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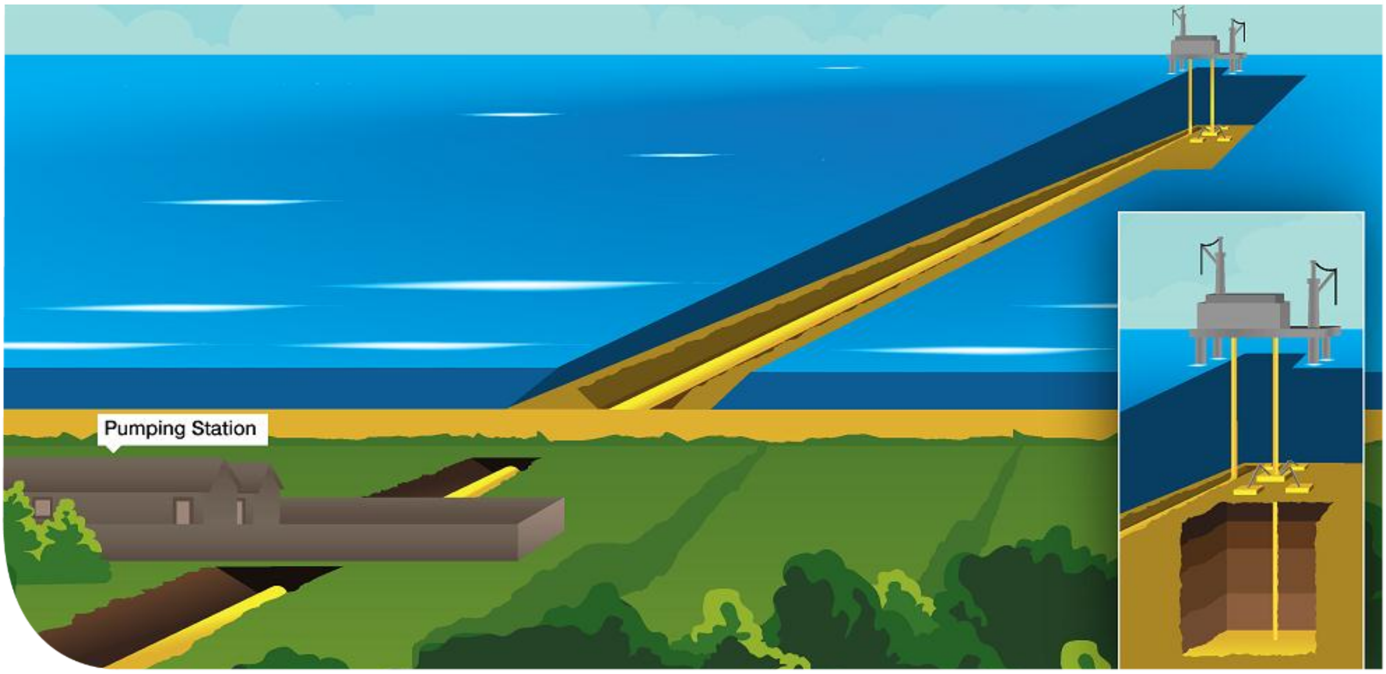
WHITE ROSE

K30 Storage Process Description

Technical: Storage



CAPTURE POWER

drax

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Contents

Key Words

Key Work	Meaning or Explanation
Carbon	An element, but used as shorthand for its gaseous oxide, carbon dioxide CO_2
Capture	Collection of CO_2 from power station combustion process or other facilities and its process ready for transportation
Feed Composition	The composition of the CO_2 is expected to change beyond the first year of operation of Drax and the CO_2 transportation network. Since small levels of impurities significantly impact the properties and phase envelope of pure CO_2 making it difficult to predict its behaviour over an anticipated operating envelope, composition specifications have been developed for different scenarios
First load	The amount of CO_2 produced during the first year of the CO_2 transportation system
Full Chain	Reports described as "full chain" would cover the complete process from the capture of the carbon at the emitter plant to its injection into the storage reservoir
Key knowledge	Information that may be useful if not vital to understanding how some enterprise may be successfully undertaken
Offshore Storage Process	The equipment and utilities required to import, inject and transfer CO_2 to other installations
Storage	Containment in suitable pervious rock formations located under impervious rock formations usually under the sea bed
Transport	Removing processed CO_2 by pipeline from the capture and process unit to storage
Wellhead Injection Platform	A small normally unmanned installation, consisting of little more than a well bay, helipad and emergency shelter. It is designed to operate remotely under normal operations, only to be visited occasionally for routine maintenance or well work

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 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, which would generate up to 448MWe (gross), integrated into a full-chain Carbon Capture and Storage (CCS) Project. CCS technology allows 90% of the carbon dioxide produced during combustion to be captured, processed and compressed before being transported to permanent 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, which is responsible for the Transport and Storage (T&S) network, and Capture Power Limited (CPL), which is responsible for the Oxy Power Plant (OPP) and the Gas Processing Unit (GPU).

