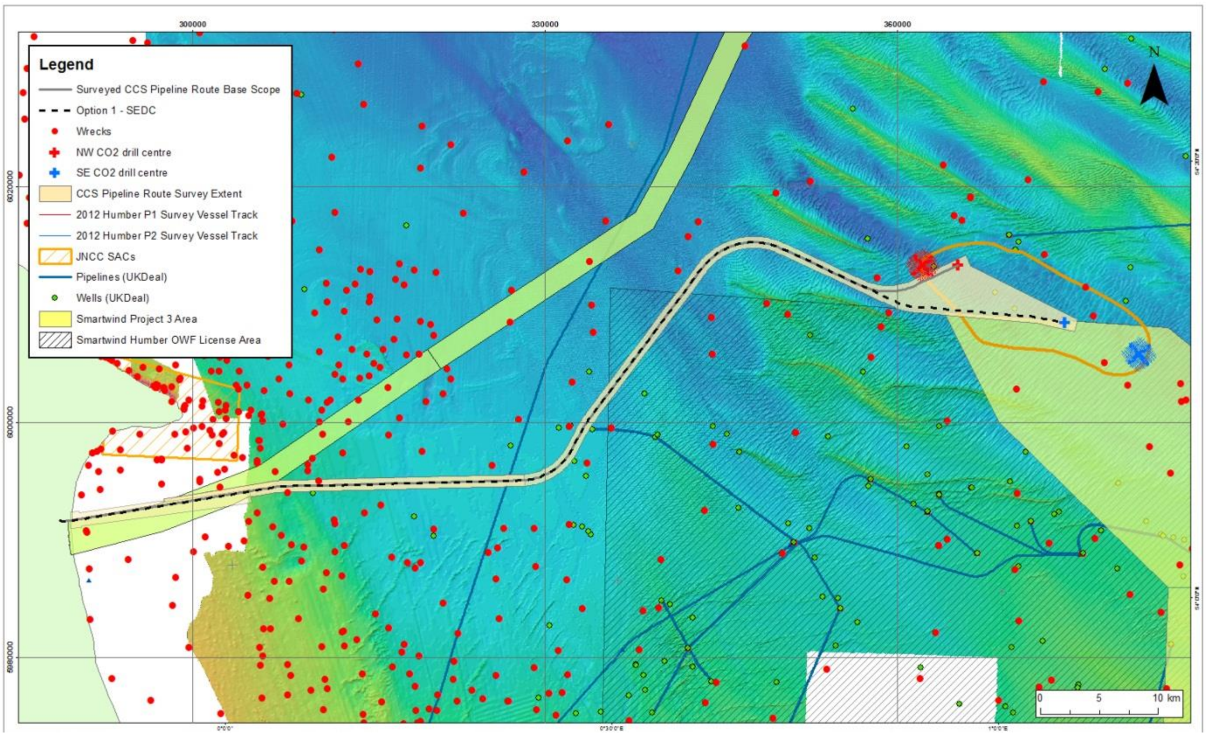
Figure 2.4: Barmston Pumping Station Location



Source: NGC

Figure 2.5 presents an overview of the offshore pipeline route corridor.

Figure 2.5: Overview of Offshore Pipeline Route Corridor



Source: NGC

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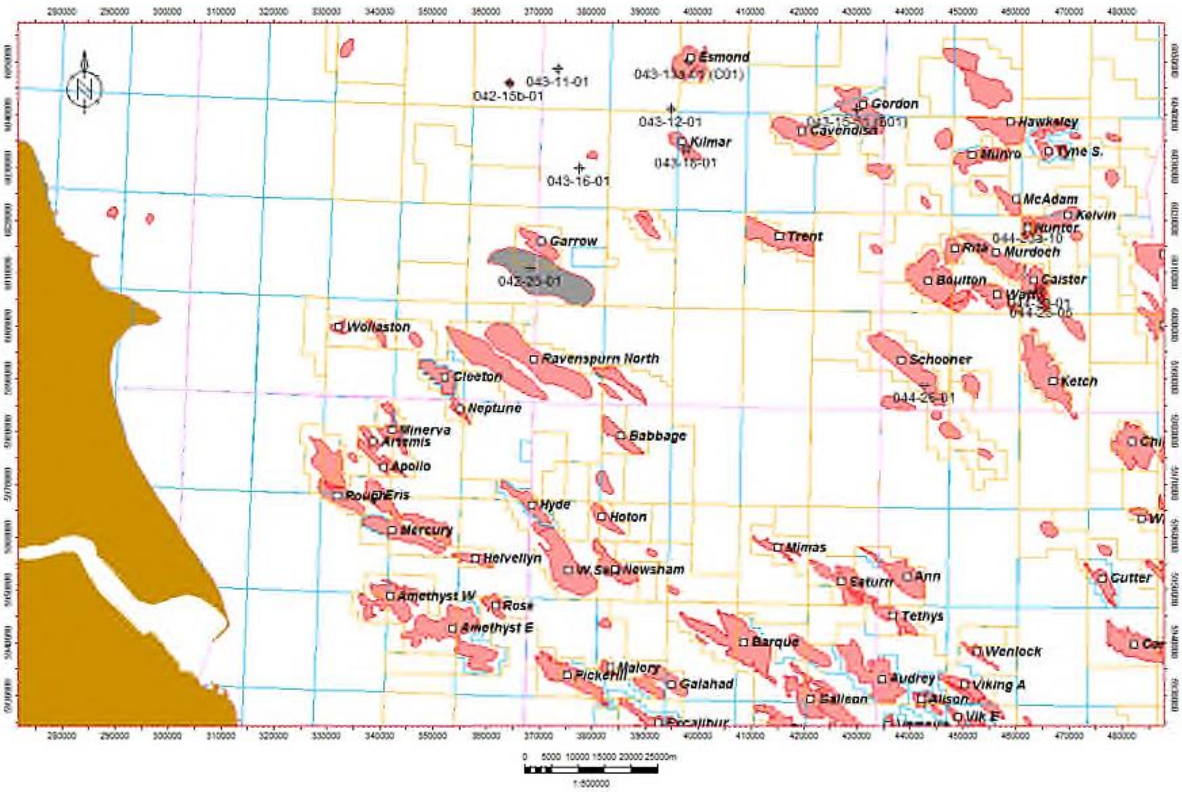
2.1.4 Offshore Site Location

The storage site (named Endurance) lies 60 to 70 km east of Flamborough head on the east coast of England in water depths ranging from 50 to 60 meters.

Figure 2.6 below gives a geographical overview of the offshore storage facility (existing gas fields are shown in pink).

Figure 2.6: Overview of Offshore Storage Location



Source: NGC

2.1.4.1 Platform Location

The coordinates of the platform and hence drill centre in UTM Zone 31 on the ED50 Datum are shown in Table 2.1.

Table 2.1: Platform and Drill Centre Location

Well Location	Location in UTM Zone 31 on the ED50 Datum
Eastings	366,882 m
Northings	6,012,790 m

The co-ordinates of the preferred injection platform (P5) and hence drill centre has been chosen as the preferred platform location since it satisfies the key fault and seabed sand wave ripple constraints and it lies outside the soft sediment Quaternary channel. The main obstacles over the route will be the crossing of a possible future Forewind power cable, crossing of the Langeled natural gas pipeline and high sandwaves located to the west of the target injection site. The water depth is around 55 m at this proposed injection site.

The schematic view provided in Figure 2.7 gives an indication of the proposed pipeline route and siting of the offshore Normally Unmanned Installation (NUI) in the context of the British Isles.

Figure 2.7: White Rose Platform North Sea Location

Source: NGC

The route will run in an easterly direction from the pipeline landfall north of Barmston to the first crossing, the future Dogger Bank power cables, if they are installed. The second crossing would be the existing Langeled pipeline (around 37 km from the shore), before turning north east and passing close by the existing Wollaston Whittle gas assets. Continuing in a north easterly direction, the pipeline corridor ultimately would turn to the south east and runs between large NW-SE orientated sandbanks (charted as the Sand Hills) before entering the Endurance storage location.

2.2 Full Chain Operation

The operating modes for both the OPP and the T&S system will be start-up, part load, base load and shutdown.

- OPP: On start-up, the flue gases will be directed to the OPP main stack until the flue gas is within the limits acceptable to the GPU. The flue gas will then be admitted to the GPU. When the processed CO_2 meets the required specification it will be directed to the inlet of the T&S system once the system is confirmed to be ready to accept CO_2.
- T&S system: On start-up, the CO_2, with confirmation of within composition limits, will proceed through the pipeline, passing the Drax AGI, Camblesforth Multi-Junction, and Tollingham, Dalton and Skerne Block Valve Stations. The booster pump station at Barmston will increase the operating pressure and the CO_2 which will be pumped to the offshore facility, where it will be filtered and injected into the saline formation.

The OPP can operate in either air or oxy firing modes. Oxy mode (i.e. with CO_2 to T&S network) is normal operation.

Air mode is only for:

- initial commissioning of the power plant;
- start-up and shutdown; and
- as a temporary back-up in case of unavailability of the ASU, GPU or T&S network.

The design and operational intention is to run the plant continuously (minimising the number of starts).

2.2.1 Normal Operation

Base load is expected to be the main operating mode. The plant would be able to ramp up and down with a normal loading and unloading ramp rate of 2% per minute.

In normal operation, the most efficient operation of the plant is expected to be between 80% and 100% load. This is due to the ASU and GPU compressors operating ranges. Below about 75% to 80% load the GPU compressors are in recycling mode. In base load operation the boiler uses the ASU oxygen production with no production of Liquid Oxygen (LOX) and no use of the stored LOX.

Dense phase CO_2 would be produced by the OPP at Drax up to a design flowrate of 306 tonnes per hour (tph) (or 2.68 million tonnes per annum (MTPA)).

Base load for each element of the chain is defined as follows:

- OPP: the plant is operating at its rated gross output and providing CO_2 to the T&S system at an outlet pressure of up to 135 barg;
- Pumping Station: a number of pumps operating at full load; and
- 3 injection wells.

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2.2.2 Flexible Operation

As this is a demonstration project, there is a requirement for the plant to prove its ability to respond to market conditions through flexible operation. Therefore the Full Chain has been designed to have the capacity to allow flexible operation in each element of the system.

Possible variations have been established as follows:

- OPP: The power plant is designed for flexibility, allowing the net output to be adjusted:
  - A "flexibility concept" which mimics traditional "2-shifting day/night" operation. During this operating regime, for periods of weeks or months or a season (up to 100 days/yr), the CO_2 production can be reduced to 35% for a period of up to approximately 8 hours on a daily basis. In this mode the plant moves to a position that results in export of no power to the grid while still generating the clean power needed to operate the ASUs and the GPU. By doing this, the plant can operate without shutting down and CO_2 is provided continuously, at a reduced rate, to the T&S system;
  - A "normal ramping" range set by turndown limits of ASU and GPU while compliant with Stable Export Limit (SEL). The CO_2 output is expected to vary in the range 100-75% during "normal ramping";
- CO_2 Pumping Station: The CO_2 pumps at Pumping Station can modulate to adjust to the CO_2 production rate and the process requirements of the pipeline;
- Injection wells:
  - The combination of injection wells in use will change the range of injection rates to accommodate the full range of CO_2 from the OPP
  - The overall injection rate range will vary as the reservoir pressure increases over the injection period; and
  - The wells maximum supply pressure of up to 182 barg and minimum of 90 barg to prevent phase separation occurring within the pipeline.

In addition, the plant could on occasions be required to turn down to 50-60% SEL in order to comply with the electrical Grid Code requirements. The OPP operating regime is presented in Table 2.2

Table 2.2: OPP Operating Regime

Operating Mode	Net MW	CO_2 Production	Comment
Normal Operation	Approx. 300 – 220	100%-75%	continuous ramp rate 2%/min
Flexibility Concept			
High Load	Approx. 310	100%	~ 13 hours operation
Min Load	~	35%	~ 5.5 hours operation
			1.5 hour transition between modes

Based on the above, the OPP is designed for a yearly production profile as shown in Table 2.3.

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Table 2.3: OPP Yearly Production Profile

Yearly duration	Load
65%	100% load
10%	75% load
10%	<50% load
15%	off line

This allows for 100 days per annum of flexible operation as well as 3-6 hours per day "normal ramping" between 100 % - 75 %.

For design, the number of starts is assumed to be as shown in Table 2.4.

