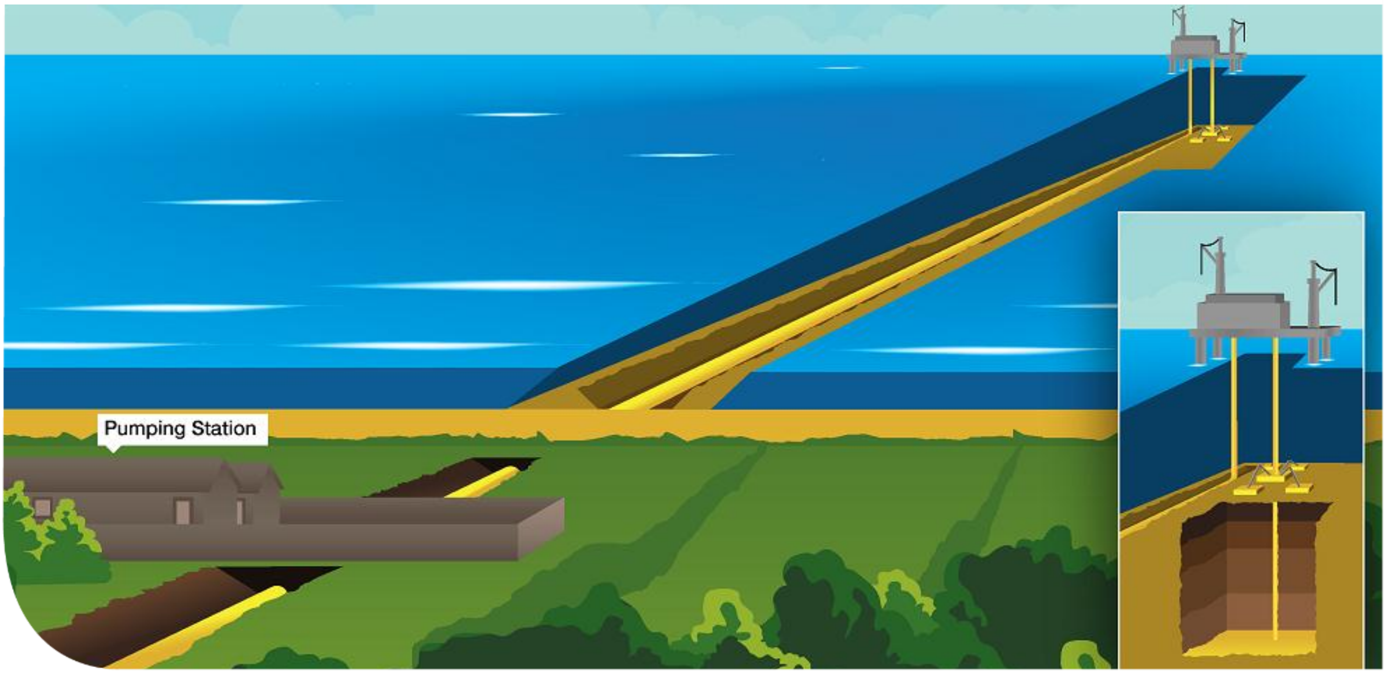
January 2016

K29: Transport - Process Description

Technical Transport



Contents

Key Words

Key Work	Meaning or Explanation
Carbon	An element, but used as shorthand for its gaseous oxide, CO_2.
Capture	Collection of CO_2 from power station combustion process or other facilities and its process ready for transportation.
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.
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	Moving processed CO_2 by pipeline from the capture and process unit to storage.

Executive Summary

This report is one of a series of reports; these “key knowledge” reports are issued here as public information. These reports were generated as part of the Front End Engineering Design (FEED) Contract agreed with the Department of Energy and Climate Change (DECC) as part of the White Rose Project.

White Rose seeks to deliver a clean coal-fired power station using oxy-fuel technology fitted with carbon capture storage (CCS), which would generate up to 448MWe (gross) while capturing at least 90% of the carbon dioxide (CO_2) emissions. CCS technology allows the carbon dioxide produced during combustion to be captured, processed and compressed before being transported to storage in dense phase. The dense phase carbon dioxide would be kept under pressure while it is pumped through an underground pipeline to the seashore and then through an offshore pipeline to be stored in a specially chosen rock formation under the seabed of the southern North Sea.

Delivery of the full-chain project is be provided by National Grid Carbon Limited (NGCL), which is responsible for the T&S network, and Capture Power Limited (CPL), which is responsible for the Oxy Power Plant (OPP) and the Gas Processing Unit (GPU).

This “key knowledge deliverable” (KKD) describes the process for the transfer of CO_2 from the OPP to offshore for storage, the pipeline transportation scheme including relevant infrastructure, the rationale behind the design and configuration of the main process equipment and it provides descriptions of the major equipment items and packages.

1 Introduction

National Grid Carbon Limited (NGCL) is a wholly owned subsidiary of the National Grid group of companies. Capture Power Limited (CPL) is a special purpose vehicle company, which has been formed by a consortium consisting of General Electric (GE), Drax and BOC, to pursue the White Rose (WR) carbon capture storage (CCS) Project (the WR Project).

CPL have entered into an agreement (the Front End Engineering Design (FEED) Contract) with the UK Government's Department of Energy and Climate Change (DECC) pursuant to which it will carry out, among other things, the engineering, cost estimation and risk assessment required to specify the budget required to develop and operate the WR Assets. The WR Assets comprise an end-to-end electricity generation and carbon capture and storage system comprising, broadly: a coal fired power station utilising oxy-fuel technology, carbon dioxide capture, processing, compression and metering facilities; transportation pipeline and pressure boosting facilities; offshore carbon dioxide reception and processing facilities, and injection wells into an offshore storage reservoir.

CPL and NGCL have entered into an agreement (the KSC) pursuant to which NGCL will perform a project (the WR T&S FEED Project) which will meet that part of CPL's obligations under the FEED Contract which are associated with the T&S Assets. The T&S Assets include, broadly: the transportation pipeline and pressure boosting facilities; offshore carbon dioxide reception and processing facilities, and injection wells into an offshore storage reservoir.

A key component of the WR T&S FEED Project is the Key Knowledge Transfer process. A major portion of this is the compilation and distribution of a set of documents termed Key Knowledge Deliverables, which this document represents.

2 Purpose

The purpose of this document is to describe the onshore and offshore pipeline transportation scheme including relevant infrastructure and the rationale behind the design and configuration of the main process equipment. It provides descriptions of the major equipment items and packages, namely:

- pumps, cooler package;
- compressed air package;
- lube-oil package;
- analyser package;
- metering package; and
- platform diesel generator.

This document also describes the philosophy and process of CO_2 transfer from the power plant source to offshore for storage. It describes the onshore and offshore pipeline, the control and monitoring systems, the venting philosophy, the CO_2 specification including the impact of impurities and design considerations for the various operational modes. The process description includes:

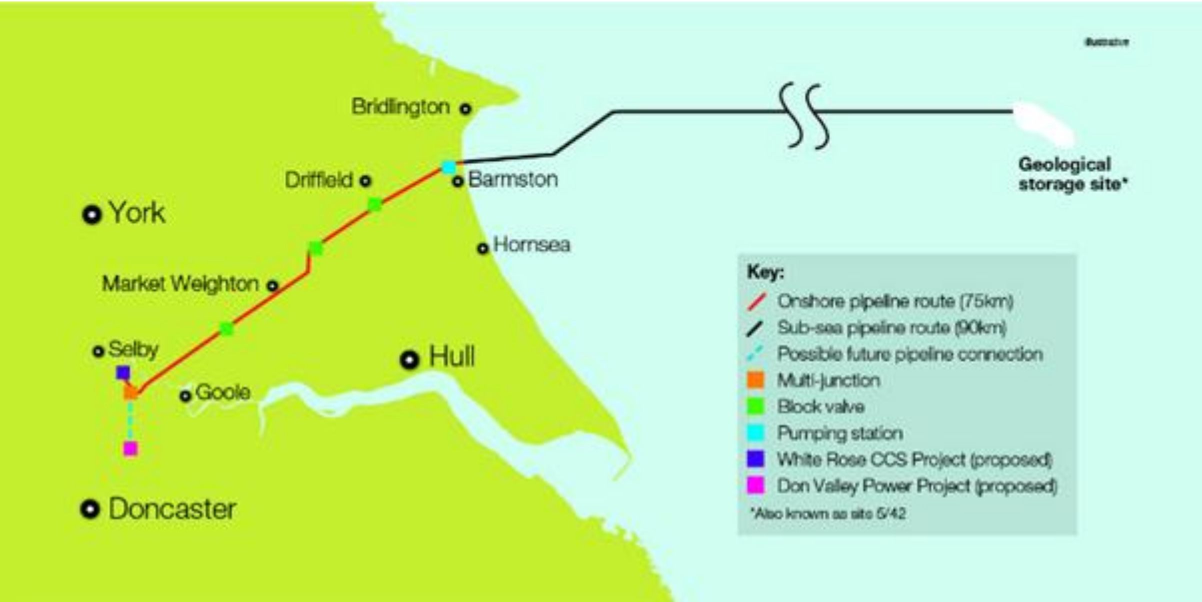
- a description of venting philosophy;
- pipeline specification;
- pipeline length, diameter, wall thickness, material and corrosion allowances (internal and external);
- pipeline operating and design conditions;
- design considerations for each of the operational modes;
- provision for shutdown and containment of pipeline contents;
- specification of CO_2 and impact of impurities;
- pipeline pressure protection systems;
- pipeline cathodic protection;
- pipe-lay method, extent and method of burial and/or other protection, construction methodology;
- line-pipe material grade and specified minimum yield stress;
- monitoring and testing (using a pipe inspection gauge (PIG));
- a description of any line packing including consideration of associated increased pressure; and
- pipeline weight coating and trenching requirements.

3 Overview

In December 2013 UK Government Department of Energy and Climate Change (DECC) awarded a Front-End Engineering Design (FEED) contract to the White Rose project as part of their CCS Commercialisation Programme.

The project comprises a state-of-the-art coal-fired power plant that is equipped with full CCS technology. The plant would also have the potential to co-fire biomass. The project is intended to prove CCS technology at a commercial scale and demonstrate it as a competitive form of low-carbon power generation and as an important technology in tackling climate change. It would also play an important role in establishing a CO_2 transportation and storage network in the Yorkshire and Humber area. Figure 3.1 below gives a geographical overview of the proposed CO_2 transportation system.

Figure 3.1: Geographical Overview of the Transportation Facility

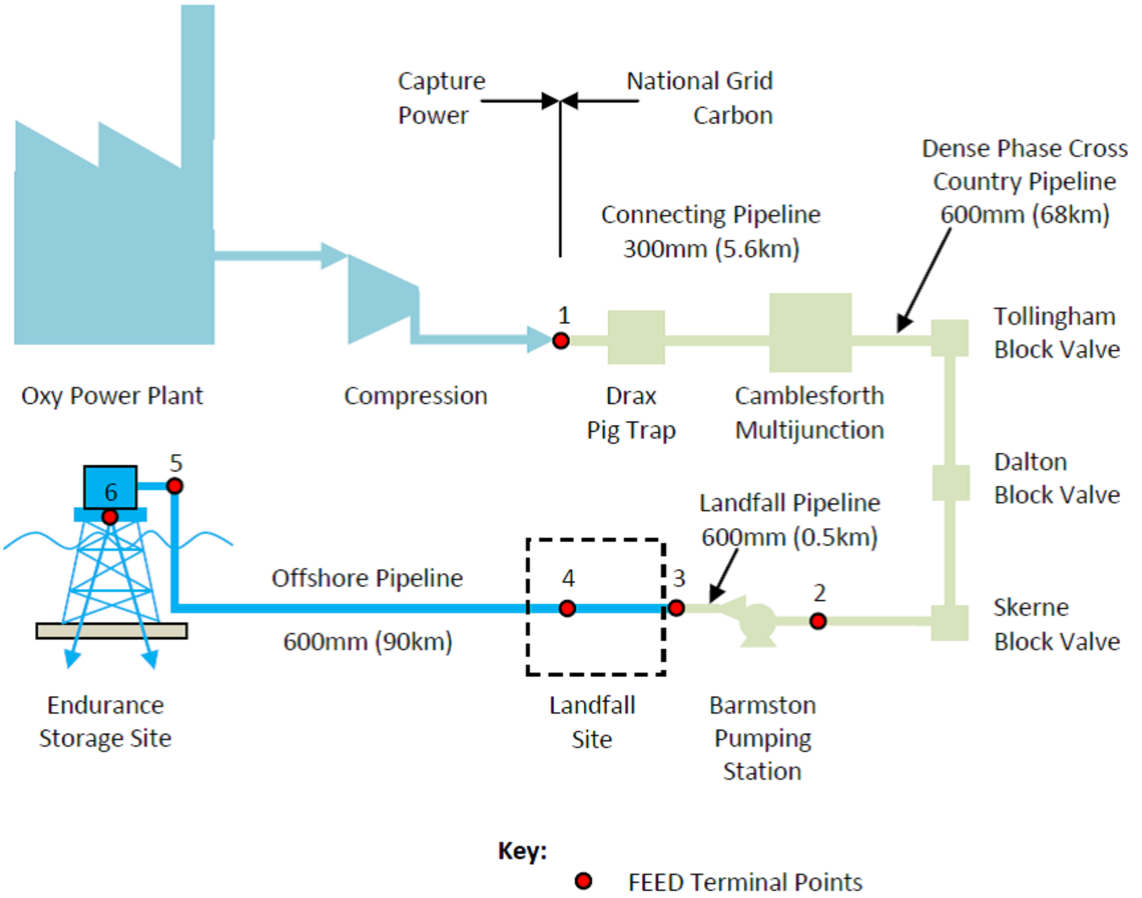


The standalone power plant would be located at the existing Drax Power Station site near Selby, North Yorkshire, generating electricity for export to the Electricity Transmission Network (the "Grid") as well as capturing approximately two million tonnes of CO_2 per year, some 90% of all CO_2 emissions produced by the Oxy Power Plant (OPP). The by-product CO_2 from the OPP would be compressed and transported via an export pipeline for injection into an offshore saline formation (the reservoir) for permanent storage.