This document provides a summary of the process description for the offshore storage facility.

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 and 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 Key Sub-Contract (KSC)) pursuant to which NGCL will perform a project (the WR Transport and Storage (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 (KKDs). This document is one of these KKDs and it provides a summary of the process description for the offshore storage facility.

2 Purpose

The purpose of this document is to provide a process description for the offshore storage facility describing the choices, selection and configuration of major equipment packages.

The process description covers the following major equipment packages:

- filters;
- manifold;
- pumps;
- PIG traps;
- venting arrangements;
- fuel / power supply;
- metering package; and
- well arrangements.

It includes:

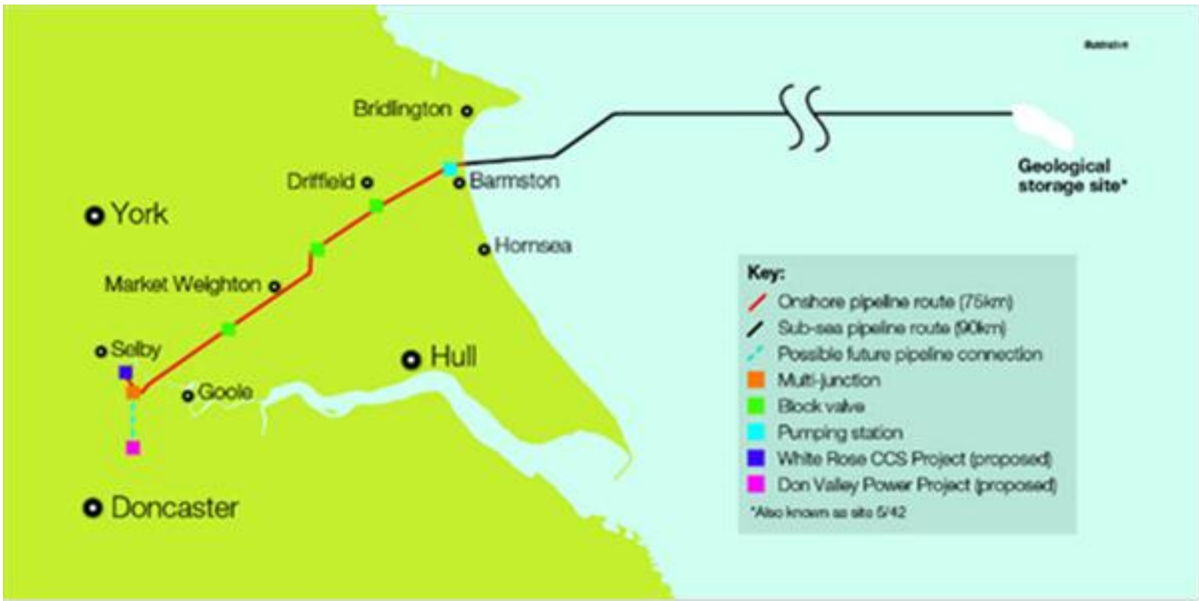
- A description of the control and performance monitoring systems including safety Instrumentation and metering systems;
- a description of the venting philosophy;
- specification of CO_2 including impact of impurities;
- pipeline length, diameter, wall thickness and material;
- pipeline operating and design conditions;
- design considerations for each of the operational modes;
- provision for shutdown and containment of pipework contents;
- a description of existing assets including any modifications required and design life;
- a description of novel items including required scale-up and previous experience;
- a description of utility facilities; and
- a description of any effluent discharge streams.

3 Overview

The White Rose CCS Project is to provide an example of a clean coal-fired power station of up to 448MW gross output, built and operated as a commercial enterprise.