Table 2.4: OPP Number of Starts

	Cold	Warm	Hot	Cycling 100 % <> 40 % or 25%
Typical number of starts	2 p.a	4 p.a	6 p.a	100 p.a

The types of start are defined as:

- Hot start: after <=8 hours shutdown;
- Warm start: after > 8h, but <= 48h shutdown (e.g. after a weekend shutdown); and
- Cold start: after > 48h shutdown (e.g. start-up from ambient temperature after maintenance overhaul).

2.2.3 OPP Turndown

The minimum CO_2 turndown rate is 0.81 MTPA.

2.2.4 Well Turndown

The minimum CO_2 turndown rate is less than the rate at which the CO_2 starts to flash downstream of the wellhead choke for 5.5" diameter well tubing. However the FEED has demonstrated the likelihood of flashing across the valve is small and that the risks are acceptable. Therefore all platform wells are 5.5" diameter.

2.3 Battery Limit Conditions between Elements of the Chain

The Terminal Point 13 (TP-13), shown as marker 1 in Figure 2.1, is the point of custody transfer of the CO_2 from the OPP to the T&S system.

The design parameters listed in Table 2.5 are for the CO_2 at the interface between the OPP and the Drax AGI at terminal point TP-13.

The maximum and minimum of CO_2 temperatures to the transport system will be protected by Safety Integrity Level (SIL) rated protection device(s) upstream OPP interface.

Table 2.5: Design Parameters at TP-13

Parameter	Units	Max	Min	Normal
Design Pressures	barg	148.5		
OPP Design Temperature upstream of TP-13	ºC	50	- 20	
Pipeline Design Temperatures at TP-13	ºC	25	0	20

Table 2.6 lists the operational envelope limits at TP-13 with respect to flowrate, operating conditions and compositional limits.

Table 2.6: OPP CO_2 Export Operational Limits Parameters

Parameter	Limit
Minimum Flowrate	0.81 MPTA
Maximum Flowrate	2.68 MTPA
Minimum Operating Pressure[1]	103 to 107 barg
Maximum Operating Pressure	135 barg
Minimum Operating Temperature	5ºC
Maximum Operating Temperature	20ºC
Maximum H_2O Content	50 ppmv
Maximum O_2 Content	10 ppmv
Maximum H_2S Content	20 ppmv

If any of the above parameters are beyond the minimum or maximum limits stated, the CO_2 would be stopped from feeding into the downstream T&S system by means of remotely operable valves and would be diverted to the OPP main stack until production returns to specification.

The OPP would deliver against the pressure in the transport network set by the offshore choke valves or, when its pumps were running, the suction pressure control at the Barmston Pumping station. Full flow relief valves at the OPP protect the onshore transport network from overpressure, while temperature measurement and compositional analysis of the CO_2 at the OPP with trip functionality is also provided to protect the transport system.

2.3.1 CO_2 Flowrates to Transport and Storage System

CO_2 flowrates from the OPP to the onshore pipeline are given below.

Table 2.7: OPP CO_2 Flowrates

Parameter	Units	Max	Min	Normal	Comments and Details
Design Flow rate	kg/hr	290,832 x 1.05			Boiler Maximum Continuous Rating (BMCR), 102% Turbine Maximum Continuous Rating (TMCR) for IM32 Colombian Coal +Straw Pellets plus 5% margin
Normal Operating Flow Rates	kg/hr		94,752	263,310	Max. at 100%TMCR Performance

[1] The Minimum Operating Pressure delivered by the OPP would be set to ensure that the pressure further down the line in the pipeline, as far as the well head does not fall below 90 barg, sufficient to ensure the that the CO_2 remains in dense phase during all operating modes. When supplying at the minimum flowrate a minimum operating pressure of 103 barg would be required and this would rise to 107 barg for a maximum flow.

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Parameter	Units	Max	Min	Normal	Comments and Details
					Coal Min. at 35% TMCR Performance Coal
Absolute Minimum Flow Rate	kg/hr		0		During OPP air mode operation

Over the design life of the Full Chain, the anticipated flowrates will increase, as the number of emitters that capture CO_2 using various technologies, become operational and start producing CO_2 for storage offshore.

The basis of design CO_2 flowrate is expected to develop as shown in Table 2.8.

Table 2.8: CO_2 Design Flows

Flow Case	Year 1 (First Load)	Year 5	Year 10
	MTPA	MTPA	MTPA
Design	2.68 (Note 1)	10.0 (Note 2)	17.0 (Note 3)
Normal	2.31	10.0	17.0
Minimum	0.81	0.81	0.90

Notes:

1. First Load Project: the maximum design CO_2 flow rate of the White Rose OPP is 2.68 MTPA;
2. Endurance storage site maximum injection capacity: Endurance has potential of storing in excess of 200 MT of CO_2 with a maximum injection rate of approximately 10 MTPA. The First Load facilities will be designed to facilitate the future expansion to meet the maximum injection rate (e.g., spare risers, J tubes, control/power system capacity);
3. Onshore and offshore 600 mm ND (24") pipeline maximum capacity.

The optimum equipment selection to allow growth shall be provided ensuring, efficiency in equipment operation; ability to turndown to desired rates for initial and future phases of the project; reliability, availability and maintenance aspects; as well as minimising variants in equipment types selected so as to minimise operator training requirements and allow ease of procurement, installation, etc.

2.3.2 CO_2 Composition

The pipeline entry specification in Table 2.9 provides the permitted limits for each component relative to safety design, integrity design and hydraulic efficiency criteria. This specification will also apply to the offshore storage system.

Table 2.9: CO_2 Entry Specification

Component	Limiting Criteria (Volume %)		
	Safety Max	Integrity Max	Hydraulic Efficiency
CO_2	100	100	96
H_2S		0.002 (Note 1)	
CO	0.2		
NOx	0.01		
SOx	0.01		
N_2			(Note 4)
O_2		0.001 (Note 2)	(Note 4)
H_2			(Note 4)

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Component		Limiting Criteria (Volume %)
Ar		(Note 4)
CH_4		(Note 4)
H_2O	0.005 (Note 3)	0.010

Notes:

1. National Association of Corrosion Engineers (NACE) limit for dense phase CO_2 at a total pressure of 150 barg. Specified to avoid requirement for sour service materials;
2. Maximum oxygen content (10 ppmv). Specified to avoid material selection issues in the well tubing, where the dry CO_2 contacts saline aquifer water;
3. Maximum water content (50 ppmv). Specified to ensure no free water occurs during normal or transient operations;
4. The allowable mixture of non-condensable components in the CO_2 stream must be:
   a. Gaseous Phase: $N_2 + O_2 + H_2 + CH_4 + Ar \leq 9.0$ vol %;
   b. Dense Phase: $N_2 + O_2 + H_2 + CH_4 + Ar \leq 4.0$ vol %, with H_2 no greater than 2.0 %.

The composition Safe Operating Limit (SOL) is a saturation pressure for the CO_2 rich mixture of no more than 80 barg along with the individual maximum allowable component levels defined in the specification for CO_2 quality requirements.

The objective operationally for the Full Chain is to maintain the CO_2 stream in the dense phase from the OPP terminal point, i.e. TP-13, through to injection wells. Since small levels of impurities significantly impact the properties and phase envelope of pure CO_2 making it difficult to predict its behaviour over an anticipated operating envelope, a CO_2 transportation pipeline composition specification has been developed.

The predicted CO_2 composition from the OPP has a much higher CO_2 content than the minimum required by the pipeline entry requirements.

The First Load composition derived to serve as the basis for the design would contain 99.7% CO_2 and up to 10 ppmv of oxygen (O_2) and 50 ppmv of water (H_2O).

As further emitters are added to the pipeline, the CO_2 composition, while still within the entry requirements, is likely to change. Two compositions, which are proposed to cover the possible range for the future operation of the CO_2 transportation system, are shown in Table 2.10.

Table 2.10: Expected Compositions

Component	First Load (Year 0 to 5)	Year 5 and 10 Composition #1	Year 5 and 10 Composition #2
	Volume %	Volume %	Volume %
CO_2	99.700	97.400	96.000
Ar	0.068	0.599	0.407
N_2	0.226	1.995	1.355
O_2	0.001	0.001	0.001
H_2O	0.005	0.005	0.005
H_2	0.000	0.000	2.000
H_2S	0.000	0.000	0.002
CO	0.000	0.000	0.200

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Component	First Load (Year 0 to 5)	Year 5 and 10 Composition #1	Year 5 and 10 Composition #2
NOx	0.000	0.000	0.010
SOx	0.000	0.000	0.010
CH_4	0.000	0.000	0.010

2.4 Future CO_2 Emitters

From Year 10 onwards, it is predicted that CO_2 would be supplied by additional sources up to a total of 17 MTPA, which is the maximum design load for the T&S system, and that a significant proportion of the CO_2 at that time would have to be routed to a remote injection facility, another platform, the location of which is yet to be determined.

As the reservoir pressure increases following prolonged CO_2 injection, the pressure required to transport the CO_2 and maintain injection rates of 10 MTPA at the injection platform exceeds the offshore pipeline MAOP of 182 barg for all cases except for low reservoir pressure and/or winter conditions when 6 wells would be available for injection.

The injection rate at the platform is limited to 9.1 – 12.8 MTPA, depending on the conditions (composition, reservoir pressure and ambient conditions) with the remainder being pumped to the remote facility.

2.5 Overall Target Availability

Established reliability analysis methods and published equipment data shall be used to demonstrate that the Reliability, Availability and Maintainability (RAM) of the Full Chain are in accordance with the overall targets.

It is recognised that the desired reliability and availability may not be achieved immediately but would progressively improve in the first few years of operation.

Reliability and availability will be calculated and reported in accordance with Institute of Electrical and Electronics Engineers (IEEE) 762 for the OPP, and according to a discrete event driven simulation for the onshore transportation system. A compatible method for the offshore storage system should also be used.

The following are the project availability and reliability targets for the Full Chain.

2.5.1 Availability

Full Chain availability target (including planned outages and unplanned outages):

- OPP: 86 %; and
- Full Chain CCS: 85 %.

The availability target is based on an average availability over a six year maintenance cycle. It was assumed that planned maintenance of the T&S system would be performed during the period of the planned maintenance for the OPP. Therefore, the reliability target for the T&S system is 99%.

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Reliability and availability assessments have been undertaken during FEED to confirm the required redundancy and to determine provisions necessary to achieve an overall availability target including planned and unplanned outages for the Full Chain. The reported availability target is supported by a detailed RAM study.

The RAM study is to be repeated during subsequent design phases of the project incorporating the final design and actual vendor data to confirm the expected plant availability and to determine the level of redundancy required across the Full Chain in more detail.

Availability of the transportation system will be dependent on maintenance requirements and be influenced as much by the storage element (the wells) as much as by the emitter.

The operating philosophy of the full well chain would be dictated by injection performance and water production performance of the specific wells in each of the injection hubs. Wells that are not required to maintain injection or water production rates would be isolated from service in order to provide redundancy throughout the life of the Full Chain.

The downhole and surface monitoring (pressure/temperature/flow rates) systems would be used to manage the well chain along with the overall reservoir monitoring system. As the life of the Full Chain advances the monitoring would be used to determine whether any additional injection or production wells are required for the system.

2.6 Metering and Monitoring Philosophy

The CCS chain is made up of three separate installations as defined in the monitoring regulations No 601/2012:

- Capture installation where fuel is combusted to generate power and the CO_2 produced is captured, refined and compressed to reach a required CO_2 specification;
- Onshore transport installation where the dense phase CO_2 is conveyed through pipelines to a pumping station and transferred to offshore pipeline; and
- Geological storage installation for injection into a secure underground saline formation.

2.6.1 Metering and Monitoring Objectives

Monitoring is a fundamental requirement of the CCS project requiring a range of metering, instrumental measurement, analytical measurement, observation, recording and reporting. These functions collectively must satisfy as minimum two sets of requirements:

- Real time
  - Safety;
  - Control;
- Retrospective and longer term
  - Regulatory;
  - Commercial (external); and
  - Commercial (internal).

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2.6.1.1 *Safety and Control*

- Sufficient instrumentation, metering and monitoring systems must be included in the plant design to allow the plant to operate safely in all routine and foreseeable upset conditions. Such systems should be sufficiently robust as to give an adequate level of confidence in the long term safe operation of chain elements and the Full Chain;
- Similarly, sufficient metering and monitoring systems must be in place to allow proper control of the plant for optimum performance and output; and
- The Integrated Chain Control Philosophy discusses the extent to which any instruments or other metering and monitoring equipment can provide dual function and where this is not permitted alternative options will be provided.