The power plant technology, which is known as Oxyfuel combustion, burns fuel in a modified combustion environment with the resulting combustion gases being high in CO_2 concentration. This allows the CO_2 produced to be captured without the need for additional chemical separation, before being compressed into dense phase and transported for storage.

The overall integrated control of the End-to-End CCS chain would have similarities to that of the National Grid natural gas pipeline network. Operation of the Transport and Storage System would be undertaken by NGCL. However, transportation of carbon dioxide presents differing concerns to those of natural gas; suitable specific operating procedures would be developed to cover all operational aspects including start-up, normal and abnormal operation, controlled and emergency shutdowns. These procedures would include a hierarchy of operation, responsibility, communication procedures and protocols. Figure 3.2 below provides a schematic diagram of the overall end-to-end chain for the White Rose CCS Project.

Figure 3.2: End To End Chain Overall Schematic Diagram



The 5/42 geological storage site and the offshore platform facility at point 6 on Figure 3.2 have been renamed “Endurance”.

4 Description of Process

4.1 Transport Facility

4.1.1 Onshore Transport Facility

The proposed CO_2 transportation system commences with the outlet of the OPP at the Drax site with a short section of above ground piping and then underground to the PIG launcher. This 300mm ND line emerges above ground adjacent to the OPP Drax site where it meets the PIG launching facility for the cross country 6km pipeline, buried at a minimum of 1.2 m depth, to a multi-pipeline junction at Camblesforth, which is one of the Above Ground Installations (AGIs).

To facilitate inspection and cleaning, the proposed multi-junction installation would require a PIG receiver for the 300mm ND incoming pipeline from Drax and a PIG launcher for the 600mm ND outbound pipeline, buried at a minimum of 1.2 m depth, routed to the Pumping Facility at Barmston at approximately 69km distance. The multi-junction would also be designed to enable multiple connections to pipelines from other regional carbon capture sources. A 600mm ND connection would be provided to accommodate the installation of PIG receivers and flows from future facilities. PIGs are carried by the fluid flow from launcher to a receiver.

Three unmanned AGIs are proposed along the 600mm ND underground pipeline from Camblesforth to the Barmston Pumping Facility, located near Tollingham, Dalton and Skerne. Block valves site at these AGIs enable the isolation of discrete sections of pipeline in the event of an emergency or for maintenance purposes.

The Barmston Pumping Facility would be located approximately 1km north of the village of Barmston and 500m landward of the proposed landfall location. The unmanned facility would be capable of meeting the First Load (calculated to be 2.68 million tons per annum (MTPA)) requirements including the minimum flow case (0.58MTPA) over the range of process conditions. Connections for additional pumping capability would be provided to accommodate the future expansion of the CO_2 transportation network.

NGCL have taken the strategic investment decision to design the transportation and storage 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. This is why the proposed onshore pipeline from the Camblesforth Multi-Junction and the offshore pipeline from Barmston to the offshore Normally Unmanned Installation (NUI) are 600mm ND with an approximate capacity of 17MTPA, which would be well in excess of First Load supply of 2.68MTPA and the 10MTPA expected maximum injection capacity into the proposed subsea storage reservoir.

Provision would be made to bypass the Barmston Pumping Facility from the onshore pipeline to offshore in the event of the pumping facility being unavailable. This bypass flow would be filtered and metered. A PIG launcher would be required at Barmston for cleaning and monitoring of the 600mm ND pipeline routed offshore to the NUI.

The 600mm ND pipeline immediately downstream of the Barmston Pumping Facility would continue to be buried at a minimum of 1.2 m depth and would be routed to the offshore NUI along a specific pipeline corridor. The NUI would be located approximately 90km offshore from landfall. The offshore section of pipeline would be buried and trenched for the first 15km to a water depth of 32m below Lowest Astronomical Tide (LAT). The remaining length of offshore pipeline would be laid on the sea bed.

The design life of the onshore and offshore pipelines, together with the AGIs at Drax, Tollingham, Dalton and Skerne and the Barmston Pumping Facility is 40 years.

4.1.2 Offshore transport Facility

A short onshore section of pipe would route the pipeline from the Barmston pumping station to the beach.

The interface between the onshore and the offshore pipeline would be the tie-in location between the two pipe sections. The tie-in would be constructed in a cofferdam on the beach at Barmston; the beach would be reinstated after completion of construction.

The 600mm ND offshore pipeline extends in an easterly direction from the landfall at Barmston to the offshore tie-in at the offshore platform. The pipeline would cross the proposed line of two HVDC Dogger Bank cables and the 44-inch Langeled pipeline.

A 600mm ND tie-in spool (prefabricated pipe) would commence at the end of the pipeline and would terminate at the bottom of the riser at the Endurance offshore platform. The offshore scope ends at the top of the riser at a dead weight support on the offshore platform.

The platform includes a PIG receiving facility and CO_2 injection wells which store the CO_2 into the saline formation of the storage site located in of the Southern North Sea.

4.1.3 PIG Utilisation

Pipeline PIGs would be used for various inspection and maintenance operations on a pipeline. This would be done without stopping the flow of the product in the pipeline. The Pipeline PIGs would be inserted into a launcher (essentially an oversized section in the pipeline, reducing to the normal diameter). The launcher would be then closed and the pressure-driven flow of the product in the pipeline would be used to push it along down the pipe until it reaches the receiving trap.

The PIG trap main barrel is normally a couple of pipe sizes bigger than the pipeline with a bottom flat eccentric reducer guiding the PIG into the pipeline When fluid is passed through the trap, the PIG is forced along the pipeline, carried by the flow. The PIG traps would be designed as part of the pipeline and would be classified as pressure vessels, but designed as quick opening enclosures rather than multi-bolt flanged ends.

4.2 Design Cases and Compositions

4.2.1 Design Flow Cases

Throughout the design life of the CO_2 transportation system, the anticipated flowrates would increase, as the number of power plants and other emitters, which capture carbon using various technologies, become operational and start producing carbon dioxide for storage offshore. The CO_2 transportation network is expected to develop in overall production as detailed in Table 4 1.

Table 4 1: Predicted Development of CO_2 Transport System

Flow Case	Year 1 (First Load) MTPA	Year 5 MTPA	Year 10 MTPA
Design	2.68	10.0	17.0
Normal	2.31	10.0	17.0
Minimum	0.58	0.58	0.90

The ramp rates (the speed at which the flow could be increased) during normal operation would be 2% of the maximum flow per minute. Table 4.2 summarises the operational scenarios and the percentage full load where the transition (change over) is permitted:

Table 4.2: Capture Plant Ramp Rates

Status Of Capture Plant	Initial Operational Mode	Target Operational Mode	Transition (% Full Load)	Ramp Rate (% maximum flow per minute)
Start-Up	Air	Oxy	40 to 50 (Note 1)	2%
Normal	Air	Oxy	40 to 50 (Note 1)	2%
Shutdown/Trip	Oxy	Shutdown	100 to 40 (Note 2)	2%

Notes on Table 4.2 above:

(1) Assuming the plant made the transition to Oxy mode (from air to carbon capture) at 40% load, there would then be a period of time following the transition, during which there was no transportation flow, to allow the CO_2 purity to be established. This would be followed by a fairly rapid ramp up of the flow to 40% flow, at a rate determined by the speed that the control valve upstream of the OPP is programmed to open, followed by a ramp from 40% to 100% at 2% per minute, hence taking an half-hour.

(2) During shut-down and plant trip the plant would ramp down from 100% to 40% at 2% per minute at which point the control valve at the OPP tie-in would close at the maximum practicable rate.

4.2.2 Captured Gas Composition

The objective, operationally, for the onshore transport system would be to maintain the CO_2 stream in the dense phase from the tie-in point with the Drax OPP through to injection wells offshore at the NUI.

It is currently anticipated that the First Load composition can be derived which contains 99.7% CO_2, up to 10ppmv of oxygen (O_2) and 50ppmv of water (H_2O); the remaining balance of composition would comprise of nitrogen (N_2) and Argon (Ar) (Table 4.3). This is a typical composition from an OPP such as Drax.

Table 4.3: Proposed Year 1 / First Load CO_2 Composition

Component	Volume %
CO_2	99.700
Ar	0.068
N_2	0.226
O_2	0.001
H_2O	0.005

The Energy Institute published a guidance note on “Good Plant Design and Operation for Onshore Carbon Capture Installations and Onshore Pipelines”, wherein the impacts of various components on pure CO_2 properties are documented. Table 4.4 below lists potential contaminant components and their effect on the density and viscosity of pure CO_2.

Table 4.4: Contaminant Components and Their Effect on Pure CO_2 Properties

Component	Effect
SO_2	Increases density and viscosity
H_2S	Minimal effect
O_2	Decreases density and viscosity
N_2	Decreases density and viscosity; more than O_2
H_2	Decreases density and viscosity; more than N_2

Since small levels of impurities/contaminants 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 CO_2 pipeline transportation system entry requirements are defined by NGCL and are set out in the NGCL Specification for Carbon Dioxide Quality Requirements for Pipeline Transportation. The composition Safe Operating Limit (SOL) is a saturation pressure for the CO_2 rich mixture of no more than 80barg along with the individual maximum allowable component levels defined in the specification for CO_2 quality. A summary of the specification is shown in Table 4.5 below for information. The entry specification provides the permitted limits for each component relative to safety design, integrity design and hydraulic efficiency criteria.

Table 4.5 below details the CO_2 specification for entry into the transportation network.

Table 4.5: CO_2 Export System Entry Requirements

Component	Limiting Criteria (Volume %)		
	Safety Max.	Integrity Max.	Hydraulic Efficiency
CO_2	100	100	96
H_2S	0	0.002 (Note 1)	0
CO	0.2	0	0
NOx	0.01	0	0
SOx	0.01	0	(Note-4)
N_2	0	0	(Note-4)
O_2	0	0.001 (Note 2)	(Note-4)
H_2	0	0	(Note-4)
Ar	0	0	(Note-4)
CH_4	0	0	(Note-4)
H_2O	0	0.005 (Note 3)	0

Notes on Table 4.5 above:

(1) NACE limit for dense phase CO_2 at a total pressure of 150barg (specified to avoid requirement for sour service materials).

(2) Maximum oxygen content (10ppmv) specified to avoid material selection issues in the well tubing, where the dry CO_2 contacts saline aquifer water.

(3) Maximum water content (50ppmv). 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:-
Gaseous Phase: $N_2 + O_2 + H_2 + CH_4 + Ar \leq 9.0\%$
Dense Phase: $N_2 + O_2 + H_2 + CH_4 + Ar \leq 4.0\%$, with H2 no greater than 2.0%.

The composition of the CO_2 would be expected to change beyond the first year of operation of the Drax OPP and the CO_2 transportation network, even if the only source of captured CO_2 is from an Oxyfuel technology power plant.

Two compositions are proposed below in Table 4.6 below to cover the possible range for the future operation of the CO_2 transportation system. This data may be fed into the computer simulation tool, HYSYS (see Section 4.2.2.1), to study the system and make predictions on how it will respond to various scenarios.