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

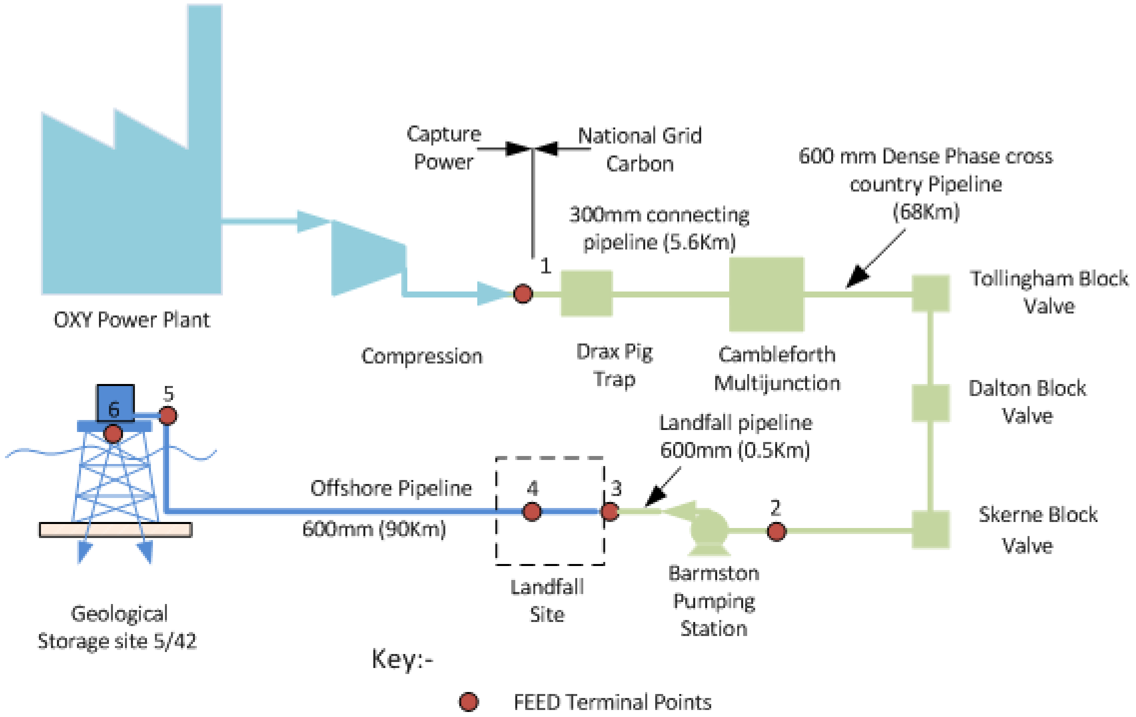


The standalone power plant would be located at the existing Drax Power Station site near Selby, North Yorkshire, generating electricity for export to the Electricity Transmission Network as (the "Grid") well as capturing approximately 2 million tonnes of CO_2 per year, some 90% of all CO_2 emissions produced by the plant. The by-product CO_2 from the Oxy Power Plant (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 Offshore Storage Facility

The offshore storage facility of the overall White Rose Carbon Capture and Storage network is a Normally Unmanned Installation (NUI) wellhead injection platform. The platform comprises of the following:

- PIG receiving facilities;
- cartridge type filters;
- injection manifold;
- metering facilities (on individual CO_2 injection well lines);
- three CO_2 injection wells which dispose of the CO_2 into the saline aquifer storage site located in block 5/42 of the southern North Sea. In the future, the numbers of injection wells can be increased; and
- utilities:
  - Mono Ethylene Glycol (MEG) storage tank and pumps to prevent CO_2 hydrate formation during well start-up operations and well water wash activities;
  - water wash treatment facilities to avoid halite build up in the near well bore region caused by CO_2 injection shut-in (seawater lift pumps and caisson, filters and chemical treatment); additional water wash facilities will be provided by a temporary skid (injection pumps, filters, power generation and chemicals);
  - corrosion inhibitor injected upstream of the choke valves;
  - other utilities (drains system, diesel storage system, nitrogen, fresh water system, waste water system, power generation system, seawater system, CO_2 vent and wellhead control panel);
  - support systems (crane, temporary safe refuge, battery room, marine navigation aids /telecoms and helideck); and
  - safety systems; fire and CO_2 gas detection systems, helideck foam, Deck Integrated Fire Fighting System (DIFFS) package and Totally Enclosed Motor Propelled Survival Craft (TEMPSC).

The platform substructure will be a four leg, liftable, steel jacket, commonly used in the North Sea. Additional allowance is to be built into the jacket and topsides to allow for the future installation of CO_2 booster pumps (and associated recycle cooler) to transport CO_2 further afield. Spare risers and J-tubes, for control and power supply, will also be provided.

Figure 3.2 on the previous page depicts the end-to-end chain overall schematic diagram from the White Rose CCS Project. The offshore storage facility is shown between terminal points 5 and 6.

4.1 Offshore Storage Facility Future Expansion

NGCL have taken a strategic investment decision to design the transportation and storage system for future expansion beyond the initial first load CO_2 supply. The aim is to create an onshore and offshore hub to reduce incremental costs for future entrants into the pipeline system.