2.6.1.2 *Regulatory*

- Power generators will be required to be party to a Contract for Difference (CfD) contract;
- Storage facilities require a permit under the Geological Storage Directive (GSD);
- Each operator within the CCS Chain is required to be permitted under the European Union Emissions Trading Scheme (EUETS); and
- Power generation is captured under the EU Industrial Emission Directive (EU IED) which is transposed into UK law by the Environmental permitting regulations.

2.6.1.3 *External Commercial*

- CfD requires monitoring of a range of electrical power volumes and measurement of Carbon and CO_2 contents and volumes to establish revenue from clean electricity;
- T&S Operators will generate revenue based on the mass of CO_2 transported and stored; and
- The purchase of Carbon Credits is required for all CO_2 emitted to the atmosphere from any part of the CCS Chain.

2.6.1.4 *Internal Commercial*

- Each Chain Element Operator will be commercially responsible for the performance, reliability and availability of each chain element; and
- Sufficient instrumentation, metering and monitoring will be required of both the Chain Elements and the interfaces between them to allow correct allocations of responsibility and risk to be determined.

Additionally consideration must also be given to the following:

- CO_2 mass flow should be quantified along the CCS chain in accordance with applicable regulations in particular:
  - Code: Commission regulation (EU) No 601/2012 of 21 June 2012.
    - On the monitoring and reporting of greenhouse gas emission pursuant to directive 2003/87/EC of the European Parliament and of the Council;
  - Code: EU, 2009. Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009.
    - Description: On the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006 ;
  - Code: Directive 2010/75/EU of the European parliament and of the Council of 24 November 2010
    - On Industrial Emission (Integrated Pollution Prevention and Control);
  - Code: Statutory Instrument No 675 –The Environmental Permitting (England and Wales) Regulations 2010 (transposes Directive 2010/75/EU).

2.6.2 OPP Metering

Table 2.11 summarises the key metering requirements for the OPP.

Table 2.11: OPP Metering Requirements

Main parameter to be measured	Maximum system measurement uncertainty	Measurement Location
Mass flow of coal As received As fired	Class 0.5 (+/- 0.25%)	Belt weigher
Net calorific value of coal As received As fired	Class 0.5 (+/- 0.25%)	Laboratory analysis samples taken from main coal feed conveyor belt
Net calorific value of coal	0.5%	Laboratory analysis samples taken from main coal feed conveyor belt
Mass fraction of total carbon in coal	0.5%	Laboratory analysis of representative samples taken from main coal feed conveyor belt
Mass flow of total ash in coal	0.5%	Laboratory analysis of representative samples taken from main coal feed conveyor belt
Mass fraction of total carbon in bottom ash	0.5%	Laboratory analysis of representative samples taken from bottom ash conveyor belt
Mass flow of fly ash	0.5%	Fly ash pneumatic conveyor flow meter
Mass fraction of carbon in fly ash	0.5%	Representative online sampling in fly ash pneumatic conveyor and laboratory analysis
Mass flow of auxiliary fuel (liquid or gaseous form)	1%	Flow meter in fuel intake at nearest practicable point(s) immediately prior to combustion
Mass fraction of carbon in auxiliary fuel	0.5%	Representative sampling at nearest practicable point(s) immediately prior to combustion
Gross electrical energy	Class 0.2S (0.2%)	Generator terminals
Auxiliary electrical energy (11kV and 3.3kV)	Class 0.2S (0.2%)	TBA
Mass flow of pure CO_2 injected into pipeline	1%	Venturi flow element with split range dP transmitters downstream of CO_2 compression, downstream of any vent points, upstream of inlet to onshore export pipeline
Mass fraction of CO_2 in fluid injected into pipeline	0.1%	On-line analyser after GPU
Mass flow of vent gas from GPU	1%	Venturi flow element before vent stack
Mass fraction of uncaptured CO_2 in vent gases	0.1%	On-line analyser before vent stack

The OPP CO_2 metering system for the White Rose project will:

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- Use a Venturi tube as primary element according to ISO EN 5167 delivered together with the required disturbance free up- and downstream piping;
- Redundant installation consisting of redundant transmitter (differential pressure, pressure, temperature and density) and redundant calibratable flow calculator;
- Use hydraulic zero adjustment for the differential pressure transmitter for highest accuracy;
- Calibrate whole installation on a test bench under similar flow conditions (with water at similar Reynolds numbers); and
- The measured volumetric flow will be compensated to the design conditions regarding pressure, temperature and density, and finally multiplied with the density.

2.6.3 Onshore Metering

- CO_2 volumetric and mass flow rates shall be measured to a fiscal standard prior to their entry into the offshore pipeline. Orifice plate metering is the proposed method of flow measurement;
- CO_2 metering devices shall be to an appropriate international standard which ensures that the uncertainty levels can be determined with the metering device in situ. The required uncertainty level is +/- 2.5%; and
- It shall be possible for nominated independent parties to validate the outputs from the CO_2 flow metering system.

2.6.3.1 Pipeline Leak Detection

Pipeline leak detection was considered prior to FEED; however it was decided that it was not required as any pin-hole leaks would be difficult to detect using available leak detection systems.

During pipeline operation, NGC will carry out frequent inspections such as PIG (Pipeline Inspection Gauge) operations to detect any defects or reduction in pipe wall thickness that may give rise to small bore leaks. Regular visual inspections will also be carried out along the pipeline route seeking any indication of leaks and to assess whether there is any construction activity taking place that could lead to a loss of containment.

In the event of a full bore rupture there are pressure transmitters, located at the above ground installations, which would show rapid reduction in pressure especially given the limited line pack available in a dense phase CO_2 pipeline. Based on the research work carried out, it has been shown that the risk of such failure is very low and, where a population is present and at risk, the ability to detect a rupture or large leak is already high. The increase in the ability to detect a rupture or large leak, which would be provided by an automatic detection system, is therefore small. Employing such measures would result in only a very small reduction of a very small risk; hence the provision of such measures is not considered to be required.

2.6.4 Offshore Metering

The total CO_2 mass arriving to the platform will be not be measured, however each platform injection well inlet arrangement would be provided with an orifice plate for metering.

CO_2 metering would be provided on each well flow line for allocation purposes. The flow meters would be orifice plate or Venturi tube and would conform to the relevant parts of ISO5167-2003 with an anticipated confidence limit of 95% for uncertainty of better than +/- 2.5%.

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Future water production wells will require flow measurement on each well. Capacity should be provided in the control system.

The mass of CO_2 vented to atmosphere through planned interventions will be calculated (i.e. not metered) based on the measured temperature, pressure and equipment inventories.

2.6.5 Subsurface Monitoring

All wells will have meters, temperature and pressure sensors to accurately measure injection rates, tubing head pressure, surface casing pressure and bottom-hole injection pressure in order to increase the understanding of the behaviour of the CO_2 plume injected into the reservoir. It is expected that fibre optic cables will be used to measure both temperature and acoustic readings Table 2.12 presents the injection wells instrumentation requirements.

Table 2.12: Injection Wells Instrumentation Requirements

Activity	Frequency
Tubing Head Pressure (THP)	Continuous
Tubing Head Temperature (THT)	Continuous
Injection Flowrate	Continuous
Permanent Down-Hole Gauges (PDGs)	Continuous
Temperature Measurement along well bore with Distributed Temperature Sensors (DTS)	Continuous
Acoustic Measurement along well bore with Distributed Acoustic Sensors (DAS)	Continuous
Well Sampling	Sporadic
Saturation Profile	Sporadic

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3 Oxy Power Plant

3.1 Oxy Combustion Technology

The OPP will be a new ultra-supercritical coal fired power plant consisting of a pulverised coal boiler designed for air or oxygen operation, a steam turbine generator unit and CO_2 capture system. The OPP will be designed with the future potential to co-fire up to 10% biomass.

The basic oxy-firing concept uses a mixture of oxygen and recirculated flue gas to replace combustion air, which after combustion produces a flue gas comprised of mainly CO_2 and water vapour and much smaller amounts of oxygen, nitrogen, argon, sulphur dioxide, etc.

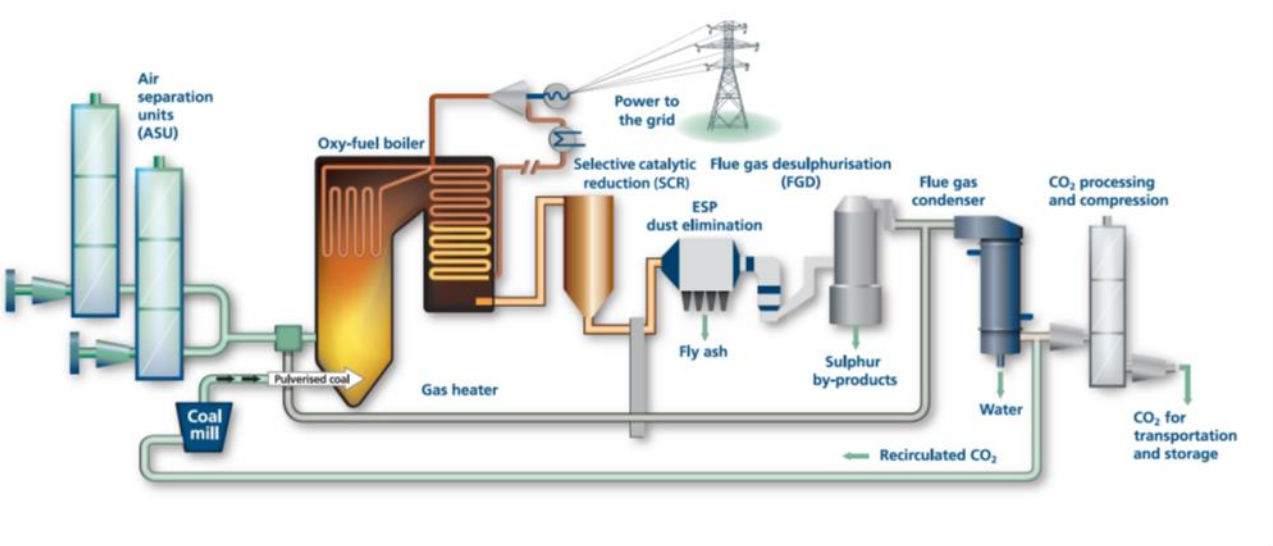
The flue gas leaving the boiler is cooled and cleaned of the particulates, SOx and NOx in the Air Quality Control System (AQCS).

The GPU is designed to capture approximately 90 % of the CO_2 produced, first removing the water vapour from the flue gas, before the remaining CO_2 is further processed to meet the specification required for the T&S system. CO_2 will be delivered in dense phase to the CO_2 pipeline header for onward transportation.

3.2 OPP Description

The main components of the OPP are shown in Figure 3.1.

Figure 3.1: Oxy Power Plant Diagram



Source: CPL

The OPP includes the following major facilities:

- Pulverized Coal Oxy Boiler including Selective Catalytic Reduction (SCR);
- AQCS including wet Flue Gas Desulphurisation (FGD), limestone handling/preparation, gypsum dewatering and Electrostatic Precipitator (ESP) removal equipment;
- Steam Turbine generator and auxiliaries;

- Water and Steam Cycle equipment;
- Cooling towers (mechanical draft low plume cooling towers);
- Closed cooling system ;
- Light Fuel Oil storage and supply;
- Ash Handling;
- Water Supply (Demineralised water treatment and cycle makeup, Waste water);
- Water / Steam cycle chemistry;
- Polishing Plant;
- Dosing equipment;
- Steam cycle sampling and analysis;
- Auxiliary steam;
- Compressed air system; and
- Plant electrical system and Control System.

Fuel is delivered via the existing DPL coal yard, with the coal imported to the yard via rail and biomass by road. New conveying systems will supply coal and biomass to the silos located at the OPP boiler house.

The cooling water system will consist of mechanical draft low plume cooling towers. Make up water will be supplied from the existing DPL facilities.

Emissions to air will meet the UK applicable standards and limits.

Industrial liquid effluents including flue gas desulphurisation effluents will be treated within the OPP before discharged to the River Ouse through DPL's existing discharge line under their current consent.

The OPP includes all facilities required for an independent electric power generating unit, excluding those facilities specifically provided by DPL.

Detailed description of the OPP processes can be found in KKD 27 – Oxy Power Plant Process Description

3.2.1 Gas Processing Unit

The GPU conditions and compresses the CO_2 rich flue gas to achieve the required purity, pressure and temperature specification for the transportation system. The CO_2 rich flue gas undergoes the following steps in the GPU:

- Bulk water removal in a Direct Contact Cooler (DCC);
- Compression in the Flue Gas Compressor (FGC);
- Final drying in molecular sieve adsorber beds;
- Mercury removal;
- Purification in a cryogenic section; and
- Compression to the required pressure required for onward T&S.