Table 4.6: Proposed Year 5 and Year 10 Future CO_2 Compositions

Component	Year 5 and 10 / Future – Generic Composition	Year 5 and 10 / Future – Sensitivity Composition – HYSYS (Note 1)	Year 5 and 10 / Future – Sensitivity Composition – non-HYSYS (Note 2)
	Volume %	Volume %	Volume %
CO_2	97.400	96.000	96.000
Ar	0.599	0.411	0.407
N_2	1.995	1.371	1.355
O_2	0.001	0.001	0.001
H_2O	0.005	0.005	0.005
H_2	0.000	2.000	2.000
H_2S	0.000	0.002	0.002
CO	0.000	0.200	0.200
NOx	0.000	0.010	0.010
SOx	0.000	0.010	0.010
CH_4	0.000	0.010	0.010

Notes on Table 4.6 above:

(1) The maximum specification for NOx and SOx is 100ppmv each (0.01 v/v%). However, these two particular components are not included the data package used in the in the HYSYS simulation work. These have therefore been omitted from the HYSYS composition for the purposes of steady state modelling.

(2) The non-HYSYS composition specified should be used for any other simulation work required for FEED, e.g., Flow Assurance.

4.2.2.1 Computer Simulation Tools

The HYSYS software package incorporates the GERG2008 equation of state and was used to carry out some basic transient modelling to provide temperature data for venting operations. HYSYS is mainly used for modelling process facilities rather than large scale pipeline and storage systems; therefore it proved to be a useful tool for simulating venting operations. The design of the vent stacks were developed to minimise temperature drop whilst also reducing the duration of vent activities. HYSYS, with the GERG2008 equation of state, was used to model various vent designs and provide temperature data for guidance on material selection for CO_2 rich mixtures.

OLGA, another software package, is capable of accurately modelling transient flow assurance cases it is more complex and hence the simulation time is significantly greater compared to HYSYS. Due to timescales, several vent design iterations were modelled using HYSYS until a final design was agreed. The final vent design was later simulated using OLGA as part of the transient flow assurance analysis.

4.3 Equipment Description

4.3.1 Overview

Section 4.1 above outlines the site installations (the AGIs) that are planned to facilitate the safe transportation of dense phase CO_2 across country from the Drax OPP, through to the offshore pipeline for storage offshore at the subsea storage site. The plot plans for these AGIs is provided by Report K32.

At the onshore and offshore pipeline terminal points, PIG launchers/receivers would be required to facilitate cleaning and monitoring operations.

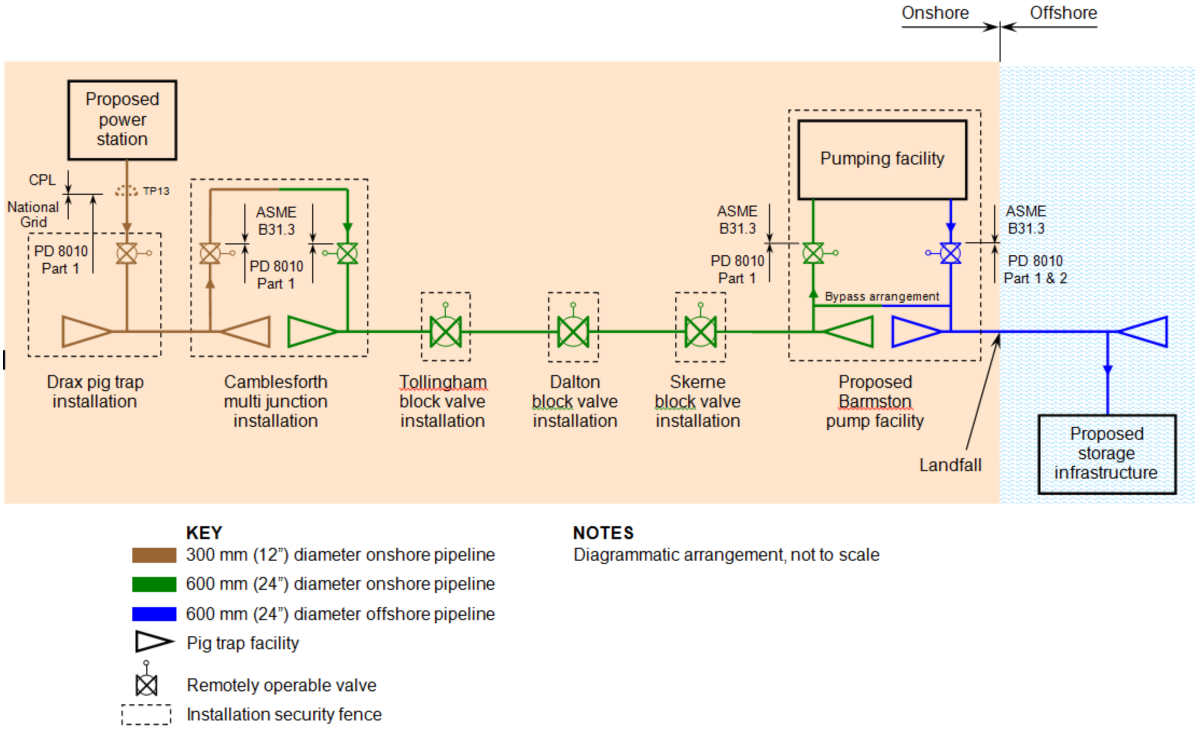
A site would be required at Camblesforth to facilitate tie-ins of branch pipelines from other regional CO_2 emitters such as other power plants.

There would be a pressure drop along the pipeline, which is the result of friction, and this pressure drop would increase with an increasing flow. In the early years the pressure in the offshore storage site is relatively low so that although Drax remained the only emitter, the pressure at which CO_2 would be produced by the OPP would alone be sufficient to complete transfer all the way to the offshore storage site.

However as the reservoir begins to fill and back pressure rises, the pressure available at the outlet from the multijunction may be insufficient in later years when other emitters tie into the pipeline. To ensure that there is sufficient pressure to ensure injection into the subsea storage site, a dense phase CO_2 pumping facility would be provided as an AGI.

Three Block Valve Stations would be provided along the onshore pipeline between the Camblesforth site and the pumping facility at Barmston to enable the isolation of discrete sections of the onshore pipeline in the event of an emergency. No block valve would be provided for the subsea pipeline. The onshore transport process is represented schematically below in Figure 4.1.

Figure 4.1: Schematic of Proposed CO_2 CCS System



The following sections outline the equipment required at each site for the anticipated range of production flow-rates over the lifetime of the onshore transportation.

4.3.2 Drax

This site would be the point at which the outlet from the Drax OPP connects to the National Grid Carbon transportation system. The Drax AGI would comprise the following major equipment items:

- 300mm ND pipeline from Drax OPP;
- 300mm ND PIG launcher; and
- 300mm ND cross-country 6km pipeline from Drax AGI site to Camblesforth Multijunction.

The pipeline is sized for the design flowrate of 2.68MTPA of CO_2 produced by the Drax OPP. The Drax AGI would also be furnished with:

- pressure relief valves (thermal venting), as required;
- associated piping and valves for isolation and PIG operations;
- 300mm ND Power actuated (Electro-Hydraulic) isolation valve; and
- local and remote monitoring, control and shutdown systems designed for unmanned operation under remote supervisory control monitoring and shutdown from the NGCL Control Centre.

This design would remain unchanged for the life of the Drax OPP, which would be expected to operate for 20 years. The Drax AGI site is planned to have a design life of 40 years. It should be noted that the Drax OPP, which would compress and cool the CO_2 to ensure the fluids are in the liquid dense phase, would provide the safety protection systems with respect to temperature and pressure: a full flow relief valve would be incorporated downstream of the OPP Gas Processing Unit (GPU) Pump to protect the downstream CO_2 transportation system beyond the connection point. Instrumentation to monitor the level of contamination would also be incorporated; an alarm message would be provided to the NGCL Control Centre should the readings exceed a specified level.

Table 4.7 below summarises the design and operating conditions for the Drax AGI site.

Table 4.7: Drax AGI Design and Operating Conditions

Conditions	Maximum	Normal	Minimum
Operating Pressure (barg)	135 (Note 2)	110 (Note 2)	90 (Note 2)
Design Temperature (°C)	50	N/A	-46
Operating Temperature (°C)	20	≤20 (Note 1)	5

Notes on Table 4.7 above:

(1) The lower the operating temperature, the higher the flowrate that could be achieved by the transport system.

(2) Operating pressure is the normal export pressure of the upstream OPP less pipeline losses and is dependent upon CO_2 flowrate within the transport system. Minimum operating pressure is set throughout the transportation system to ensure a margin above the critical point so that the CO_2 remains in the dense phase. The constituent pipework items of the plant are classed as pressure vessels and would be designed to the ASME B31.3 code. The pipeline would be designed in line with the PD-8010-1 code and at a maximum allowable operating pressure (MAOP) of 135barg.

4.3.3 Camblesforth Multi-Junction

The Camblesforth AGI would be the point where the Drax OPP CO_2 production combines with captured CO_2 production from other emitters, such as future power plant sources, as the CO_2 transportation network in the Yorkshire and Humber region expands.

The major equipment items required for operation are:

- 300mm ND PIG receiver;
- 600mm ND PIG launcher; and
- 600mm ND 69km cross country pipeline to the Barmston Pumping Facility.

A 600mm ND spur connection (with adequate double block and bleed and venting valve arrangements) would be provided to facilitate future CO_2 contributors from elsewhere in the Yorkshire and Humber region to connect into the transportation network for storage offshore. Plot space would be set aside for two future 300mm ND PIG receivers and one 600mm ND PIG receiver.

The 600mm ND pipeline is sized for the future CO_2 design mass flowrate of 17.0MTPA, which is anticipated for Year 10 operation. An intermediate Year 5 operation CO_2 flowrate of 10.0MTPA has been predicted and it is proposed to install at least one of the three PIG receivers for Year 5 operation ready for a new incoming pipeline, in line with the transportation needs of the future captured CO_2 contributors. The remaining two PIG receivers should be installed on an as-needed basis dependent on the physical location of the future capture CO_2 sources and the route of incoming transportation pipelines to Camblesforth.

The Camblesforth Multi-Junction AGI would also be furnished with:

- thermal venting relief valves, as required;
- associated piping and valves for isolation and PIG operations;
- 300mm ND Power actuated (Electro-Hydraulic) isolation valves; and
- local and remote monitoring, control and shutdown systems designed for unmanned operation under remote supervisory control monitoring and shutdown from the NGCL Control Centre.

Table 4.8 below summarises the design and operating conditions for the Camblesforth Multi-Junction AGI site.

Table 4.8: Camblesforth Multi-Junction Design and Operating Conditions

Conditions	Maximum	Normal	Minimum
Operating Pressure (barg)	135 (Note 2)	110 (Note 2)	90 (Note 2)
Design Temperature (°C)	50	N/A	-46
Operating Temperature (°C)	20	≤20 (Note 1)	5

Notes on Table 4.8 above:

(1) The normal operating temperature is the normal export temperature of the OPP less pipeline losses.

(2) Operating pressure is the normal export pressure of the upstream OPP less pipeline losses and is dependent upon CO_2 flowrate within the transport system. Minimum operating pressure is set throughout the transportation system to ensure a margin above the critical point so that the CO_2 remains in the dense phase. The constituent pipework items of the plant are classed as pressure vessels and would be designed to the ASME B31.3 code. The pipeline would be designed in line with the PD-8010-1 code and at a Maximum Allowable Operating Pressure (MAOP) of 135barg.

4.3.4 Block Valve Stations

The 600mm ND onshore pipeline from the Camblesforth Multi-Junction to the Barmston Pumping Facility would be approximately 69km in length. Three Block Valve AGIs are proposed at Tollingham, Dalton and Skerne, approximately 20km apart, in order to sectionalise the pipeline in case depressurisation is required for emergency reasons, thereby reducing the inventory that requires venting. These three Block Valve Stations would be identical in process design to each other for ease of familiarisation with operation and maintenance. These AGIs would normally be unmanned.

The major equipment items at the AGIs are:

- 600mm ND cross country pipeline; and

- 600mm ND power actuated (Electro-Hydraulic) isolation valve with associated valves and piping for required emergency sectionalisation complete with pressurisation bypasses to enable start-up from a depressurised state.

The sizing of the onshore pipeline and hence each AGI's shutdown valve is for the future Full Flow case of 17.0MTPA of CO_2. The AGIs would also be furnished with the following:

- Associated piping and valves for isolation; and
- Local and remote monitoring, control and shutdown systems designed for unmanned operation under remote supervisory control monitoring and shutdown from the NGCL Control Centre.

Bypass arrangements (300mm ND) across the entire block valve facility would be provided to enable the continuation of dense phase CO_2 transportation to storage offshore when the pipeline isolation valve is closed for maintenance and functional checks. The piping bypass arrangements would be buried underground; therefore provisions for thermal relief to protect the pipework during blocked-in conditions/thermal expansion of CO_2 would not be required. It is noted that the valves would be operable from the surface and connections for vent valves/instrumentation would be above ground for operational/practical purposes.