3.2.2 Air Separation Unit

Gaseous oxygen to the boiler is supplied at low pressure from two identical ASUs each sized to produce up to about 3,145 tonnes per day of oxygen.

For each unit, air is filtered, compressed, cooled and dried before being separated through cryogenic distillation in a cold box to produce the oxygen product stream. The nitrogen by-product is used for regeneration of the molecular sieve units which dry and remove CO_2 from the air before it enters the cold boxes, and also to produce chilled water used to pre-cool the air.

As well as producing gaseous oxygen, the ASU has been designed to liquefy oxygen during off- peak power periods (e.g. night time).

The liquid oxygen (LOX) produced is stored in two systems:

- a back-up system where LOX from dedicated storage vessels can be vaporised in the steam heated vaporisers to maintain the oxygen flow to the boiler in the event of an ASU outage; and
- a system to inject LOX, from a separate storage vessel, to the ASU during peak power demand in order to reduce the ASU load (the load of the ASU's main air compressor) and thereby increase the net power output of the OPP to the grid.

Heat is recovered from the ASUs into the boiler by using the heat of compression from the main air compressors to pre-heat a condensate stream which is returned to the boiler.

Steam is imported from the boiler to each ASU to provide the heat needed for regeneration of the pre-purification units and for the LOX vaporisers.

The Air Separation Plant will include the following major items:

- 2 x 50% ASU including cold compressor, external expander and external liquefier;
- LOX storage;
- oxygen vaporisers;
- pressurised O_2 buffer tank;
- low pressure O_2 buffer tank;
- steam condensate heat integration;
- instrument air system;
- plant electrical system; and
- control system.

3.3 Summary of Changes to a Conventional Plant Specific to CCS

To allow operation in oxy mode some modifications to the power plant itself, versus a conventional unit, are necessary, in particular:

- Partial recirculation of the flue gas in order to maintain appropriate temperature and heat absorption in the furnace and convection pass,;
- Removal of the water from the flue gas before treatment in the GPU in the Flue Gas Condenser;
- Minimisation of leakage of air into the boiler;
- Sizing of equipment (e.g. cooling and electrical systems), taking into account the additional needs of ASU and GPU; and
- Injection/mixing of oxygen in the flue gas path.

3.4 Site Ambient Conditions

The OPP will be designed with the assumed design criteria listed in Table 3.1**.**

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Table 3.1: Temperature, Humidity, Pressure

	Value
Ambient temperature:	
- Extreme summer case	+35°C (DB), 50% RH
- Summer case, average high	+25°C (DB), 60% RH
- Design case (reference for performance test)	+18°C (DB), 65% RH
- Average ambient case (reference for design/outside communication on the project)	+ 11°C (DB), 85% RH
- Winter case, low average temperature	+ 1°C (DB), 90% RH
- Extreme winter case	-15°C (DB), 100% RH
Design atmospheric pressure	1013 mbar
Low Plume Design	Plume free down to 5°C / 95% RH

The values in Table 3.1 are derived from meteorological data recorded at RAF Waddington (2001-2010) which includes hourly measurement of dry bulb temperatures, wind speed, wind direction, rainfall and relative humidity.

Precipitation, wind, seismic conditions and wind rose are shown below.

Table 3.2: Precipitation

	Value
Rainfall:	Approx.650 mm / year (York)
Site drainage	Return period retained: 100 Years plus Climate Change (CC)
Snowfall	Snow loads in accordance with BS EN 1991-1-3 Eurocode 1: "Actions on structures - General actions - Snow loads" and UK National Annex

Table 3.3: Wind, Seismic Condition

	Value
Wind	Exposure factor II (green field with isolated obstacles) Prevailing wind direction: Attached wind roses diagram is based on Meteorological data derived from RAF Waddington 2000-2009 period. Data recorded at a height of 10m, with a station altitude of 68m Minimum wind loads in accordance with BS EN 1991-1-4 Eurocode 1: "Actions on structures - General actions - Wind actions" and UK National Annex
Seismicity	No seismic verification for the structures nor particular design provisions shall be considered

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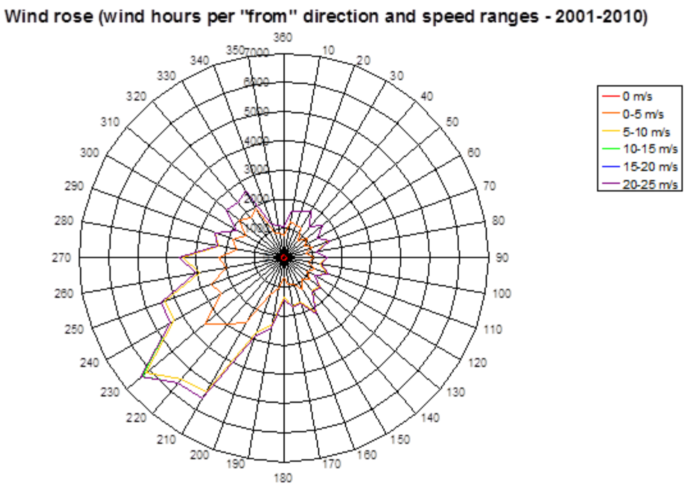
Figure 3.2: Wind Rose

	Total wind hours of 2001 to 2010					
Dir (°)	0 m/s	0-5 m/s	5-10 m/s	10-15 m/s	15-20 m/s	20-25 m/s
360	86	759	287	3	0	0
10	86	1232	397	7	0	0
20	86	1153	518	12	0	0
30	86	1168	648	35	0	0
40	86	763	620	16	0	0
50	86	1022	692	25	0	0
60	86	807	516	22	0	0
70	86	1013	628	29	0	0
80	86	748	363	21	0	0
90	86	999	487	24	0	0
100	86	870	400	8	0	0
110	86	1119	487	12	0	0
120	86	912	304	12	0	0
130	86	1177	406	17	0	0
140	86	946	531	44	1	0
150	86	1273	900	70	0	0
160	86	988	638	46	0	0
170	86	924	754	51	1	0
180	86	685	679	89	0	0
190	86	1074	1237	121	0	0
200	86	1368	1402	134	1	0
210	86	2585	2748	237	1	0
220	86	2968	2459	192	2	0
230	86	3558	2605	199	5	0
240	86	2441	1882	164	9	0
250	86	2642	1695	139	6	2
260	86	1971	978	111	4	0
270	86	2212	1251	101	3	0
280	86	1628	617	37	0	0
290	86	1836	654	30	0	0
300	86	1497	360	1	0	0
310	86	2020	513	3	0	0
320	86	1759	704	2	0	0
330	86	1946	692	2	0	0
340	86	909	326	3	0	0
350	86	843	280	0	0	0



3.5 Design Life

The OPP will be designed for a 30 year design life.

3.6 Design Assumptions

Power plant size is up to 448 MW gross, leading to a net output of 300 MW in oxy mode.

3.7 Fuel Envelope

3.7.1 Coal

The coal for plant performance test and guarantees will be 100% SC Ravenstruther.

Table 3.4: Coal Size

Coal Size	Raw Coal Topsize
100% to be less than	50.0 mm
No more than 20% less than	6.35 mm
No more than 10% less than	2.00 mm

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Table 3.5: Coal Range

Coal Range	Min	Max
Proximate Analysis (wt%)		
Moisture	9.10	15.00
Volatile Matter	27.80	35.30
Fixed Carbon	41.00	48.20
Ash	5.72	18.00
Ratio Fixed Carbon / Volatile Matter	1.27	1.56
Ultimate Analysis (wt%)		
Moisture	9.10	15.00
Hydrogen	3.38	4.28
Carbon	57.35	67.68
Sulphur	0.37	2.00
Nitrogen	1.05	1.80
Oxygen (diff)	3.77	10.86
Chloride	0.01	0.18
Ash	5.72	18.00
HHV, kJ/kg	23,517	26,810
kg Moisture/10^6 kJ	3.50	20.32
kg Sulphur/10^6 kJ	0.15	0.85
kg Ash/10^6 kJ	2.26	7.56
kg Nitrogen/10^6 kJ	0.41	0.68
Hardgrove Grindability Index	45	63
Ash Analysis (wt%)		
SiO_2	46.18	61.14
Al_2O_3	18.65	30.84
BaO	0	0.12
Fe_2O_3	0.12	9.64
CaO	0.9	10.01
MgO	1	2.8
Na_2O	0.07	3.48
K_2O	1.52	2.5
TiO_2	0.83	1.6
Mn_3O_4	0.04	0.3
P_2O_5	0.1	0.8
SO_3	0.6	10.75
Ash Fusion Temperature (C)		
Initial Deformation	1163	1482
Softening	1207	1482
Hemisphere	1232	1500
Flow	1310	1520

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3.7.2 Biomass

The future potential co-firing of 10% (heat content) biomass is one of the design cases (in addition to 100% coal firing). Biomass will be pelletised**.**

The primary biomass fuel is expected to be timber pellets but a range of agricultural by-products and energy crop miscanthus are also considered in the design.

Table 3.6: Biomass Range

	Timber Pellet		**All biomass sources including: Agricultural By-products and Energy Crop Miscanthus**	
	Min	Max	Minimum	Maximum
Proximate Analysis				
Total moisture (% a.r.b.)	5.2	10.1	5.2	21.7
Ash (% a.r.b.)	0.4	2.5	0.4	13.7
Volatile matter (% a.r.b.)	74.2	80.7	52.2	80.7
CV Net MJ/kg (H det. A.r.b.)	15.9	18	13.5	18
CV Gross MJ/kg (a.r.b)	17.9	19.3	15	19.3
Ultimate Analysis				
Chlorine (% a.r.b.)	0	0.03	0	0.47
Sulphur (% a.r.b.)	0	0.1	0	0.46
Nitrogen (% a.r.b.)	0	2.4	0	6
Carbon (% a.r.b.)	44.8	48.3	38.24	48.3
Hydrogen (% a.r.b.)	5.3	5.7	4.1	6.5
Oxygen (% a.r.b.)	38.2	41.3	27	41.3
Ash Analysis				
SiO_3 (%)	4.9	22.4	2.9	74.2
Al_2O_3 (%)	2.2	7.6	0.18	24.5
Fe_2O_3 (%)	2.9	8.3	0.3	23.45
TiO_2 (%)	0.14	0.97	0.03	3.26
MnO (%)	2.1	5	0.1	5
CaO (%)	30.3	45.4	2.41	45.4
MgO (%)	7.2	11.5	1.18	12.4
Na_2O (%)	0.58	3.6	0.06	3.6
K_2O (%)	12.8	20.3	1.06	29.2
P_2O_5 (%)	2.9	5.3	0.15	42.4
SO_3 (%)	1.4	3.1	0.66	10.3
Ash Fusion Reducing (C)				
Initial Deformation	1130		800	1390
Softening Temperature	1170		900	1400
Hemispherical Temperature	1190		930	1250
Flow Temperature	1200		1100	1260

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3.7.3 Liquid Fuel Interface Data

The start-up fuel will be Light Fuel Oil BS 2869:2010 – Class A2 – Sulphur free. Light Fuel Oil will also be used for the auxiliary boiler.

3.8 Key Feed and Product Streams Specification

3.8.1 Limestone

Table 3.7: Limestone Chemical Specification

Design Limestone Chemical Specification	Value
Purity	Min. 95%
$CaCO_3$	Min. 54.6% as CaO
$MgCO_3$	Max. 0.48% as MgO
SiO_2, total	Max. 1%, as SiO_2
Fe_2O_3, total	Max. 0.1%, as Fe_2O_3
Al_2O_3, total	Max. 0.3%, as Al_2O_3
Insoluble, total	<1.8%
SiO_2, insoluble	Max. 0.45%, as SiO_2
Fe_2O_3, insoluble	Max. 0.1%, as Fe_2O_3
Al_2O_3, insoluble	Max. 0.2%, as Al_2O_3
Pb	Max. 20 mg/kg
Mn	Max. 200 mg/kg
F	Max. 200 mg/kg
B	Max. 25 mg/kg
Mo	Max. 5 mg/kg
Se	Max. 3 mg/kg
Cd	Max. 2 mg/kg
Hg	Max. 3 mg/kg
Ni	Max. 15 mg/kg
Zn	Max. 25 mg/kg
Sn	Max. 10 mg/kg
V	Max. 20 mg/kg
Quartz, respirable	Max. 0.5%
CO_2	>42.9%

Table 3.8: Limestone Sizing Criteria

Sieve Size (mm)	% Passing Through Sieve	
	Max.	**Min.**
14	100	100
10	93	73
0.08	8	1
Hardness		
Bond Work Index		Max. 10.0 kW/metric ton

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3.8.2 Gypsum

Table 3.9: Gypsum Quality Specification

Parameter	Specification Level	Acceptable Analytical Error
Moisture	10% maximum	+/-0.25%
Purity % $CaSO_4$, $2H_2O$	95% minimum	+/-0.5%
$CaCO_3$	5% maximum	+/-0.5%
$CaSO_3$	0.5% maximum	+/-0.05%
Chloride	100 ppm maximum	+/-10ppm
K_2O, MgO, Na_2O	0.1% max Na_2O 0.05% max	+/-0.01% (Na_2O+/-0.005%)
SiO_2		+/-0.15
Fe_2O_3	0.4% max	+/-0.04%
pH	6-8	+/-0.1 pH Unit
Crystal size	<75% at 16 microns <10% at 100 microns	-
Odour	Not objectionable	-

Notes:
1. For any parameters not listed above, specification is as per published Euro Gypsum Specification (Standard CEN/TC/241).
2. Current agreed test methods have a range in acceptable analytical error as defined in Table 8. Conformity to the quality specification will be achieved where the defining parameters are not greater or less than half the range in acceptable analytical error with respect to maximum/minimum limits quoted.
3. All limits (except moisture) are on dry weight basis.

3.8.3 Pulverised Fly Ash

The targeted ash quality is as per EN450 standard – ash use in concrete (carbon/ash ratio 6%).

3.9 Interfaces with Drax Power Plant

The following services from the existing DPL Facility will be supplied to the OPP:
- coal;
- raw limestone;
- dry gypsum return;
- raw water;
- water return (to include treated process waste water and rain water as well as cooling tower blow down);
- sanitary sewage treatment;
- pulverised fly ash disposal; and
- furnace bottom ash disposal.

Figure 3.3 below shows the interconnections between the OPP and DPL facilities.

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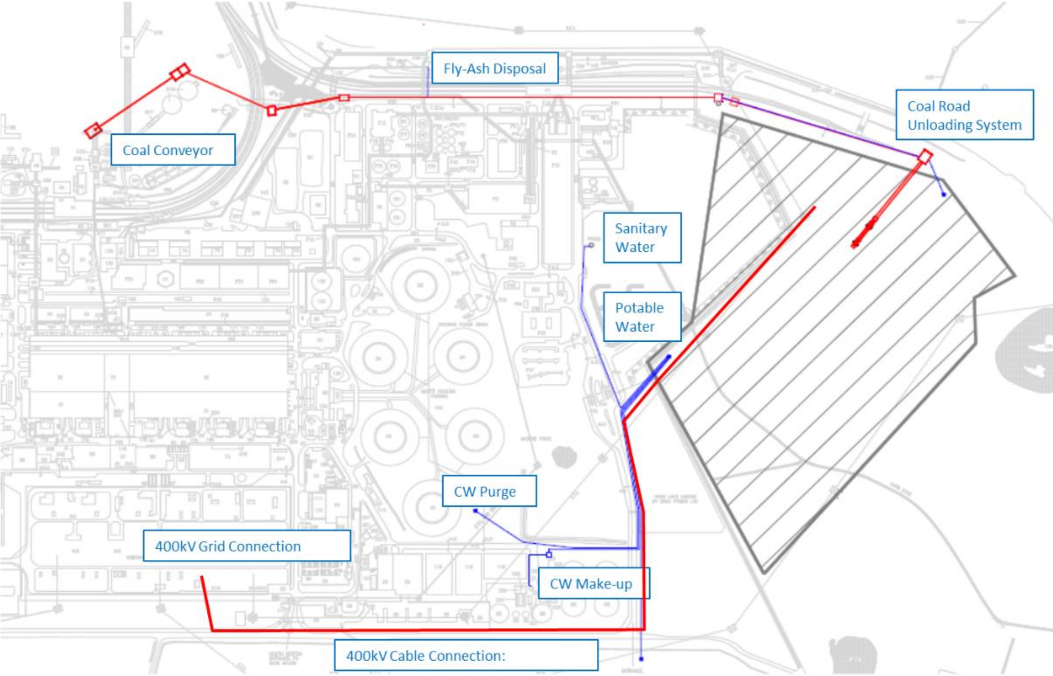
Figure 3.3: Interconnections with the DPL Facilities



Source: CPL

Table 3.10 below summarises the interfaces design parameters.

Table 3.10: Interconnection Process Details

Terminal Point (TP)	Description	From	To	Pressure / Temp (design)	Flow
1	Coal Supply	Drax	OPP	N/A	2x 320 t/h
2	Biomass Supply (future potential)	Drax	OPP	N/A	1x 80 t/h
5	Cooling Water (CW) Make-up	Drax	OPP	4 bar / 30°C	1600 m^3/h
6	Potable Water	Yorkshire Water	OPP	6 bar / 20°C	10 m^3/h
8a	CW Purge	OPP	Drax	4 bar / 30°C	1,650 m^3/h
9	Sanitary Water	OPP	Drax	4 bar / 30°C	10 m^3/h
10a	Pulverised Fly Ash	OPP	Drax	N/A	100 t/h
12c+d	11 kV Connection	Drax	OPP	N/A	9 MVA
13	CO_2	OPP	NGC	135 barg	291t/hr
12b	400 kV	OPP	NGET	N/A	400 MVA

Source: Drax

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3.10 Grid Connection

The electrical output from the plant will be exported to the National Grid Electricity Transmission (NGET) 400kV network. A new connection will be made from the OPP to a bay in NGET's existing switchyard at DPL.

Power will be generated at medium voltage and the main generator step up transformer will match the voltage to the grid voltage. Auxiliary systems will be provided from a number of auxiliary transformers supplied from the generator terminals. Synchronisation will normally be over a medium voltage generator circuit breaker.

The OPP will be designed to match the UK grid code requirements.

ASUs can be started from the 400kV grid independently of the OPP.

OPP earthing system will be separate from the DPL main site earthing system.

3.11 Emissions Limits

One main stack, 120m height, will be provided combining three flues: one for oxy mode operation (GPU venting), one for air mode operation (combustion gases) and one to collect cold dry relief header vents from the GPU safety valves.

3.11.1 Air Mode Operation

Stack emissions during air mode will be compliant with values EU Directive as shown in Table 3.11.

Table 3.11: Stack Emissions in Air Mode

Stack emissions[2]	Unit	EU Directive Value
SOx	mg/Nm^3, 6% O_2 dry	150
NOx	mg/Nm^3, 6% O_2 dry	150
	corresponds to mg/MJ	52
Particulates	mg/Nm^3, 6% O_2 dry	10

3.11.2 Oxy Mode Operation

The formation of NOx in case of oxy mode is significantly reduced compared to the combustion in air.

When fuel is burned in oxygen, the same quantity of CO_2 and the same or lower quantities of pollutants are produced, but the total quantity of flue gas produced is significantly reduced (~25% of air-firing). The flue gas, after clean-up in the AQCS, undergoes additional purification in the GPU. A small stream of inert gases (such as argon and nitrogen) and remaining pollutants, which represents about 10% of the flue gas to the GPU and about 2.5% of the typical quantity of flue gas emitted from air-firing, are vented to atmosphere.

2 Current European directive max acceptable – min to full load

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The mass flow rates of emission compounds (SOx, NOx, etc.) to the atmosphere in oxy mode are significantly lower than in the air mode but, due to the lower volumes to the stack, they appear higher if expressed on a volume basis. For the OPP it is proposed that emission limits for the plant should be expressed on an energy basis as milligrams per Mega-Joule (mg/MJ) and will be agreed as part of the Environmental Permit application process.

3.12 List of Key Codes and Standards

The OPP shall comply with the relevant codes and standards in force at the time of Engineering Procurement and Construction (EPC) Contract award, safety, legal and other regulations (local and national), acts and legislation in force in the United Kingdom.

As a general principle:

- EN codes and standards will be used;
- Revision of codes to be used: date of signature of EPC Contract;
- Appropriate DIN or BS variant (usually equivalent but there may be slight differences, in which case BS would normally apply unless agreed otherwise for a specific case); and
- Health and Safety Executive (HSE) regulations and guidelines as required.

The Construction Design and Management (CDM) Regulations 2015 apply to the OPP.

The Control of Major Accident Hazards (COMAH) 2015 applies to the OPP.

Applicable codes and standards are listed in the table below.

Table 3.12: Applicable Codes/Standards

	Code/Standard
ABMA	American Boiler Manufacturers Association
AGMA	American Gear Manufacturers Association
AISC	American Institute for Steel Construction
AISI	American Iron and Steel Institute
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
AWWA	American Water Works Association
BS	British Standard
CENELEC	European Committee for Electro-technical Standardisation
CI	Chlorine Institute, Inc. (Chlorine Handbook)
DIN	Deutsches Institut fuer Normung
EJMA	Expansion Joint Manufacturers Association
EN	European Standards (including Eurocodes)
FEM	Federation Europeenne de Maintenance

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	Code/Standard
HEI	Heat Exchange Institute
HIS	Hydraulic Institute Standards
HMSO	Her Majesty's Stationary Office
IEC	International Electro technical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISA	Instrument Society of America
ISO	International Organisation for Standardisation
NACE	National Association of Corrosion Engineers
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
RAL 840 HR	Colour codes
SAE	Society of Automotive Engineers
SPI	Society of Plastics Industry
SSPC	Steel Structure Painting Council
TEMA	Tubular Exchangers Manufacturers Association
UL	Underwriters Laboratories
VDE	Verband Deutscher Elektrotechnischere
VDI	Verein Deutscher Ingenieure
Others	as specifically included in the equipment specifications

Materials and equipment shall comply at least with one of the following standards and codes:

- International ISO, IEC, EN;
- UK: British Standard;
- German VDE, VDI, AD, TRD, DIN, VGB;
- American ANSI, ASME, ASTM, IEE, NEMA, NFPA;
- ASTM, JIS shapes and materials for structural steel and ductwork; and
- GB shapes and materials for structural steel for turbine hall and boiler structural steel.

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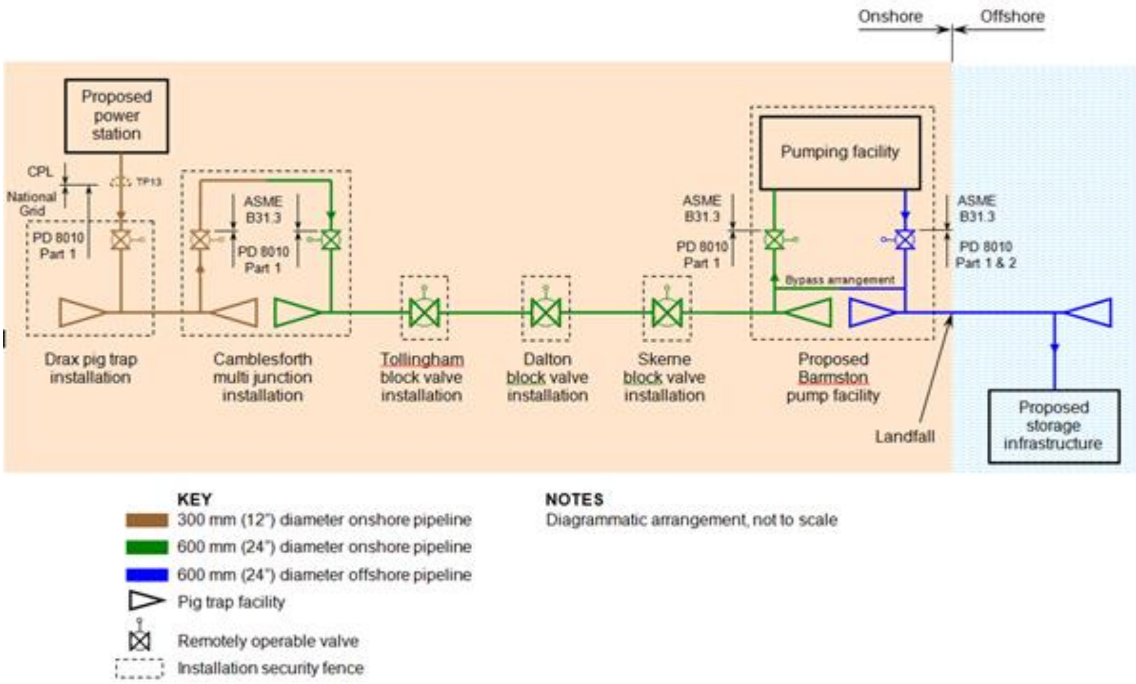
4 Transport and Storage

Figure 1.3 gives a geographical overview of the proposed CO_2 transportation system to the storage site in the North Sea.