Table 4.9 below summarises the design and operating conditions for the three Block Valve Station AGI sites.

Table 4.9: Block Valve Station AGI Design and Operating Conditions

Conditions	Maximum	Normal	Minimum
Operating Pressure (barg)	135 (Note 2)	110 (Note 2)	90 (Note 2)
Design Temperature (°C)	50	N/A	-46
Operating Temperature (°C)	20	≤20 (Note 1)	5

Notes on Table 4.9 above:

(1) The normal operating temperature is the normal export temperature of the OPP less pipeline losses.

(2) Operating pressure is the normal export pressure of the upstream OPP less pipeline losses and is dependent upon CO_2 flowrate within the transport system. Minimum operating pressure is set throughout the transportation system to ensure a margin above the critical point so that the CO_2 remains in the dense phase. The constituent pipework items of the plant are classed as pressure vessels and would be designed to the ASME B31.3 code. The pipeline would be designed in line with the PD-8010-1 code and at an MAOP of 135barg.

4.3.5 Barmston Pumping Facility

4.3.5.1 Main Facility

The purpose of the Barmston Pumping Facility would be to provide the requisite pressure to the dense phase CO_2 received from Drax OPP and other future emitters over the range of anticipated process conditions for transportation to the offshore NUI for injection into the subsea storage site.

Space would be set aside in the pump enclosure for up to eight electrically driven centrifugal pumps. This would be to accommodate the full range of pumping requirements from First Load (2.68MTPA), including Minimum Flow (0.58MTPA) up to the future Full Flow design case (17.0MTPA).

Standardised equipment such as pumps and filters are selected for the purposes of full operational flexibility, for ease of maintenance and availability.

The major equipment items required for first load and future operation are detailed below:

- 600mm ND PIG receiver;
- two inlet filters, each of approximate capacity 5.7MTPA; 1 operational and 1 in standby for First Load and Year 1 operation. An additional two connections for future identically sized inlet filters, each of approximate capacity 5.7MTPA, to be installed in phases from Year 5 onwards. For the anticipated Year 5 CO_2 flowrate of 10.0MTPA, three filters each of capacity 5.7MTPA would be required, 2 operational, plus 1 standby. For Year 10, four filters would be required for the expected CO_2 flowrate of 17.0MTPA, 3 operational, plus one in standby;
- three variable speed drive electrically driven pumps will be provided at year 1; the pumps would be sized to allow the 17MTPA flow to be provided by 8 pumps; to cover the full operating range each pump would be rated at 2.43MTPA; so that there would always be one pump available in standby mode, to be brought on-line in case of a fault on an operational pump. At Year 5, 3 additional pumps would be supplied at 2.43MTPA capacity, and the last 2 pumps supplied in Year 10 at 2.43MTPA capacity; pumps will be variable speed drive to provide flexibility.
- Pump recycle air cooler sized for the full flow of one CO_2 Booster Pump (for use during pump start-up only);
- CO_2 metering and compositional analysis package (employing orifice type meters), sized for the future CO_2 mass flowrate 17.0MTPA;
- air compression and drying package;
- two instrument air receivers;
- 600mm ND PIG launcher; and
- 600mm ND cross country pipeline to Landfall and on to Offshore.

Additionally, the Barmston Pumping Facility would also be furnished with:

- pressure relief valves (thermal venting), as required;
- High Integrity Pressure Protection System (HIPPS) Package
- local and remote monitoring and control systems designed for unmanned operation under remote supervisory control monitoring & shutdown from NGCL Control Centre. It would also have the facilities suitable for local operation and shutdown for commissioning and in the event of communications failure, maintenance and upsets;
- permanent vent stack, about 8m in height.

A bypass arrangement would be provided to ensure the continued onward flow of CO_2 from the 600mm ND onshore pipeline to the offshore NUI in the event of a shutdown or failure of the Barmston Pumping Facility. Flow assurance work indicated that the pressure generated by the OPP GPU pump would be adequate to overcome the pressure losses associated with the expected design flowrates for the first five years of operation. In this instance the pumps at Barmston could be bypassed and the flow to the injection wells achieved using the OPP GPU pump only. The bypassed dense phase CO_2 would be filtered to meet the requirements of the offshore facilities and the flowrate measured for monitoring purposes. It would be fitted with a non-return valve to prevent recirculation of the CO_2 stream when the CO_2 Booster Pumps are operating.

A high integrity pressure protection system (mechanical) would be required to protect the downstream offshore pipeline as the CO_2 Booster Pumps are capable of delivering pressures in excess the design pressure (“1500 rating”). Therefore the equipment and pipework on the discharge of the pumps, up to and including the Barmston Pumping Facility boundary maintenance valve would have a higher design pressure (“2500 rating”).

The design and operating conditions of each individual equipment item downstream and inclusive of the CO_2 Booster Pumps are listed in Table 4.10 below.

Table 4.10: Barmston Pumping Facility Equipment Design and Operating Conditions

	Design Conditions		Operating Conditions	
Barmston Equipment Item	Pressure (barg)	Temperature (°C)	Pressure (barg)	Temperature (°C)
PIG Receiver	148.5	-46/50	90 to 135 (Note 2)	4.5 to 15
Inlet Filters	148.5	-46/50	90 to 135 (Note 2)	4.5 to 15
CO_2 Booster Pumps	281.5	-46/50	90.1 (suction)/ 178.2 (discharge)	4.5 to 15
CO_2 Booster Pumps Recycle Cooler	281.5	-46/50	Up to 178.2	4.5 to 45 (Note 3)
PIG Launcher	281.5 (Note 1)	-46/50	Up to 182	4.5 to 45 (Note 3)

Notes on Table 4.10 above:

(1) A HIPPS system, located downstream of the pumps, would be employed to protect the offshore pipeline (designed for 182barg) from overpressure in the event of a blocked discharge.

(2) Operating pressure is the normal export pressure of the upstream OPP less pipeline losses and is dependent upon CO_2 flowrate within the transport system. Minimum operating pressure would be set throughout the transportation system to ensure a margin above the critical point so that the CO_2 remains in the dense phase.

(3) Pump maximum operating temperature during proving/start-up operation when pump is operating in recycle.

4.3.6 Supporting Utilities

At the Barmston Pumping Facility the following utilities would be furnished:

- permanent vent stack (to allow for maintenance and emergency depressurisation only; there will be no routine venting operations);
- air compressor and drier package supplying air at a dew point of -40°C for all pneumatic valve actuation (control valves, ESDVs). The equipment within the package would have spare capacity to

allow for redundancy within the system. Receiver vessels (pressure vessels providing a reservoir of compressed air) are expected to be two 100% and provide 20 minutes supply upon loss of the air package;

- water system - potable usage;
- a dual circuit 66kV power supply, which would be connected to the Driffield to Marton Gate T1 circuit and transported by underground cable, would be provided. The pumping facility electrical scope would terminate at the supply point prior to the disconnector on the customer's side of the circuit breaker; and
- back-up power to each site would be via a suitably sized UPS system (three phase with supply up to 8hrs). The UPS system would power the safety systems, the Integrated Control Shutdown System (ICSS) and telecommunication system.

4.3.7 Onshore Pipeline

4.3.7.1 300mm ND Onshore Pipeline

The section of onshore pipeline from the Drax OPP to the Camblesforth Multi-Junction AGI would be 300mm ND approximately 6km in length.

The pipeline would be 323.9mm outside diameter, carbon steel grade L450/(X65), with 11.9mm minimum wall thickness. Pipe installed at all road, rail, major river and canal crossings would have a minimum wall thickness of 17.05mm. No internal corrosion allowance would be required as the dense phase CO_2 would be dry. Protective coatings would be applied to external surfaces and cathodic protection provided.

Table 4.11 below summarises the design and operating conditions for the 300mm ND onshore pipeline.

Table 4.11: 300mm ND Onshore Pipeline Design and Operating Conditions

Conditions	Maximum	Normal	Minimum
Maximum Allowable Operating Pressure (MAOP) (barg)	135 (Note 2)	N/A	N/A
Operating Pressure (barg)	135 (Note 2)	110 (Note 2)	90 (Note 2)
Design Temperature (°C)	25	N/A	0
Operating Temperature (°C)	20	≤20 (Note 1)	5

Notes on Table 4.11 above:

(1) The normal operating temperature is the normal export temperature of the OPP less pipeline losses.

(2) Operating pressure is the normal export pressure of the upstream OPP less pipeline losses and is dependent upon CO_2 flowrate within the transport system. Minimum operating pressure would be set throughout the transportation system to ensure a margin above the critical point so that the CO_2 remains in the dense phase. The pipeline would be designed in line with PD-8010-1 code. Pipeline design pressure (MAOP) 135barg is the pressure at which calculations are based on for the pipeline.

The external corrosion control strategy would be based on the provision of high quality factory or field applied coatings and cathodic protection.

4.3.7.2 600mm ND Onshore Pipeline

The onshore pipeline for the CO_2 transportation system from the Camblesforth Multi-Junction AGI to the Barmston Pumping Facility would be 600mm ND and approximately 69km in length. This would be sized to allow for future CO_2 contributions from other power plants in the Yorkshire and Humber region.

The pipeline would be 610mm outside diameter, carbon steel grade L450/(X65), with 19.1mm minimum wall thickness (including at any crossings). The pipeline wall thickness may be increased for structural design reasons where required. As the pipeline is designed to transport dry CO_2, no internal corrosion allowance is required. Externally, corrosion would be controlled through the provision of high quality coating (Fusion Bonded Epoxy) and cathodic protection.

Table 4.12 below summarises the design and operating conditions for the 600mm ND onshore pipeline.

Table 4.12: 600mm ND Onshore Pipeline Design and Operating Conditions

Conditions	Maximum	Normal	Minimum
Maximum Allowable Operating Pressure (MAOP) (barg)	135 (Note 2)	N/A	N/A
Operating Pressure (barg)	135 (Note 3)	110 (Note 3)	90 (Note 3)
Design Temperature (°C)	25	N/A	0
Operating Temperature (°C)	20	≤20 (Note 1)	5

Notes on Table 4.12 above:

(1) The normal operating temperature is the normal export temperature of the OPP less pipeline losses.

(2) Operating pressure is the normal export pressure of the upstream OPP less pipeline losses and is dependent upon CO_2 flowrate within the transport system. Minimum operating pressure is set throughout the transportation system to ensure a margin above the critical point so that the CO_2 remains in the dense phase. The pipeline is designed in line with PD-8010-1 code. Pipeline design pressure (MAOP) is the pressure at which calculations are based on for the pipeline.

4.3.7.3 Onshore Pipeline Construction

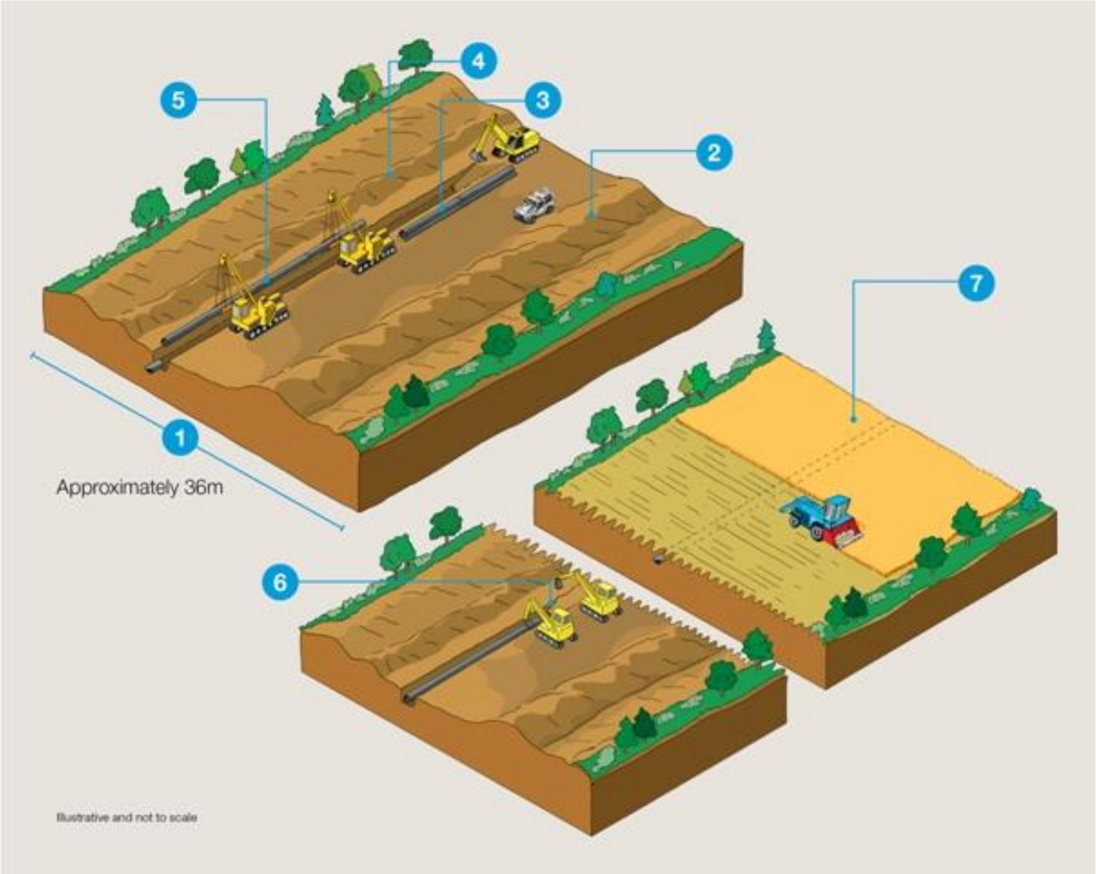
Pipeline construction would be undertaken on a “production line” basis. Crews dedicated to a particular task would start at one end of the pipeline route and work towards the other end. The sequence of the many tasks upon which the crews would be employed to construct the pipeline would be generally as follows:

- survey (to peg the route and locate and mark existing services);
- working width preparation/installation of temporary site access points and signing;
- fencing;

- pre-construction drainage;
- remove (strip) the topsoil to a temporary location;
- archaeological surveys and watching brief;
- levelling and benching;
- breaking up of rock (if encountered);
- pipe stringing (lay out the pipe along the working width);
- field bending (i.e. pipes bent to angles previously determined by the bending engineer);
- welding and inspection (end preparation, front end welding, back end welding, fabrication welding);
- non-destructive weld testing;
- joint coating;
- dewatering (well point de-watering, pumping and discharge);
- trench excavation;
- lower and lay;
- backfill the trench (sand padding around the pipe);
- pipeline tie-ins;
- re-grading of soil;
- post-construction drainage;
- reinstatement (cross-ripping of subsoil and reinstatement of topsoil, boundary walls, hedges and fences);
- hydrostatic testing and final tie-ins (swab and gauge pipeline test sections, fill, test and dewater, reinstate test locations); and
- commissioning (final gauge plate and calliper surveys, drying and commissioning).

All the above are essential activities, but the basics are described below; the Step numbers are labelled in Figure 4.2.

Figure 4.2: Basic Onshore Pipeline Construction Sequence



Step 1 First, the working width, the total area within which construction work will take place, is marked out.

Step 2 Next, the topsoil is carefully stripped and stored next to the pipeline route. National Grid has extensive expertise in designing, building and operating safe and effective high-pressure gas pipelines in the UK.

Step 3 The pipeline is delivered in short lengths and placed on supports. These short lengths of pipeline are welded together into longer sections called 'strings'.

Step 4 The pipeline trench is dug, with the excavated material being stored separately from the topsoil on the opposite side of the trench.

Step 5 The pipeline 'strings' are lowered into the trench using special vehicles called 'side booms' and welded to the pipeline already laid.

Step 6 The trench is filled in using the previously excavated material and the topsoil is replaced.

Step 7 Once the land above the pipeline has been fully reinstated, it can be returned to its previous use, for example farming.

4.3.7.4 Onshore Pipeline Protection

All buried piping would be coated with fusion bonded epoxy to prevent corrosion and to further protect the pipeline from external corrosion an impressed current cathodic protection system is used. Cathodic Protection (CP) on the CO_2 pipeline is maintained by rectifiers located along the pipeline. Cathodic protection (CP) on the pipeline and AGIs, including the Barmston Pump Station and offshore pipeline would be developed in accordance with appropriate specifications such as NACE SP0169:2007 - Control of External Corrosion on Underground or Submerged Metallic Piping Systems and/or 49 CFR 192.451 - Requirements for Corrosion Control.

To prevent mechanical damage, the pipeline would be protected using a range of measures. Protection of pipelines on land includes cover, increased wall thickness (as detailed in Section 4.3.7.1 for crossings), markers and marker tape, mechanical protection, controlling access to the pipeline route, or a combination of these measures.

As a minimum depths of cover would be in accordance with Table 4.13. Cover may be increased on a site specific basis. Cover depth would be measured from the lowest possible ground surface level to the top of the pipe, including coatings and attachments.

Table 4.13: Pipeline Burial Depth

Location	Cover Depth (m)
Areas of limited or no human activity	1.2
Agricultural or horticultural activity (never less than the depth of normal cultivation)	1.2
Ditch, Stream (measured from true clean bottom)	1.7
Railways (measured from the bottom of the rail and determined in conjunction with the rail authority)	3.0
Roads (measured from the road surface to the product pipe -2.0m to the sleeve)	2.15
Major river (measured from true clean bottom)	2.0
Residential, industrial and commercial areas	1.2
Rocky ground	1.2

4.3.8 600mm ND Landfall Section

The 1.5km short onshore section of offshore pipeline that would run from the Bramston Pumping Facility to landfall (the point at which the pipeline transitions from onshore to offshore) and would be 600mm ND.

The pipeline would be constructed from carbon steel material grade BS EN ISO 3183 Grade L450. The wall thickness of the short onshore section would be a minimum of 19.1 mm and would be the same throughout the length of the pipeline, except where increased wall thickness may be required for structural reasons. Externally, corrosion would be controlled through the combined use of high quality coating (Fusion Bonded Epoxy) and cathodic protection.

Table 4.14 below summarises the design and operating conditions for the Landfall section of the 600mm ND offshore pipeline.

Table 4.14: 600mm ND Offshore Pipeline Design and Operating Conditions - Landfall

Conditions	Maximum	Normal	Minimum
Design Pressure / Maximum Operating Pressure (barg)	182 (Note 3)	132 (Note 1)	90 (Note 4)
Design Temperature (°C)	50	N/A	-46
Operating Temperature (°C)	45	30 (Note 2)	4.5

Notes on Table 4.14 above:

(1) The normal operating discharge pressure for the pump would initially be 132barg for Year 5 flowrates with an injection pressure of 113barg at the offshore platform. Over time the injection pressure would need to be increased; this would require a greater discharge pressure from the pump.

(2) Normal operating temperature taken as the approximate average of the minimum and maximum operating temperatures.

(3) Pipeline is designed in line with PD-8010-2 code. Pipeline design pressure (MAOP) is the pressure at which calculations are based on for the pipeline.

(4) 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.

4.3.9 Offshore Pipeline

The main offshore pipeline transporting CO_2 from landfall to the platform for injection and storage offshore would be 600mm ND and approximately 90km in length. In line with the review in KKD Report K33, it would be designed in accordance with the Code of Practice for Subsea Pipelines (BS PD 8010-2). The pipeline would be constructed from carbon manganese steel material grade national standard BS EN ISO 3183 Grade L450 (X65). The 600mm ND pipe would be manufactured using submerged arc welding techniques. The outside diameter of the pipe would be 610mm with a wall thickness of 24mm.

The offshore wall thickness selected is primarily based on pressure containment requirements. An increased wall thickness is selected for the section of the route, which is routed over the sand waves, due to the pipe overstressing which is caused by large imperfection heights of the sand waves. The spool wall thickness would be increased to match the riser wall thickness, which increases the safety within the platform area and decreases the pipe buoyancy.

Concrete Weight Coating (CWC) is a plant applied coating developer to provide negative buoyancy, mechanical protection, and on bottom stability for submarine pipelines. The pipeline “on-bottom” stability would be performed using a 2-D balance calculation. The CWC thickness would be determined using high density CWC of 3450kg/m^3 as shown in Table 4.15.

Table 4.15: Selected Concrete Thickness

Section	Water Depth Range [m]	OD [mm]	Wall Thickness [mm]	Thickness CWC [mm]	Burial Condition
1 – Landfall	0 to 7.5	610	22.23	95	Pre-lay dredged and backfill

Section	Water Depth Range [m]	OD [mm]	Wall Thickness [mm]	Thickness CWC [mm]	Burial Condition
(the first 1.3km)					
2 – Shore Approach (the next 15km)	5.7 to 36	610	19.05	95	Pre-lay dredged and backfill
3 – Shallow Depth (the next11km)	36 to 49	610	19.05	115	Post-lay trenched
4 – Flat (the next 19.2km)	49 to 53.4	610	19.05	160	Exposed
5 – Sand Waves (the last 41.9km)	49.1 to 60.6	610	25.4	145	Pre-swept

Over sections 4 and 5, if the pipe were to be fully buried, which would protect from or mitigate the effects of excessive marine growth, then concrete requirements would reduce to 75mm for the 61.1km (up to the platform. For Section 5, the wall thickness would be increased from 19.05mm to 25.4mm in line with the on-bottom roughness analysis and CWC would then be reduced from 160mm to 145mm.

Over Sections 4 and 5, the on-bottom roughness assessment indicated that the section of the pipeline route, which would be laid over the sand waves, would overstress the pipeline due to the large seabed imperfections. Therefore, the sand waves would be pre-swept prior to laying of the pipe to reduce span length, heights and the level of imperfections. Pre-sweeping the route would require the laying down of the pipeline to ensure that it remains within the swept section of the seabed.

The pipeline size (600mm ND) and depth of water is ideally suited for using an S-lay barge to lay the offshore pipeline between. The pipeline installation would be initiated at the landfall and with the laydown at the platform. This would be performed by a single pipe-laying vessel with a low draft, which would allow it to approach the shore. Shallow water (less than 8m deep) extends to about 8km from the coast.

To initiate the pipe laying the pipe would be pulled ashore from the offshore based vessel. This would avoid additional onshore based works and the need for an onshore laydown area and would avoid the requirement of a shallow water tie-in.

The soil conditions at the landfall site consist of a silty sand overlying Boulder clay and Cretaceous chalk. Direct pipe method was ruled out due to limitations in installable pipe diameter. Although the pipeline could be installed at the landfall using Horizontal Direct Drilling (HDD) or the micro-tunnel method, it would be installed using is a sheet piled cofferdam starting on the beach leading to an open-cut trench offshore. An onshore micro-tunnel upstream of the cliff face will terminate in the cofferdam on the beach.

Over sections 1 and 2, reaching water depth of 36m, the pipeline would be pre-dredged to ensure pipeline stability during temporary conditions: to a trench depth of 4.8m in section 1 and to 2m in section 2. Near-shore the route would be pre-dredged using a cutter suction hopper to ensure the capabilities of dredging through boulder clay and chalk soil layers.

Over section 3 the pipeline would be trenched (water depth 49m) to ensure a stable pipeline during operation condition in stormy conditions.

4.3.9.1 Internal Corrosion Protection

The pipeline would not be internally coated as the pipeline will operate dry (free of water) at all times and be protected by high integrity water monitoring systems at CO_2 source. Hence, corrosion on the internal surface of the pipe would not be anticipated and no corrosion allowance would be accounted for in the pipeline design.

4.3.9.2 External Corrosion Protection

The offshore pipeline would be protected against external corrosion using a high integrity coating system and a galvanic anode sacrificial cathodic protection system incorporating aluminium-zinc-indium bracelet anodes. Anode electrical connection to the pipe would be made using copper cables braze welded to the pipe. A pipeline isolation joint would be installed at the point where the offshore buried pipeline emerges from the ground and connects to the onshore facilities.

Cathodic protection of risers would be provided by bracelet type sacrificial anodes in conjunction with coatings for external corrosion protection. Anodes for protection of risers may be installed at the pipeline ends and risers would be electrically isolated from the jacket.

A fusion bonded epoxy, single layer anti-corrosion coating would be selected for external corrosion protection of the pipeline. The anti-corrosion coating shall be compatible with the application of the concrete weight coating.

5 Description of Equipment Items

5.1 Barmston Booster Pumps

5.1.1 Pump Houses

Each pump skid would be installed in its own dedicated unheated, ventilated pump house. The only equipment within the pump houses would be that associated with that pump. The seal top-up skid would be installed in a separate dedicated building near to the pump houses, also unheated and ventilated. The pump houses and seal top-up rooms would be classified as Zone 2 hazardous areas due to the potential of a flammable mist of oil from a pin-hole leak in the high pressure seal system. Equipment should be suitably rated for the area classification. The buildings would have a structural steel frame and wide access doors for maintenance. The pump houses would have a permanent straight runway beam installed over the centre line of the pump skids and running up to the roller door for maintenance. Each pump house would have a separate non-hazardous rated room, which is accessed by a separate door leading outside, to house the Variable Speed Drive (VSD) for that pump. Entry to the buildings would be controlled due to the possibility of CO_2 leaks.