Figure 4.1 provides a schematic diagram of the T&S system for the White Rose CCS Project.

Figure 4.1: Overall Schematic Diagram of the T&S System



Source: NGC

4.1 Onshore Transport Facility Description

4.1.1 Drax AGI

The Drax AGI is located in a fenced area within the overall OPP site. The AGI will include a 300mm ND (12") pipeline from the OPP, a Pig Launcher, valves, pipework with local and remote control and monitoring systems to enable on-going operations and maintenance of the transportation system, including the internal inspection of the proposed onshore pipeline.

Downstream of TP-13 at Drax AGI, there will be an electro-hydraulic valve to enable isolation of the transport system from the OPP. No duplication of filters and meters, rather repeat signals will be provided from the upstream OPP to NGC.

The GPU will include suitable SIL rated protection systems to protect the onshore transportation system.

The 300mm ND (12") pipeline will run approximately 6km from the Drax AGI to the Camblesforth Multi-Junction Installation.

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4.1.2 Camblesforth Multi-Junction Installation

The 300mm ND (12”) cross country pipeline (from the Drax pig launcher) arrives at a pig receiver located on the proposed Multi-Junction Installation, near Camblesforth (the Camblesforth Multi-Junction Installation). The purpose of this installation is to gather potential future pipelines from other regional carbon capture sources to be transported and stored within the White Rose storage system.

A 600mm ND (24”) connection with appropriate isolation valves will be provided to accommodate the installation of CO_2 pipelines from future facilities and their associated pig receivers (space for 1 x 600mm ND (24”) and 2 x 300mm ND (12”) future pig receivers). An electro-hydraulic valve to enable isolation of reverse flow to Drax / OPP from the future facilities in the event of transportation line catastrophic failure will be provided. A cross connection to a 600mm ND (24”) pipeline will be provided starting with a pig launcher and extending to a 69km, underground cross country pipeline to a pig receiver on the proposed pumping facility near Barmston, South of Bridlington (Barmston Pumping Facility).

4.1.3 Block Valve Stations

Three Block Valve Stations (BVS) across the 600mm ND (24”) pipeline between the Camblesforth Multi-Junction Installation and the Barmston Pumping Facility will be provided. They will be spaced at approximately 20km intervals across the pipeline. The proposed location is close to Tollingham, Dalton and Skerne. The purpose of the block valve stations is to enable the isolation of discrete sections of pipeline in the event of an emergency and the requirement to depressurise that section of pipeline, thereby reducing the inventory that requires venting.

The BVS will comprise of 600mm ND (24”) electro-hydraulic maintenance valves with associated pressurisation bypass across the block valve complete with valves, pressure and temperature monitoring to permit safe re-start.

4.1.4 Barmston Pumping Facility

The purpose of the Barmston Pumping Facility is to provide the requisite head to the liquid CO_2 over the range of anticipated process conditions for transportation to the offshore NUI for injection into the saline formation storage site located approximately 90 km away from the pumping facility.

Space is set aside in the pump enclosure for all electrically driven pumps, across initial and future phases. This is to accommodate the full range of pumping requirements from First Load (2.68 MTPA), including Minimum Flow (0.81 MTPA) and the future Full Flow design case (17.0 MTPA).

The equipment at the site includes, but is not limited to:

- 600mm ND (24”) pig receiver;
- Inlet filters (with adequate provision for future tie-in to accommodate full design flow of the CCS chain).
  - Proposed phasing is 2 x 100% at Year 1 (5.7 MTPA each);
  - An additional filter supplied in Year 5 at 5.7 MTPA capacity, creating a 3 x 50 % configuration;
  - A further filter supplied in Year 10 at 5.7 MTPA capacity, creating a 4 x 33.3 % configuration;
- Electrically motor driven pumps in a suitable configuration to accommodate first load, including expected minimum flow, with adequate tie-in for future pumps to accommodate full design flow for the CCS chain;

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- Proposed phasing is 3 x 50% at Year 1 (2.43 MTPA each);
  - An additional 3 pumps supplied in Year 5 at 2.43 MTPA capacity, creating a 6 x 20 % configuration;
  - A further 2 pumps supplied in Year 10 at 2.43 MTPA capacity, creating an 8 x 14.3% configuration;
- Pump recycle air cooler to cool the full flow from one booster pump during pump proving/testing operations;
- CO_2 metering and compositional analysis package;
- Mechanical High Integrity Pressure Protection System (HIPPS) valves to protect against offshore pipeline overpressure;
- Air compression and drying package;
- 600mm ND (24”) pig launcher (for offshore pipeline); and
- 600mm ND (24”) pipeline to landfall from where it is routed offshore.

A bypass arrangement will be provided around the Pumping Facility to ensure the continued onward flow of CO_2 from the 600mm ND (24”) onshore pipeline to the offshore NUI in the event of a shutdown or failure of the Barmston Pumping Facility. The bypassed dense phase CO_2 must be filtered to meet the requirements of the offshore facilities and the flowrate measured for metering purposes.

Emergency shutdown valves will be provided at the pumping site inlet and outlet along with shutdown valves at the suction and discharge of each pump to allow isolation of each pump in the event of an emergency (e.g. gas leak in the pump house).

A HIPPS is required to protect the downstream 1500# offshore pipeline as the CO_2 Booster Pumps are capable of delivering pressures in excess of 200 barg, offshore pipeline Maximum Incidental Pressure (MIP). The equipment and pipework on the discharge of the pumps up to and including the Barmston Pumping Facility boundary maintenance valve will be 2500# rated. This is likely to stretch to the landfall/offshore pipeline interface to satisfy HSE requirements.

4.2 Offshore Pipeline and Storage Facilities Description

4.2.1 Offshore Pipeline

The dense phase CO_2 is transported from the Barmston Pumping Facility to the offshore storage facility via a 600mm ND (24”) offshore pipeline which has a nominal length of 88 km.

4.2.2 Offshore Facilities

The White Rose offshore storage facility is a NUI wellhead injection platform. The platform comprises the following:

- Pig handling facilities;
- Cartridge type filters;
- Injection manifold;
- Three CO_2 injection wells which dispose of the CO_2 into the saline formation site located in the Southern North Sea. In the future, the numbers of injection wells can be increased. Each well will be individually metered;
- Utilities:
  - Mono Ethylene Glycol (MEG) storage and pumps to prevent CO_2 hydrate formation during well start-up operations and water wash activities;

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- – Water wash treatment facilities to avoid halite build up when CO_2 injection is shut-in (seawater lift pumps and caisson, filters and chemical treatment). Additional water wash facilities will be provided by a temporary skid (injection pumps, filters, power generation and chemicals);
- – Other utilities (drains system, diesel storage system, nitrogen (quads), fresh water system, power generation system, CO_2 vent, wellhead hydraulic power unit);
- Support systems (crane, temporary safe refuge, local equipment room, marine navigation aids, telecoms and helideck); and
- Safety systems (fire and CO_2 gas detection systems, helideck foam and Deck Integrated Fire Fighting System (DIFFS) package, life rafts and Totally Enclosed Motor Propelled Survival Craft (TEMPSC)).

The platform substructure will be a steel jacket. Additional allowance is to be built into the jacket with a module support frame to allow for the potential future installation of piping/equipment and associated instrumentation to transport CO_2 further afield of the Endurance storage site. Spare risers and J tubes will also be provided to accommodate the potential future modifications.

The installation is a NUI fixed four leg jacket offshore wellhead platform. The installation will initially have three platform wells for CO_2 injection. Each well will have a comparable design but with divergent trajectories, and have a tubing diameter of 5.5”. A total of six conductor slots will be installed to allow future expansion of the number of platform wells and in the future to install further wells to tie-back to the main platform.

The three platform CO_2 injection wells are specified for the First Load project on the basis of the specified flow rate flexibility required by the First Load.

4.2.3 Reservoir

The reservoir is the Bunter Sandstone formation of Triassic age. It is widely developed across the southern basin and in this area is between 200 and 250 metres thick. The sandstones were deposited in an arid fluvial / aeolian environment and form a thick package of fine grained sands with few shale inter-beds. The reservoir is heterogeneous at the small scale but analysis of the production test results in the appraisal well suggests that there are few barriers to horizontal flow in the reservoir. Baffles to vertical flow were identified but these are expected to be beneficial to the overall development of the CO_2 plume. Reservoir properties are good to excellent and are summarised in Table 4.1. Porosity is derived from well log data in the three wells which penetrate the structure and permeability is based on log derived values calibrated with both Modular Dynamic Tester (MDT) mobilities and the results of the 24 hour flow test which was carried out on the appraisal well.

Table 4.1: Reservoir Data

Parameter	
Top perforation depth TVD (P5W1/P5W2/P5W3) (Note 1)	1290/1292/1295 m
Top perforation depth MD (P5W1/P5W2/P5W3) (Note 1)	2029/2031/1588 m
Thickness	200-250 m
Porosity (average)	20-25%
Porosity (range)	10-30%
Permeability (average)	260 mD
Permeability	1 mD to > 5000 mD

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Parameter	
Reservoir Temperature at datum (Note 2)	57.2ºC
Temperature gradient	3.16 ºC per 100 m
Reservoir pressure at datum (Note 2)	141.2 barg
Pressure gradient	0.115 bar/m

Notes:
1. P5W1/P5W2/P5W3 are well identifiers.
2. Reservoir datum depth 1300 m TVDSS

4.3 Transport and Storage System Future Expansion

The strategic decision was taken to design the T&S system for future expansion beyond the initial First Load CO_2 supply. The intention is to create an onshore and offshore hub to reduce incremental costs for future entrants into the pipeline system. The proposed onshore and the offshore pipeline have an approximate capacity of 17 MTPA, which is well in excess of First Load supply of 2.68 MTPA from the OPP and the 10 MTPA expected maximum injection capacity into the proposed subsea storage reservoir.

Several key expansion decisions have been taken:

- The 600mm ND (24") pipeline has a capacity of 17MTPA (well in excess of the First Load supply of 2.68 MTPA and expected maximum injection capacity of the Endurance storage site of 10 MTPA);
- Space and tie-in's allowed for an additional filter supplied in Year 5 at 5.7 MTPA capacity, creating a 3 x 50 % configuration at the Barmston Pumping Station;
- Space and tie-in's allowed for a further filter supplied in Year 10 at 5.7 MTPA capacity, creating a 4 x 33.3 % configuration at the Barmston Pumping Station;
- Space and tie-in's allowed for an additional 3 pumps supplied in Year 5 at 2.43 MTPA capacity each, creating a 6 x 20 % configuration at the Barmston Pumping Station;
- Space and tie-in's allowed for a further 2 pumps supplied in Year 10 at 2.43 MTPA capacity each, creating an 8 x 14.3 % configuration at the Barmston Pumping Station;
- The platform will be designed to allow for future expansion of the CO_2 injection systems. This includes:
  - Spare well slots to allow for additional CO_2 injection wells within the Endurance storage site;
  - A spare export riser will allow for future onward transportation to further CO_2 storage sites;
  - A weight allowance will be provided in the platform jacket structure and module support frame to allow for the potential future installation of piping/equipment and associated instrumentation to permit injection into future CO_2 storage sites.
  - Spare J tube(s) will be provided for future import power cable(s);
  - Spare risers and J tubes will be included in the jacket to allow for future CO_2 and water production well tiebacks to maximise the storage site capacity;
  - Space for future temporary pig launchers/receivers will be allowed for in the design;
  - Space and tie-in's for additional filtration vessel(s);
  - Space and tie-in's for flowlines to/from future remote subsea injection wells /water producers and associated hydraulic control equipment;
  - Spare capacity will be included in the control systems for future CO_2 injection wells and water production wells.
- Once CO_2 injection rates increase beyond First Load, water production will be required from the Endurance storage site to maintain acceptable reservoir pressure. It is expected that up to eight water producers will be installed over the design life. Water must be discharged near the sea surface to allow

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for adequate dispersion. This can be achieved either by having individual well head structures for each water producer or by piping subsea water producers back to the central platform. This decision is not required to be made during FEED. However, the provision of spare water production risers on the platform hub and a water disposal caisson facilitates future tieback of water producers if this option is selected. No electric submersible pumps will be required. It is expected that any future water production wells will be controlled and powered via umbilical from the central platform.

At First Load (Year 1), the manifold will have three connections to the injection wells. Additional space is allowed for the following future connections:

- three connections to platform injection wells; and
- two connections for future sub-sea tie-backs.

4.4 Site Baseline Conditions

4.4.1 Barmston Pumping Station

Barmston area local meteorological conditions and maritime environment are shown in Table 4.2.

Table 4.2: Barmston Area Meteorological Design Data

Meteorological Conditions and Maritime Environment Data	
Temperature	
Based upon Meteorological Office data from Bridlington Marine Rescue Sub- Centre from 30.04.1987 to 15.10.2012.	
Maximum Recorded	31.2°C
Design Maximum	28°C
Minimum Recorded	-10.5°C
Design Minimum	-7°C
Precipitation	
Based upon Meteorological Office data from Bridlington Marine Rescue Sub- Centre from 2001 to 2010 inclusive.	
Wettest Day	58.2 mm
Wettest Month	183 mm
Maximum Snow Depth	12 mm
Wind	
Based upon Meteorological Office data from Bridlington Marine Rescue Sub-Centre from 2001 to 2010 inclusive.	
Highest Daily Mean Speed	32.5 Knots
Highest Gust Speed	62 Knots
According to the Met Office Regional Climate summary for NE England, the majority of the time the wind will blow from the range of directions between south and north west and the strongest winds nearly always blow from this range of directions. Spring time tends to have a maximum frequency of winds from the north east, due to a build-up of high pressure over Scandinavia at this time of year.	
Sunshine	
Based upon Meteorological Office data from Leconfield from 2002 to 2010 inclusive	
Maximum average monthly total sun	180.6 Hours
Minimum average monthly total sun	55.1Hours

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Barometric Pressure	
Taken from Jacobs' Feasibility Study Report for CO_2 Booster Facility although the original source is unclear	
Barometric Pressure Upper	96 kPa
Barometric Pressure Lower	104.4 kPa
Seismic Activity	
Data from the British Geological Survey (BGS) suggests that the site is located in an area of low seismic activity. According to the BGS website (www.bgs.ac.uk), most earthquakes occur on the western side of the British mainland and earthquakes are almost completely absent from north east England; however, the largest known British earthquake occurred near the Dogger Bank in 1931, with a magnitude of 6.1 on the Richter Scale (ML). This was located in the North Sea offshore from Barmston (latitude 54.080 longitude 1.500) at a depth of 23km.	

4.4.2 Offshore Environmental Data

4.4.2.1 Sea and Air Temperature

Air and seawater temperatures are shown in Table 4.3.

Table 4.3: Air and Seawater Temperatures

Parameter	Temperature(ºC)
Air (minimum)	-3.4
Air (maximum)	20.6
Sea surface (minimum)	4.2
Sea surface (maximum)	19.4
Sea bed (minimum)	4.2
Sea bed (maximum)	14.4

Notes:

1. Maximum and minimum ambient air temperatures are to be used for design of instrumentation, electrical equipment and Heating, Ventilating, and Air Conditioning (HVAC) on the platform.

4.4.2.2 Sea Water Properties

Seawater salinity in the Endurance storage area ranges between 34.25‰ (34.25 practical salinity units or psu) in winter and 34.5‰ in summer (UK Hydrographic Office), with average sea surface temperatures of between 5.3ºC in February and 14.0ºC in August (Cefas website). The water column does not stratify thermally in summer so the surface and bottom water temperatures will remain similar year round. The chemical composition of seawater with a salinity of 34.5% is given in Table 4.4.

Table 4.4: Seawater Chemical Ion Concentrations in the Endurance Storage Area

Chemical Ion Contributing to Seawater Salinity	Concentration in ‰
Chlorine	18.99
Sodium	10.55
Sulphate	2.65
Magnesium	1.27
Calcium	0.41
Potassium	0.38

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Chemical Ion Contributing to Seawater Salinity	Concentration in ‰
Bicarbonate	0.14
Bromide	0.07
Borate	0.03
Strontium	0.01
Fluoride	0.001
Other	<0.001

Typical seawater properties for the area are given in Table 4.5.

Table 4.5: Typical Seawater Properties

Parameter	Units	Value
Density	kg/m^3	1,025
Temperature - Ambient	ºC	4
Resistivity	ohm · m	0.20
Thermal conductivity	W/mºC	0.626
Volumetric expansion coefficient	Per ºC	0.1807×10^{-3}
Specific heat capacity	kJ/kgºC	4.2
Kinematic viscosity	m^2/s	1.2×10^{-6} (at 6ºC)

4.4.3 Geotechnical and Hydrographical Data

4.4.3.1 Metocean Data

Metocean criteria have been derived at 6 offshore sites as shown in Figure 4.2.

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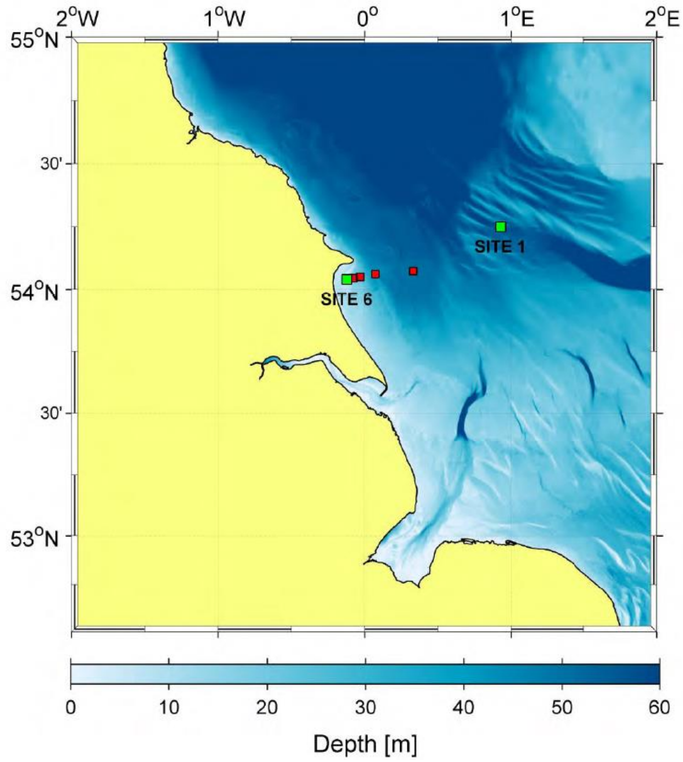
Figure 4.2: Offshore Metocean Sites



Source: NGC

Site 1 is the main platform location, with Sites 2 to 6 representing key points along the proposed pipeline route.

4.4.3.2 *Waves*

Wave data is presented below. Directional data specifies the direction where waves appear to originate.

Table 4.6: Maximum Wave Data

Site	Parameter	1 Year Maximum Wave Data	10 Year Maximum Wave Data	100 Year Maximum Wave Data
1	Hmax (m)	12.1	15.1	17.9
	Tass (s)	10.9	12.2	13.2
2	Hmax (m)	11.2	14.2	17.0
	Tass (s)	10.7	12.0	13.1
3	Hmax (m)	10.5	13.2	15.7
	Tass (s)	10.5	12.1	13.3
4	Hmax (m)	8.9	11.1	13.2
	Tass (s)	10.3	11.8	13.0
5	Hmax (m)	8.2	10.2	11.9
	Tass (s)	10.1	11.5	12.5

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Site	Parameter	1 Year Maximum Wave Data	10 Year Maximum Wave Data	100 Year Maximum Wave Data
6	Hmax (m)	4.8	5.9	6.9
	Tass (s)	7.5	8.3	8.8

Wave data was sourced for all six sites indicated in Figure 4.2 above. The table below provides the wave data for Site 1.

Table 4.7: Site 1 Wave Data

Direction	1 Year Wave Data		10 Year Wave Data		100 Year Wave Data	
(From)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
Omni - directional	6.3	11.2	8.0	12.6	9.5	13.7
North	6.3	11.2	8.0	12.6	9.5	13.7
North – East	5.6	10.6	7.1	11.9	8.5	12.9
East	4.8	9.8	6.1	11.0	7.2	12.0
South – East	5.0	10.1	6.4	11.3	7.6	12.3
South	4.9	10.0	6.3	11.2	7.5	12.2
South – West	5.1	10.2	6.5	11.4	7.7	12.4
West	5.4	10.4	6.8	11.6	8.1	12.7
North - West	5.9	10.9	7.5	12.2	8.9	13.3

4.4.3.3 Currents

Current data was sourced for all six sites indicated in Figure 4.2 above. The table below provides the data on currents for Site 1. Directional data specify the direction currents are going "towards".

Table 4.8: Site 1 Current Data

	1 m Above Bed (m/s)			3 m Above Bed (m/s)			Mid - Depth			Surface		
Direction (Towards)	1 Year Data	10 Year Data	100 Year Data	1 Year Data	10 Year Data	100 Year Data	1 Year Data	10 Year Data	100 Year Data	1 Year Data	10 Year Data	100 Year Data
Omni - directional	0.55	0.60	0.64	0.65	0.70	0.75	0.90	0.97	1.03	0.99	1.07	1.14
North	0.52	0.56	0.60	0.60	0.65	0.70	0.83	0.90	0.96	0.92	1.00	1.06
North-East	0.19	0.20	0.22	0.22	0.24	0.25	0.30	0.33	0.35	0.33	0.36	0.39
East	0.20	0.21	0.23	0.23	0.25	0.27	0.32	0.34	0.37	0.35	0.38	0.40
South-East	0.54	0.59	0.63	0.63	0.69	0.73	0.88	0.95	1.01	0.97	1.05	1.12
South	0.54	0.58	0.62	0.63	0.68	0.73	0.87	0.94	1.00	0.96	1.04	1.11
South-West	0.23	0.25	0.27	0.27	0.29	0.31	0.37	0.40	0.43	0.41	0.44	0.47
West	0.26	0.28	0.30	0.30	0.33	0.35	0.42	0.45	0.48	0.46	0.50	0.53
North-West	0.55	0.60	0.64	0.65	0.70	0.75	0.90	0.97	1.03	0.99	1.07	1.14

4.5 Design Life

The T&S facilities will be designed for a 40 year design life when practical. Some facilities, subject to obsolescence (e.g. control systems) or wear (e.g. wells choke valves), may have shorter a design life and require upgrade or replacement.

4.6 Design Conditions Onshore Transport System

4.6.1 Onshore Pipeline and AGIs

The pressure and temperature conditions for the onshore pipelines and the AGIs are given in Table 4.9.

Table 4.9: Onshore Pipeline and AGIs Pressure and Temperature Conditions

Parameter	Units	Max	Min	Normal	Comments
Pipeline Maximum Allowable Operating Pressure (MAOP)	barg	135	-	-	According to Pipeline Code PD8010-1, the design pressure is of the pipeline is taken as the MAOP. The MIP allows excursions up to 10% above the MAOP for short, infrequent periods. The MIP = 148.5 barg. The MIP level will be protected by the upstream OPP SIL rated protection device(s).
Pipeline Design Pressure	barg	135			
Pipeline Normal Operating Pressures	barg	135	90	-	Operating pressure is the normal export pressure of the upstream OPP less pipeline losses. Minimum operating pressure is set along the length of the pipeline to ensure a margin above the critical point so that the CO_2 remains in the dense phase.
AGI Design Pressure	barg	148.5	-	-	-
AGI Design Temperature	°C	50	-46	-	-
Pipeline Design Temperature	°C	25	0	-	The maximum and minimum design temperatures will be protected by upstream OPP SIL rated protection device(s). Additional charpy testing at -20°C recommended to facilitate pipeline depressurising operations.
Pipeline Normal Operating Temperatures	°C	20	5	≤20	The normal operating temperature is the normal export temperature of the OPP less pipeline losses.
Buried Pipeline Temperature	°C	15	4	-	-

4.6.2 Pumping Station

The pressure and temperature conditions for the pumping station inlet/ outlet are given in Table 4.10.