Noise emissions from the pumping station would be restricted, so pump skids would be designed to be low noise without requiring acoustic enclosures.

Buildings would be fitted with internal lighting, so there would be no requirement for lighting on the pump or seal top-up skids.

5.1.2 CO_2 Service

The pumps would be specifically designed for dense phase CO_2 service. Corrections would be made to the pump performance, efficiency and power curves to account for the CO_2 compressibility and other properties including the disproportionate effect of the various specified CO_2 contaminants. It is anticipated that the pumps would start-up at low flow against closed discharge check valve rather than in recycle. Each pump would have a recycle connection from the discharge pipework to the suction manifold with air cooler and control valve. The intention would be that this recycle would be used only for pump testing/proving during commissioning and after major pump maintenance. Pumps would operate on suction pressure control by the plant ICSS.

Pump materials would be selected to cope with the low temperatures that would occur in the event of a CO_2 leak; the flange bolting and seal chambers would be areas given special attention.

5.1.3 Mechanical Seals

The pumps would be required to operate at varying speeds, varying suction pressures, varying discharge pressures, varying temperatures, varying CO_2 compositions and being started and stopped several times in a day. They would be fitted with double mechanical seals systems selected to give reliable service and long seal life. The barrier fluid would be low viscosity mineral oil that does not contain additives that are detrimental to seal faces.

The Pumping station would be unmanned and so high reliability and long maintenance intervals are required. Each seal would have its own dedicated seal system, mounted on the skid, including accumulator, air cooler and instrumentation. The Accumulator would be sized for at least 5 days of operation at normal leakage rates. Each system would include appropriate instrumentation to permit remote monitoring and trending of barrier fluid consumption as an indication of seal condition and would have connections to allow topping up using a mobile top-up unit with hand pump in the event that seal top-up skid is out of service for a prolonged period.

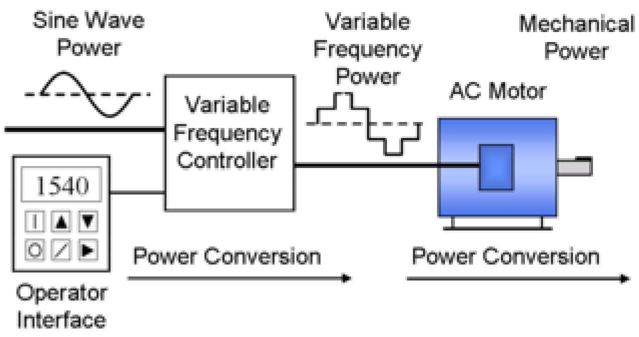
The seal top-up skid would be powered by compressed air and/or electrically. The skid would be sized to serve four of the CO_2 booster pumps. The top-op reservoir would be sized to cope with 2 months' normal seepage. Filters and pumps would have installed full-duty spare units which would allow them to be isolated and maintained without interrupting the supply of barrier fluid to the CO_2 booster pumps.

If required, the reservoirs would be fitted with an electric heater, which could be removed without having to drain any liquid from the reservoir. The skids would be fully instrumented with transmitters for remote operation/monitoring and would include suitable connections, isolations and valves, which would allow the barrier fluid to be supplied from the other seal top-up skid in the event of one of the skids is out of service for a prolonged period.

5.1.4 Pump Turndown

The pumps would be selected to cater for the range of flowrates that would be required. In order to achieve the range, the pumps would be powered by 2-pole electric motors with direct-drive, but the motors would be controlled by a VSD (Figure 5.1).

Figure 5.1: Variable Speed Drive



5.1.5 Lubrication

The bearing specification would be for long life and with at least 6 months between oil changes. Bearing/lube-oil temperatures and vibration levels would be remotely monitored.

Lube-oil heaters would be provided to allow standby CO_2 booster pumps to be available for instant starting.

Cooling water supply would not be provided at the pumping station. Lube-oil cooling would be achieved by skid-mounted air-coolers.

All lube-oil cooling pipework would be stainless steel. If a pressurised lube-oil system is to be provided then this would be mounted on the skid and would include stainless steel tank with electric heater (thermostatically controlled and withdrawable without have to drain the tank), single air cooler (with thermostatic valve), duplex filters and separate PCV (with block and bypass valves). The system would have two positive displacement pumps, one main and the other 100% standby.

5.1.6 Pump Type

The CO_2 booster pumps would be horizontally mounted electro-submersible derived type multi-stage centrifugal pumps, which would provide reliability, efficiency across the required wide operating envelope together with ease of maintenance.

5.1.7 Monitoring

The pump skids and auxiliary equipment would be sufficiently instrumented to allow remote operation and monitoring.

5.1.8 Transportation

Each pump and drive motor, pressurised lube-oil system and seal systems (excluding seal top-up skid) would be mounted on a single structural steel skid. Skid dimensions would be such as to allow road transportation.

5.1.9 Instrument and Drier Package

5.1.9.1 Air Compressor and Drier Package

The two-set Compressor and Dryer Package would generate dry, compressed, instrument-grade air which would be at a dew point of -40^{o}C. This would drive all pneumatic valve actuation (control valves, ESDVs) at the Barmston Pumping Facility. The package would also supply the plant air system for the use of a plant air hose/pneumatic tools. A small quantity of air would be used to drive the pumps on the seal oil top up skids. This would be on an intermittent basis and would not exceed plant air capacity. One set would operate as the duty package while another set would be used as a spare/stand-by package.

5.1.9.2 Air Receivers

Instrument air consumption would be of the order of 0.02 Nm^3/h per ESDV and 1.7Nm^3/h per control valve. Plant air would be supplied intermittently to meet an estimated consumption of 80.9Nm^3/h.

Two Air Receiver vessels would provide 20 minutes buffer capacity each (for instrument air demand only, between operating pressures of 6.5barg and 9.0barg) in the event that air supply from the Compressor and Dryer Package was lost. In normal operation, both receivers would be in service providing additional buffer capacity (40 minutes).

5.1.10 Potable water

As it is planned that Barmston Pumping Facility would normally be unmanned, potable water would only be required during occasional visits for sanitary and equipment cleaning purposes. The supply for potable water would probably be taken from the local water company system. Potable water demand is sized using the following basis and assumptions:

- A maximum of 20 people at site;
- 300 litres per day per person;
- 1 day at site; and
- equipment cleaning consumption of $2m^3$.

This would yield a maximum total volume of $8m^3$ per visit.

5.2 Control and Safety System

5.2.1 General

In addition to the transportation and storage system sites, a remotely located control centre would be constructed for the remote operation of the sites. The control centre would house a central control room for the operators and all associated office and personnel support facilities required for a permanently manned control centre.

Communication links would connect the control centre to the various transportation and storage system sites. The control centre would handle the transmission of control and monitoring data to and from the AGIs and NUI; it would handle other IT infrastructure links and voice communication.

Additionally the control centre would have communication links with the OPP to provide operational data links between the systems and voice communication between the operatives. The control centre would also be linked to NGCL offices to provide data handoff for supervisory and reservoir management purposes.

Control of the CO_2 transport and storage facilities would be independent of the OPP and its associated carbon capture plant (CCP). Interfaces will however be provided between the systems to enable integrated operation of the facilities.

Local operation of the sites shall be possible for commissioning start up and maintenance requirements, but the various sites associated with the transportation and storage facilities would all be designed for unmanned operation, and to be operated remotely from the control centre (which might be at a location remote from any of the White Rose sites).

A Supervisory Control and Data Acquisition (SCADA) System would be installed at the control centre, which would be interfaced to each of the transport and storage system sites, which in turn would be equipped with their own autonomous control and safety systems.

The End-to-End chain control systems would be based on standard, developed control system technology, which has already been established in the respective industries for each element of the chain. Unproven techniques or systems would be avoided where practicable.

5.2.2 Control Centre SCADA System

The control centre SCADA system would be computer based, providing operator interface for control of the overall CO_2 transfer and storage system; it would be a dual redundant Master Terminal Unit (MTU) based system. The operator console will include PC based Human Machine Interfaces (HMIs)

Selective onshore installation and offshore storage performance data (process status and metering information) would be transferred to the NGCL main office. The SCADA system would handoff data to a Historian/Live Telemetry Database Management information system (a Data Warehouse). A limited sub-set of data from this system may be made available to the OPP as required.

The SCADA system would be interfaced to the OPP with a limited exchange of data required to provide permissive and status signals to facilitate operation of the overall system.

5.2.3 AGI Control and Safety Systems

The process facilities and the control and safety system requirements at the Drax, Multi-Junction and Block Valve AGIs would be relatively simple with limited data quantities. Instrumentation sufficient to allow operation of the actuated valves for pipeline isolation would be installed. CO_2 detection would be provided at each site for the detection of pipeline leaks. CO_2 leak detection would send an alarm to the control centre, without local executive action. Stand-alone CO_2 detection panels would be provided at each AGI with local alarm facilities and interface to the site Remote Terminal Units (RTUs).

It is envisaged that RTU based systems will be installed at each of these sites, which will be supplied as part of the overall SCADA system.

Local operator interfaces could be provided either by in-built operator HMIs, with limited functionality, for the use of maintenance/operations staff or by the use of laptops taken to the sites by attending operations teams.

Communications between these sites and the control centre would be by means of VSAT satellite links backed up by PSTN landlines.

The Barmston Pumping Facility would be a more complex site than the other AGIs; as such will be equipped with an integrated control and safety system (ICSS) for facility control monitoring and safeguarding.

5.2.3.1 ICSS

The ICSS is defined as a fully integrated control and safety system. Integrated is defined to mean an overall system purchased from a single supplier which integrates the various control and safety system components into a single system.

The ICSS contains the following system functional elements:

- Process Control System (PCS);
- Emergency Shutdown element (ESD); and
- Fire and Gas (F&G) element.

The ICSS would include a local HMI consisting of PC based operator workstations, to allow local control of the facility as and when required. The HMI would be located in a local control room (LCR) adjacent to the local equipment room (LER) that would house the control and safety system equipment cabinets and system marshalling.

Machine Conditioning Monitoring (MCM), For CO_2 Booster Pumps, would be provided to predict mechanical wear and failure by monitoring vibration, noise, and temperature measurements. The MCMs would be incorporated in the PCS.

Communications between the ICSS and the control centre would be by means of VSAT satellite link backed up by PSTN landline.

5.2.3.2 Flow Metering Computers

CO_2 flow at Barmston would be measured with an uncertainty of better than +/- 2.5% using an orifice plate meter. Fluid analysis will also be included in the metering system. Flow metering computers (FMCs) will be installed for flowrate calculation and analyser data gathering. Some redundancy (back-up) would be engineered into the interfacing link between the FMC and the ICSS.

5.2.3.3 HIPPS

The pipeline downstream of the Barmston Pumping Facility would not be fully rated to handle the maximum discharge pressure that could be supplied from the booster pumps and therefore would be protected from overpressure. Full flow relief would not be provided and therefore a HIPPS would be installed for downstream system protection.

The HIPPS system would be a stand-alone, SIL rated system consisting of pressure sensors, safety logic and actuated isolation valves, with adequate redundancy (back-up) to meet the necessary system rating.

The HIPPS system will be interfaced to the ICSS which would provide remote monitoring of the system.

5.2.3.4 Pipeline Leak Detection

Pipeline leak detection had been considered prior to FEED; however it was decided that it was not required. NGCL would carry out frequent inspections such as pigging runs to detect any defects or reduction in pipe wall thickness to prevent small bore leaks from occurring. Regular visual inspections would also be carried out to inspect the pipeline route for any leaks, which were not detected, and to assess if there is any construction activity taking place that could lead to a loss of containment. Any pin-hole leaks will be difficult to detect through leak detection systems.

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 the ability to detect a rupture or large leak where a population is present and at risk is high. The increase in the ability to detect a rupture or large leak by means of an automatic detection system is therefore small. This would result in a very small reduction of a very small risk hence the provision of such measures is not considered to be required.

5.2.4 Offshore Platform

The offshore platform would also be equipped with an integrated control and safety system (ICSS) for facility control monitoring and safeguarding. It also would include the following system functional elements:

- PCS;
- Emergency Shutdown System (ESD); and
- F&G element.

The ICSS would include a local HMI consisting of PC based operator workstations, to allow local control of the facility as and when required. The HMI would be located in a local equipment room (LER) that would house the control and safety system equipment cabinets and system marshalling. The LER would be located adjacent to the platform Emergency Overnight accommodation.

The platform would be designed for unmanned operation under remote supervisory control; systems would operate and control autonomously from the land based system at the control centre. Communications between the platform and the NGCL control centre would be by means of dual redundant VSAT satellite links.