Table 4.10: Pumping Station Pressure and Temperature Conditions

Parameter	Units	Max	Min	Normal	Comments
Pumping Facility Inlet Conditions					

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Parameter	Units	Max	Min	Normal	Comments
Design Pressure	barg	148.5	-	-	-
Normal Operating Pressure	barg	135	90	-	Operating pressure is the normal export pressure of the upstream OPP less pipeline losses. Minimum operating pressure is set throughout the pumping station to ensure a margin above the critical point so that the CO_2 remains in the dense phase.
Design Temperatures	°C	50	-46	-	Design temperatures quoted are based on low temperature carbon steel material limits, and limits within the onshore pipeline design codes.
Normal Operating Temperatures	°C	18	4.5	15	The normal operating temperature is the normal export temperature of the OPP less pipeline losses.
Pumping Facility Outlet Conditions					
Design Pressure	barg	281.5 (Note 1)	-	-	This is the pressure up to the point of the Barmston Pumping Facility boundary maintenance valve (34-HV-008). A HIPPS system, located downstream of the pumps, is employed to protect the offshore pipeline (designed for 182 barg, with a MIP of 200 barg) from overpressure in the event of a blocked discharge.
Normal Operating Pressure	barg	182 (Note 1)	138	-	The minimum operating discharge pressure of the pump will initially be 138 barg for Year 5 flowrates with a reservoir pressure of 171 barg (winter case). Normal operating discharge pressure. Over time the injection pressure will need to be increased which will require a greater discharge pressure from the pump.
Design Temperatures	°C	50	-46		Design temperatures quoted are based on low temperature carbon steel material limits, and limits within the onshore pipeline design codes.
Normal Operating Temperatures	°C	30	4.5	-	Maximum pump forward flow operating temperature is 30°C. However, in “recycle” mode for pump proving/start-up operations, maximum anticipated temperature is 45°C.

Notes:

1. Following Year 10 operation there may be a requirement to up-rate the pumps at Barmston (therefore avoiding the requirement for additional pumping and associated recycle cooler at the offshore platform), to transport CO_2 via the offshore hub to remote storage sites. The offshore pipeline and riser will be mechanically designed to be suitable for an increased MAOP of 235 barg (and MIP 250.5 barg, limited to the platform piping 1500# class limit at 50°C). The equipment, piping and instrumentation at the pumping station installed for Year 1 operation should have its suitability assessed for the increased pressure (class limits for increased pressures and temperatures, testing and certification requirements including hydrotest pressures, etc).

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4.7 Design Conditions Offshore Facilities

4.7.1 Design Conditions Offshore Pipeline

Key design and operational parameters for the offshore pipeline are provided within Table 4.11 below.

Table 4.11: Offshore Pipeline Operating and Design Conditions

Parameter	Units	Max	Min	Comments
Offshore Pipeline Design Pressure		235		
Pipeline MAOP	barg	182 (Note 1)	-	According to Pipeline Code PD8010-2, the design pressure of the pipeline is taken as the MAOP. MIP allows excursions up to 10% above the MAOP for short, infrequent periods. The MIP = 200 barg.
Pipeline Normal Operating Pressures	barg	182	90	
Pipeline Normal Operating Temperatures	°C	29.3 (Note 2)	1	
Pipeline Design Temperature	°C	40	0	Additional charpy testing at -20°C recommended facilitating pipeline depressurising operations.
Riser Design Temperature	°C	50	-46	

Notes:

1. The offshore pipeline and riser will be mechanically designed to be suitable for an increased MAOP of 235 barg (and MIP of 250.5 barg, limited to the offshore platform 1500# piping class limit at 50°C). This is to facilitate the future potential for up-rating the pumps at Barmston Pumping Station (therefore avoiding the requirement for additional pumping and associated recycle cooler at the offshore platform) post Year 10 operation to transport CO_2 via the offshore hub to remote storage sites.
2. The maximum operating temperature at the pump discharge pressure of 235 barg has been estimated as 33.4°C.

4.7.2 Offshore Facilities Design Conditions

The pressure and temperature conditions for the platform are given below.

Table 4.12: Offshore Facilities Pressure and Temperature Conditions - Process

Parameter	Units	Max	Min	Comments
Design Pressure	barg	200 (Note 1)	-	This pressure is the maximum incidental pressure of the incoming 600mm ND (24”) pipeline and riser.
Normal Operating Pressure	barg	182 (Note 1)	90	182 barg is the maximum allowable operating pressure of the incoming 600mm ND (24”) pipeline and riser. Initial injection pressure set point at the offshore platform (upstream of the chokes) is estimated to be 100 barg (winter-summer) to avoid CO_2 entering the two-phase region. Over time the injection pressure will need to be increased which will require a greater discharge pressure from the onshore pumps. Minimum operating pressure is set along the length of the pipeline to ensure a margin above the critical point so that the CO_2 remains in the

Parameter	Units	Max	Min	Comments
				dense phase.
Design Temperatures	°C	50	-46	Maximum temperature is that for black body. The minimum possible theoretical temperature of dense phase CO_2 during depressurisation to atmospheric pressure is -79ºC. Heat input and metal heat capacity will increase this temperature.
Normal Operating Temperatures	°C	16	1	

Notes:

1. Post Year 10 operation, the design pressure may require up-rating to 250.5 barg (1500# piping class limit at a design temperature of 50°C. The corresponding MAOP will be 235 barg) to facilitate up-rated pumps at Barmston Pumping Station (therefore avoiding the requirement for additional pumping and associated recycle cooler at the offshore platform), to transport CO_2 via the offshore hub to remote storage sites.

Table 4.13: Offshore Facilities Pressure and Temperature Conditions - Utilities

Parameter	Units	Max	Min	Comments
Design Pressure (atmospheric storage tanks)	mbarg	70 plus static head	-	Tanks with an open vent to atmosphere. Static head when full of water or product if specific gravity exceeds 1.
Shut-in Pressures downstream of chokes	barg	80barg	-	
Design Temperatures	°C	50	-10	Maximum temperature is that for black body.
Normal Operating Temperatures (exposed to atmosphere)	°C	28	-7	Maximum and minimum ambient air temperatures shown on the left include a margin on those shown in Section 4.4.2.
Normal Operating Temperatures (involving seawater)	°C	19	4	See Section 4.4.2.

4.8 Regulations, Codes and Standards

The CDM Regulations 2015 apply to the onshore transportation system up to the connection point for the offshore pipeline at the landfall.

The Offshore Storage Facility shall comply with the requirements of the Offshore Installations (Safety Case) Regulations 2005.

All plant and materials shall be designed in accordance with suitable codes and standards as appropriate. The order of precedence for codes and standards shall be:

- UK legal requirements (laws, edicts, regional or local regulations, etc.);
- Company Specifications;
- Data sheets / drawings (where applied);
- Project design philosophies;
- Primary project specifications;
- Contractor specifications and standards approved by Company; and
- International Codes and Standards.

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5 Basis of Design Changes during FEED

5.1 OPP

5.1.1 OPP Performance Coal and Coal Range

The range of coals to be burned by the OPP was revised as a result of the closure of a number of UK collieries (Kellingley, Maltby,Draw Mill). This resulted in a change in the specified range for sulphur and ash.

While the plant is designed to burn a range of UK and imported coal, an alternative UK coal specification was taken as the performance coal (SC Ravenstruther SC01).

5.1.2 Limestone and Gypsum

Limestone and gypsum will be transported by trucks instead of conveyors.

5.1.3 Minimum Stable Load

The maximum, normal, and minimum CO_2 flowrates to the pipeline underwent a minor revision during FEED:

- Design Flowrate: increased from 302.7 TPH to 305.4 TPH , a small increase (~1%) reflecting an increase in the CO_2 captured;
- Normal Flowrate: increased from 259 TPH h to 263.3 TPH, a small increase of ~1% reflecting an increase in the CO_2 captured; and
- Minimum Flowrate changed from 70 TPH to 95.5 TPH reflecting revision of minimum stable load from 25% to 35% TMCR.

CO_2 Flowrates

The maximum, normal, and minimum CO_2 flowrates to the pipeline underwent a minor revision during FEED:

- Design Flowrate: increased from 302.7 TPH to 305.4 TPH , a small increase (~1%) reflecting an increase in the CO_2 captured;
- Normal Flowrate: increased from 259 TPH h to 263.3 TPH, a small increase of ~1% reflecting an increase in the CO_2 captured; and
- Minimum Flowrate changed from 70 TPH to 95.5 TPH reflecting revision of minimum stable load

5.1.4 Biomass

Biomass co-firing considered in FEED but now a future potential option rather than part of base OPP design.

5.1.5 Coal Conveyor Sizing

Coal conveyor sizing reduced from 2 x 320 tph to 2x 160 tph.

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5.1.6 Grid Connection

The connection to the electrical grid was changed from 132 kV to 400 kV following an assessment of the options by NGET.

This changed the location of the connection, route of the cable from the OPP to the NGET switchyard and transformer selections within the OPP.

5.2 Transport and Storage

5.2.1 Well Sizes

At the start of FEED the basis was to include a 4.5” well as well as two 5.5” wells, as it was thought that the smaller well would help reduce the tendency for two phase flow at start-up and shut-down.

However through FEED it was concluded that:

- two phase flow would not be eliminated by the use of a 4.5” well;
- if there was a benefit in a 4.5” well then on the basis of reliability there should be two; and
- using 4.5” wells that could only handle a maximum flowrate of 1.8 MTPA, which is only about two thirds of the First Load design flowrate reduced flexibility.

A decision was taken to use three 5.5” wells only.

5.2.2 Barmston Pumps

To reduce the quantity and cost of sparing, a decision was to use the same specification for all the booster pumps to be located at the Barmston Pumping Facility.

5.2.3 Offshore Pipeline

Originally it was envisaged that space would be provided on the offshore platform for a second series of booster pumps. The additional pressure provided by these pumps would be used to transport the CO_2, still in dense phase, to wells further afield of the original platform. However, these “future” pumps would require a power source such as a diesel engine or, as was judged more economical over the project lifetime, electric motors supplied by a subsea cable laid from the mainland. Although the cheaper option for powering the offshore pumps, such a cable would still be expensive.

A further assessment concluded that the pressure required to service the remote wells would not exceed 235 barg and that this pressure could be provided by land-based pumps at the Barmston AGI. To provide this future option the equipment at the pumping station, the offshore pipeline and installation could be designed with a sufficiently high pressure rating to allow for this change in operating pressure. Estimates indicated that the costs associated with this design change would be significantly lower than the future cost of installing a subsea cable to the platform.

As a result the decision was made that the likelihood of the need for the increased CO_2 pressure, justified the additional initial investment.

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6 Glossary

AGI	Above Ground Installation
AOD	Above Ordnance Datum
AQCS	Air Quality Control Systems
ASU	Air Separation Unit
bara	bar absolute
barg	bar gauge
BGS	British Geological Survey
BMCR	Boiler Maximum Continuous Rating
BOC	The BOC Group Ltd
BoD	Basis of Design
BVS	Block Valve Stations
C	Degrees Celsius
CC	Climate Change
CCS	Carbon Capture and Storage
CDM	Construction Design and Management
CfD	Contract for Difference
CO_2	Carbon Dioxide
COMAH	Control of Major Accident Hazards
CPL	Capture Power Limited
CW	Cooling Water
DAS	Distributed Acoustic Sensors
DCC	Direct Contact Cooler
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
DIFFS	Deck Integrated Fire Fighting System
DPL	Drax Power Ltd
DTS	Distributed Temperature Sensors
EPC	Engineering Procurement and Construction
ESP	Electrostatic Precipitator
EUETS	European Union Emissions Trading Scheme
EUIED	EU Industrial Emission Directive
FEED	Front End Engineering Design
FGC	Flue Gas Compressor

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FGD	Flue Gas Desulphurisation
GPU	Gas Processing Unit
GSD	Geological Storage Directive
HIPPS	High Integrity Pressure Protection System
H_2O	Water
H_2S	Hydrogen Sulphide
HSE	Health and Safety Executive
HVAC	Heating, Ventilating, and Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
KKD	Key Knowledge Deliverable
LOX	Liquid Oxygen
MAOP	Maximum Allowable Operating Pressure
MDT	Modular Dynamic Tester
MEG	Mono Ethylene Glycol
MIP	Maximum Incidental Pressure
MTPA	Million Tonnes Per Annum
MWe	Megawatt (electrical)
NACE	National Association of Corrosion Engineers
ND	Nominal Diameter
NGC	National Grid Carbon
NGET	National Grid Electricity Transmission
NTS	National Transmission System
NUI	Normally Unattended Installation
O_2	Oxygen
O&M	Operation and Maintenance
OPP	Oxy Power Plant
PDG	Permanent Down-Hole Gauge
PIG	Pipeline Inspection Gauge
ppmv	Parts per million by volume
RAM	Reliability, Availability and Maintainability
SCR	Selective Catalytic Reduction
SEL	Stable Export Limit
SIL	Safety Integrity Level

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SOL	Safe Operating Limit
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
THP	Tubing Head Pressure
THT	Tubing Head Temperature
TMCR	Turbine Maximum Continuous Rating
TP	Terminal Point
T&S	Transport and Storage

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