5.3 Electrical Supply / Power consumption

Power would be required to operate major equipment such as the CO_2 booster pumps, air cooler fans, the compressed air and drier package and the metering and analysis package. It would also be required for the support and control systems such as the Integrated Control and Shutdown System (ICSS) via the UPS system, telecommunications and motor operated valves.

At the Barmston Pumping Facility a dual circuit 66kV power supply, connected to the Driffield to Marton Gate T1 circuit, and transported by underground cable, would be provided. The pumping facility electrical scope would terminate at the supply point prior to the disconnector on the customer's side of the circuit breaker. The voltage would be stepped down to 6.6kV and 400V using transformers. Equipment would be operated from either the 6.6kV (CO_2 Booster Pumps) switchboard or 400V switchboard (all other equipment).

Drax, Camblesforth, Tollingham, Dalton and Skerne AGIs would operate from 400V switchboards. The main power consumers are detailed within Table 5.1 below.

Table 5.1: Main Power Consumers

Equipment Description - Consumer	Power Demand (kW)	Operational Demand
CO_2 Booster Pumps	1200 (each) (Absorbed Power)	Continuous
Future CO_2 Booster Pumps (Yr 5)(Future Demand)	1200 (each) (Absorbed Power)	Continuous
Future CO_2 Booster Pumps (Yr 10)(Future Demand)	1200 (each) (Absorbed Power)	Continuous
Compressor & Dryer Package	15.3 (Absorbed Power)	Continuous
CO_2 Booster Pump Recycle Cooler	15.3 (Note 1) (Absorbed Power)	Intermittent
Metering & Analysis Package	10	Continuous
Motor Operated Valves	6.8 (each) (Note 2)	Intermittent
ICSS (Barmston)	13	Continuous

Equipment Description - Consumer	Power Demand (kW)	Operational Demand
Buildings (Barmston)	179 (Note 3)	Continuous

Notes on Table 5.1 above:

(1) Power provided per fan. There would three fans in total.

(2) Motor Operated Valves would be provided at the following locations:
Camblesforth (3 valves), Barmston (11 + 2 future valves).

(3) A nominal 2.5kW demand has been specified for buildings located at Drax, Camblesforth, Tollingham, Dalton and Skerne AGIs.

Back-up power to each site would be via a suitably sized UPS system (battery with supply for 8hrs) and would be used to supply the telecommunication system and ICSS only. Valves at the block valve stations and the isolation valves at Drax and Camblesforth would be operated by electro-hydraulic actuators; on loss of electrical supply, the accumulator should still be capable of performing a minimum of two sequential operations.

A cathodic protection transformer/rectifier would be provided at each site.

5.4 Temporary Utilities / Auxiliary Utilities

Space would be provided at the Barmston Pumping Facility and other AGIs for site nitrogen quads/cylinders to permit purging of equipment during maintenance activities; temporary hoses would be connected to the systems that require intervention.

Lube-oil for the CO_2 booster pumps would be provided on the same skid as the pumps, however the pump seal system top-up oil would be provided on a separate skid located between the two pump houses. The pump Seal System Top-up Skid would serve four CO_2 booster pumps, a future skid would be provided later for the four future CO_2 booster pumps.

6 Operation

6.1 Normal Operation

For ease and practicality of transportation of captured CO_2 for storage offshore, the CO_2 is compressed into the dense phase (liquid). The pressure-temperature diagram for CO_2 defines the permissible operating envelope for the CO_2 stream throughout its transportation stages from the tie-in point with Drax OPP through to the injection wells at the offshore NUI.

Key process conditions to consider are listed below in Table 6.1.

Table 6.1: Pure CO_2 Key Process Parameters

Parameter	Pressure (bara)	Temperature (°C)
Triple Point	5.1	-56.6
Critical Point	73.8	31.1

Maintaining the pressure significantly above the critical pressure along the entire transportation route would be paramount. Similarly, maintaining the temperature below the critical temperature is also targeted.

The above ground installations at Drax, Camblesforth, Tollingham, Dalton, Skerne and Barmston would all be designed for unmanned operation under supervisory control by the T&S Control Room.

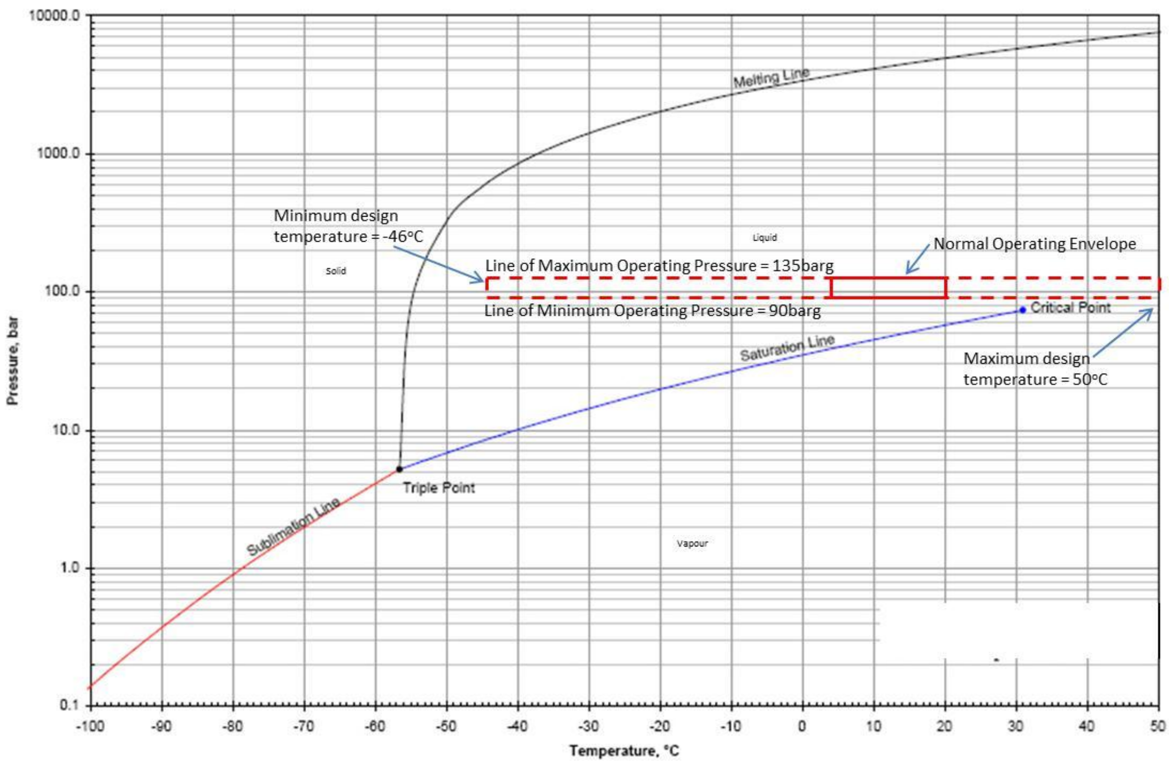
Dense phase CO_2 would be produced by the OPP at Drax up to a design flowrate of 2.68MTPA. The range of process conditions and quality of the CO_2 stream would be limited to specific design parameters through the use of suitably SIL rated protection systems within the OPP Gas Processing Unit, which would respond to the input from the instrumentation monitoring the pressure, temperature and the water, oxygen and H_2S content of the CO_2 stream, to protect the onshore transportation system from any operational upsets.

Table 6.2 lists the operational envelope limits for the CO_2 stream, which would be flowing from Drax OPP, with respect to flowrate, operating conditions and compositional limits. Figure 6.1 overleaf provides a graphical representation of the design and operating envelope of the transportation system.

Table 6.2: Drax OPP CO_2 Export Operational Limits

Parameter	Limit
Minimum Flowrate	0.58MPTA
Maximum Flowrate	2.68MTPA
Minimum Operating Pressure	90barg
Maximum Operating Pressure	135barg
Minimum Operating Temperature	5°C
Maximum Operating Temperature	20°C
Maximum H_2O Content	50ppmv
Maximum O_2 Content	10ppmv
Maximum H_2S Content	20ppmv

Figure 6.1: CO_2 P-T Diagram with Operating Envelope



If any of the above parameters are beyond the minimum or maximum limits stated, the produced CO_2 would be stopped from feeding into the downstream Transport and Storage system by means of SIL rated equipment and would be diverted to the OPP main stack until production was once again within specification.

There are a number of flow cases that span the initial and future anticipated captured CO_2 production rates. For the early years, only the First Load flowrate from Drax OPP would be transported. The flowrate ranges from a minimum flow of 0.58MTPA to 2.68MTPA. For these low flowrates, the pressure required at the discharge of Drax OPP would not need to be much greater than 90barg (approximately 102barg to 104barg) in order to overcome the frictional line losses and storage reservoir pressure as discussed in Section 4.3.5.1 above.

For the future years, e.g. Year 5 producing 10MTPA and Year 10 producing 17MTPA, the pressure at the OPP tie-in would need to be significantly greater than 90barg to overcome the frictional losses, of the order of 20bar to 30bar. The CO_2 Booster Pumps would be in service during this period of operation.

The liquid CO_2 from the OPP would flow under pressure from Drax to the multi-junction AGI at Camblesforth. There, the CO_2 captured at Drax would mingle with CO_2 from other power plants from other locations within the Yorkshire and Humber region. Contributions from other power plants are predicted from Year 5 onwards.

It would be required that future power plants that produce captured dense phase CO_2 for introduction into the transportation network shall ensure the quality and process conditions of the CO_2 that they produce individually matches that of the design requirements for the CO_2 transportation system. It shall be within the scope of the individual future power plants to ensure that the captured CO_2 meets the same specification and process conditions as the Drax OPP.

The combined CO_2 would continue, under its residual source pressure, through to the Barmston Pumping Facility by way of the three Block Valve Stations at Tollingham, Dalton and Skerne. The limitation on the arrival pressure at the CO_2 Booster Pumps is set at 90barg, which is a comfortable operating margin above the critical pressure (73.8barg) and the saturation pressure of 80barg, for fracture control purposes, given the variation in individual non-condensable components as impurities in the CO_2 stream.

The CO_2 Booster Pumps would operate over a range of flowrates providing a range of discharge pressures in order to maintain a destination pressure greater than 90barg at the offshore NUI injection wells. Injection pressure is expected to increase over time as the storage site is filled up with CO_2. The CO_2 Booster Pumps would be limited to a maximum discharge pressure of 182barg in order to safeguard the containment integrity of the storage site.

The pumps would be variable speed drive and would be controlled on the suction pressure. Over time, the pressure of the reservoir would increase. Also, the required pressure at the destination would vary depending on the frictional pipeline losses resultant from the flowrate. The speed would also be adjusted to accommodate the variation in flowrate over the lifetime of the CO_2 transportation system.

The outlet temperature of pump recycle cooler would be controlled by adjusting the speed of the air cooler.

6.2 Abnormal Operation

All the AGIs would be furnished with bypass arrangements should there be a requirement to take any of the onshore pipeline isolation valves or the Barmston Pumping Facility out of service.

If the Barmston Pumping Facility were to be out of service, the transportation of dense phase CO_2 would be reliant on the source pressures being sufficient to overcome the frictional pipeline losses generated by the particular production rate and the destination pressure at the CO_2 injection wells. Transportation of the dense phase CO_2 purely via the Pumping Facility bypass would be self-limiting dependent on the process conditions, on the production flowrate and on the destination pressure (refer to Sections 4.3.5.1 and 6.1). As a result, the flowrate within the transportation system may have to be decreased during this abnormal period of operation, particularly in later years of operation.

As the Drax OPP would be the first captured CO_2 provider to the end-to-end transportation and storage system, there would be a requirement for it to demonstrate its flexibility. For up to 100 days per year, the Drax OPP would be required to operate at a reduced production rate, including a minimum flowrate of 0.58MTPA proposed for approximately 37 days. The Drax OPP also would be required to prove ramp rates, for the 75% to 100% range, which are set at 2% of the design flowrate.

6.3 Normal Start-up/Shutdown

Start-up may be from a pressurised state or a depressurised one, depending on the circumstances of the preceding shutdown. Where possible, the stagnant system after a shutdown should be retained in a pressurised state for ease of restart. In the case of maintenance activities, the isolated system or equipment item(s) would require complete depressurisation.

During a normal start-up sequence, the CO_2 would not, to begin with, be within specification. For the inlet to pipeline transportation system, the out of specification CO_2 would be vented at the power plant site until all the specification criteria are met. Only then would the production stream be permitted to flow forward into the transportation system. There is an analyser package downstream of the OPP GPU pump which should be used in conjunction with the permanent vent stack at the OPP for this purpose.

A normal shutdown, such as a planned shutdown for maintenance on a specific equipment item such as a CO_2 Booster Pump, would ramp down at a planned rate to a level that would allow switchover to a spare equipment item, or a bypass arrangement.

6.3.1 Line Packing

The compressibility of the CO_2 is less pronounced in the proposed normal operating range. However, it is possible that 'line-packing', the ability to compress the fluid, in the pipeline by a small additional margin, could be used, to a very limited extent, to manage abnormal conditions and small transients due to time lags between balancing supply and demand.

Inventory (the fluid being transported) may be held in a pipeline within the operating pressure range to allow resumption of its transportation on an immediate basis.

6.4 Emergency Start-up/Shutdown

Scenarios such as regional electrical grid failure, or catastrophic failure of a valve or flange within the pipeline transportation network, would initiate an emergency shutdown of the end-to-end CO_2 transportation and storage chain. All the safety critical valves within the chain are provided with emergency back-up motive systems to ensure that the valves move to their safe positions. There is no automatic depressurisation of any systems; the venting philosophy is discussed below, in Section 7.

Depressurisation of the onshore and offshore pipelines would only be performed when absolutely necessary. The intention would be to retain the pipeline transportation system in a pressurised state over the 40 year design life.

7 Venting Philosophy

7.1 Venting Objectives

Venting of CO_2 from the entire end-to-end transportation and storage system, in other words the complete depressurisation of the pipeline, would be a very rare event and would mainly be required for safety, reasons. Venting large volumes of high concentration (≥ 96v/v%) high pressure CO_2 into the atmosphere has health, safety and environmental implications which impacts the engineering design.

Limited local venting would be required for the following objectives:

- commissioning;
- start-up;
- off specification CO_2;
- thermal relief;
- maintenance activities; and
- the continued operation of systems when certain sections of the full chain are shutdown.

Since CO_2 is heavier than air at atmospheric conditions, care would be required when locating vent stacks. The dispersion of the CO_2 would be carefully modelled to determine that normally or occasionally occupied building in the proximity of the discharge vent (usually a stack) would not be impacted by the CO_2 as it disperses.

7.2 Permanent and Temporary Vent Stacks

Both permanent and temporary vent stacks are proposed for use throughout the transportation and storage system located at the various above ground installations.

Permanent vents would be located at:

- Drax OPP (sized for the full CO_2 mass flowrate);
- Barmston Pumping Facility (to allow maintenance of some items of equipment), and
- the offshore NUI.

These stacks would discharge vertically upwards into a freely ventilated area; the end of the stack would be sized for local operating conditions, but would be probably at of the order of 8m above ground level. The visual impact of these structures would be a constraint on the height.

At Barmston, the discharge lines from relief valves protecting major equipment items such as PIG receivers/launcher, CO_2 fine filters, CO_2 Booster Pumps Recycle Cooler would be routed vertically to atmosphere at a safe location point 3m above ground level. The discharge lines are sized in order to maintain a high velocity to aid dispersion, but within sonic velocity limits, so that the flow would not be choked.

Permanent vent stacks would be required for:

- metering package;
- downstream filter vents; and
- CO_2 Booster Pump Discharge pipework.

Temporarily installed vent stacks may be required for:

- block valve installations (excluding depressurisation of pipeline section, see paragraph below);
- PIG launchers/receivers; and
- pressurising bridle arrangements (pipework spurs).

Where required for the depressurisation of a pipeline section via a Block Valve Station, the temporary vent stack would discharge vertically upwards, locally into a freely ventilated area with the end of the stack being 5m above ground level.

7.3 Depressurisation

Depressurisation of the onshore or offshore pipelines would only be performed in an emergency. The operational intent for the pipelines would be to keep the CO_2 content in the dense phase by means of maintaining the pressure above 90barg throughout their lifetime.

Depressurisation of the onshore pipeline would be a manual operation of the affected section via a temporary vent stack at the appropriate Block Valve Station (Tollingham, Dalton or Skerne).

7.4 Noise

The noise generated at the vent tip as a result of CO_2 venting operations would require consideration of the limits agreed with the Local Planning Authority as well as occupational health limits. Refer to Table 8.1 below for noise limits.

7.5 Dispersion

An Environmental Impact Assessment has been carried out and is included as part of the Development Consent Order application.

Venting and dispersion modelling has been carried out and has been validated against the experimental work that was conducted as part of the NGCL research programme and an assessment of credible releases, which includes venting, has been made based on experimental results and dispersion modelling analysis.

7.6 Low Temperature

The cooling effects of depressurisation need to be taken into account when designing the vent systems for a CO_2 transportation system. In cases where very low temperatures are predicted, venting procedures would need to be developed to mitigate these effect, for example, controlling the time period for venting, thereby pausing the procedure and allowing it to warm up for a period of time before continuing venting.

The venting systems would also be designed to minimise the likelihood of personnel coming into contact with the released CO_2 as this could result in cold burns.

Consideration would be given to the design and location of the vents as a means of mitigating the effects of the resultant low temperatures; for example, venting from the bottom of a pipe reduces the cooling affect as liquid CO_2 has a lesser Joule-Thomson effect (cooling upon expansion) than gaseous CO_2.

7.7 Venting of the Entire Pipeline

Venting of the entire pipeline would be a rare possibility during its operational life, but will be carefully managed with procedures in place. This is not considered to be normal operation; however while decommissioning, venting of the entire pipeline is a possibility. This case is analysed in the Transient Flow assurance report (KKD K34).

The minimum metal temperature reached while venting is dependent upon venting rate, venting duration, CO_2 inventory in the pipeline, orifice size and various other factors including ambient conditions. This has been analysed as part of a computational fluid dynamics study of venting under various scenarios and has been analysed as reported in KKD K34.

Blowdown of vessels and flow loops were carried out as part of the NGCL research programme, which confirmed the minimum expected temperatures likely to occur. The vent system has been designed to minimise temperature drop to maintain safe operation whilst aiding dispersion to reduce the impact on the local environment.

8 Safety & Environmental Considerations

Safety considerations would be the most important factor influencing the design of the end-to-end CO_2 transportation and storage chain.

Carbon dioxide is not harmful at small concentrations; people breathe out CO_2, but large volumes of nearly pure (higher than 96%) CO_2 presents a hazard. Key issues for consideration are the toxicity of CO_2 and its physical properties as the fluid is subjected to changes in process conditions.

8.1 CO_2 Toxicity

The toxicity of CO_2 is a measure of the harm it can do to our bodies.

The individual workspace exposure level of 0.5% (5,000ppm) for long term exposure (8 hours weighted average) and 1.5% (15,000ppm) for short term exposure (15 minutes weighted average) are to be used for the target CO_2 concentration for all safety cases and design studies. Indefinite outdoor exposure levels are deemed to be 0.2% (2,000ppm) over the average working life of 100,000 hours.

8.2 CO_2 Physical Properties

In the event of an uncontrolled release of CO_2, the escaping fluid would rapidly expand from the dense phase to a gas. The temperature of the released CO_2 would decrease rapidly and because CO_2 sublimes (transitions directly from vapour to solid) at lower pressures (≤ 5.1bara), some CO_2 “snow” would form. As a result of this low temperature CO_2, the moisture in the surrounding air would condense and a thick fog would form.

CO_2 readily forms hydrates with water and these have the potential to choke or block flowing pipelines if sufficient free water is available. For this reason, the specification on water within the CO_2 product stream is stringent, set at 50ppmv.

Since the phase of CO_2 may be affected by atmospheric temperature fluctuations and solar gain, piping systems and equipment would be predominantly buried, unless it is impractical to do so.

8.3 Environment

The environmental impact of the onshore pipeline is discussed in report K.35 *Onshore Pipeline Route Plans*, but noise levels are a prime consideration in the siting and design of the various AGIs, due to the proximity to local populations. Noise emissions would be limited to a maximum of 5 decibels (dBA) above the ambient background noise when measured at the boundary fence. The maximum permitted noise level at the Nearest Sensitive Receptor (NSR) would be no greater than 70dBA.

Table 8.1 lists the maximum allowable noise at the source per site based on a 70dBA noise limitation at the NSR.

Table 8.1: AGI Noise Limits for Maintenance Venting

AGI	Approximate Distance to NSR	Noise Limit at AGI based on 70dBA at NSR
Drax AGI	326m (Drax Abbey Farm)	120dBA
Camblesforth Multi-Junction	225m (Wade House Lane)	117dBA
Tollingham Block Valve Station	547m (2 Tollingham Cottage)	125dBA
Dalton Block Valve Station	408m (Holm Wood Cottage)	122dBA
Skerne Block Valve Station	490m (Copper Hall Farm)	124dBA
Barmston Pumping Facility	70m (Sands Lane boundary)	127dBA
Barmston Pumping Facility	150m (Sands Lane boundary)	128dBA

Visual impact would be also prime consideration when designing the structures and how they interact with each other and the surrounding landscape. The vertical limit of the site would not exceed 15m above ground level.

9 Glossary

Abbreviations	Meaning or Explanation
AGI	Above Ground Installations
Ar	Argon
bara	Bar Absolute
barg	Bar Gauge
C	Degrees Celsius
CCP	Carbon Capture Plant
CCS	Carbon Capture and Storage
CH_4	Methane
CO_2	Carbon Dioxide
CPL	Capture Power Limited
dBA	Decibel
DECC	The UK Government's Department of Energy and Climate Change
Dense Phase	Fluid state that has a viscosity close to a gas while having a density closer to a liquid. Achieved by maintaining the temperature of a gas within a particular range and compressing it above a critical pressure.
Disconnector	Isolation of power equipment from the network (usually where no significant change in voltage occurs across the terminals)
EIA	Environmental Impact Assessment
ESD	Emergency Shutdown
ESDV	Emergency Shutdown Valve
F&G	Fire and gas
FEED	Front End Engineering Design
FEED Contract	Contract made between DECC and CPL pursuant to which WR Project FEED (as defined) will be performed.
GPU	Gas Processing Unit – processes the flue gases to provide the dense phase carbon dioxide
H_2	Hydrogen
H_2O	Water
H_2S	Hydrogen Sulphide
HIPPS	High Integrity Pressure Protection System
HMI	Human Machine Interface
HYSYS	A powerful engineering simulation tool
ICSS	Integrated Control and Shutdown System
KKD	Key Knowledge Deliverable
km	Kilometre
KSC	Key Sub-Contract
LCR	Local control room
LER	Local equipment room
m	Metres
mm	Millimetres
MAOP	Maximum Allowable Operating Pressure
MCM	Machine Conditioning Monitoring
MTPA	Million Tonnes Per Annum
MTU	Master Terminal Unit

Abbreviations	Meaning or Explanation
MW	Mega Watt
N_2	Nitrogen
NACE	NACE International (formerly National Association of Corrosion Engineers)
ND	Nominal Diameter
NGCL	National Grid Carbon Limited
NGCL FEED Sub-contractors	Contractors entering into a contract with NGCL to carry out a part of the obligations under the KSC.
NGCL KSC	Contract made between CPL and NGCL pursuant to which that part of the WR Project FEED (as defined) which appertains to the WR T&S assets will be performed.
NGCL WR Team	The NGCL team established to meet the obligations in the KSC.
NSR	Nearest Sensitive Receptor
NUI	Normally Unmanned Installation. A term usually applied to an offshore installation.
OLGA	An engineering simulation tool
OPP	Oxy Power Plant
O_2	Oxygen
PC	"Personal"/Desktop Computer
PCS	Process Control System
PIG	Pipeline Inspection Gauge: a unit, which is inserted into the pipeline, to clean and/or monitor the inner bore surface of the pipe.
PIG Trap	A facility to allow PIGs to be inserted into and removed from the pipeline.
Plot Plans	Drawings outlining the arrangement of plant items and associated features including vehicle parking, materials storage, cabins and welfare facilities and any soft landscaping.
ppmv	Parts per million by volume
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SIL	Safety Integrity Level, the relative level of risk-reduction provided by a safety function
SOL	Safe Operating Limit
SOx	Sulphur Oxide (various)
SO_2	Sulphur Dioxide
T&S	Transportation and Storage
UK	United Kingdom
UPS	uninterruptible power supply
VSD	Variable speed drive
v/v%	A measure of concentration of a substance in solution expressed as the ratio of the **volume** of the solution
WR	White Rose
WR Assets	All those assets that would be developed pursuant to the WR Project
WR FEED Project	Project to carry out a FEED (as defined in the FEED Contract) with regard to the WR Assets.
WR Project	White Rose CCS Project
WR T&S Assets	That part of the WR Assets which would carry out the carbon dioxide transportation and storage functions of the WR Project and to which the KSC Contract relates.
WR T&S FEED Project	The project to be pursued by NGCL in order to meet its obligations under the NGCL KSC.