Several key expansion decisions have been taken:

- the 600mm ND (24in) pipeline has a capacity of 17 Million Tonnes Per Annum (MTPA), this is well in excess of the first load supply of 2.68MTPA and expected maximum injection capacity of the aquifer of 10MTPA;
- the platform will be designed to allow for future expansion of the CO_2 injection systems. This includes:
  - spare well slots to allow for additional platform CO_2 injection wells within the storage site;
  - a spare export riser will allow for future onward transportation to further CO_2 storage sites;

  - a weight allowance and module support frame will be provided in the platform jacket structure design that could accommodate a potential future module containing electric driven CO_2 booster pumps and their associated recycle cooler, if deemed necessary;
  - spare J-tubes will be provided for future import power cables;
  - spare risers and J-tubes will be included in the jacket to allow for future subsea CO_2 injection and water production well tiebacks to maximise Endurance storage capacity;
  - space for future PIG launchers/receivers will be allowed for in the design;
  - space and tie-in provision for additional filtration vessels; and
  - spare capacity will be included in the control systems for future CO_2 injection wells water production wells and CO_2 booster pumps;
- seawater lift pumps will be sized for the first load requirements, however the future booster pumps recycle cooler seawater requirement represents the greatest seawater demand (447 m^3/h). This will be required in year 10 of facility life when the expected transport system flow rates will exceed the capacity of the Endurance storage site, requiring pumping of excess fluids to other storage sites through an export pipeline; and
- once CO_2 injection rates increase beyond the first load, water production will be required from the aquifer to maintain acceptable reservoir pressure. It is expected that up to eight water producers will be installed over the design life. Produced water must be discharged at the sea surface to allow for adequate dispersion. This can be achieved either by having individual well head structures for each water producer or by piping subsea water producers back to the central platform. This decision is not required to be made during FEED. However, the provision of spare water production risers on the platform hub would facilitate future tieback of water producers if this option is selected. No electric submersible pumps will be required to lift produced water from the aquifer. It is expected that any future water production wells will be controlled and powered via an umbilical from the central platform.

5 Design Cases and Composition

5.1 Design Flow Cases

Throughout the design life of the CO_2 transportation system, the anticipated flow rates will increase, as the number of power plants that 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 production over time and the predicted flowrates are shown in Table 5.1.

Table 5.1: Predicted Development of CO_2 Transportation System

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

5.2 Feed Composition

The operational objective of the onshore transport system is to maintain the CO_2 stream in the dense phase from the tie-in point with the Drax OPP through to injection wells at the offshore platform.

A definitive composition for the anticipated design flow cases has not been specified, however, a first load composition has been derived by combining the CO_2 compositions from the landfall, offshore facilities and pipeline basis of design for FEED with the basis of design for the Barmston carbon dioxide pumping facility. The first load composition contains 99.7% CO_2 and up to 10 ppmv of oxygen (O_2) and 50 ppmv of water (H_2O) with the remaining balance of composition comprised of nitrogen (N_2) and argon (Ar). The first load CO_2 composition in year 1 is given in Table 5.2.

Table 5.2: 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

Since small levels of impurities significantly impact the properties and phase envelope of pure CO_2 making it difficult to predict its behaviour over an anticipated operating envelope, a CO_2 transportation pipeline composition specification has been developed.

The entry specification applies to the offshore storage system and provides the permitted limits for each component relative to the following criteria:

- safety design;
- Integrity design; and
- hydraulic efficiency.

The safe operating limit of the composition has also been investigated and comprises:

- a saturation pressure for the CO_2 rich mixture of no more than 80barg: and
- the individual maximum allowable component levels defined in the specification for CO_2 quality requirements.

A summary of the composition specification is shown in Table 5.3 below.

Table 5.3: 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	0
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:

1. National Association of Corrosion Engineers (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 (10 ppmv).Specified to avoid material selection issues in the well tubing, where the dry CO_2 contacts saline aquifer water.
3. Maximum water content (50 ppmv). Specified to ensure no free water occurs during normal or transient operations.
4. The allowable mixture of non-condensable components in the CO_2 stream must be:
   Gaseous Phase: $N_2 + O_2 + H_2 + CH_4 + Ar \leq 9.0$ vol%
   Dense Phase: $N_2 + O_2 + H_2 + CH_4 + Ar \leq 4.0$ vol%, with H_2 no greater than 2.0%

The composition of the CO_2 is expected to change beyond the first year of operation of Drax 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; see Table 5.4, to cover the possible range for the future operation of the CO_2 transportation system. Note that HYSYS is an oil and gas process simulation software that enables the optimisation of conceptual design and operations.

Table 5.4: 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

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)
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:

1. The maximum specification for NOx and SOx is 100ppmv each (0.01 vol%). However, these two components are not available for use in the GERG2008 fluid package specified for the HYSYS simulation work (the GERG2008 is an equation of state used for modelling CO_2 with impurities flow assurance studies.). 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 the FEED, for example, Flow Assurance, and where the software permits the use of NOx and SOx.

5.3 Impact on CO_2 properties due to impurities

The impacts of various components on pure CO_2 properties are summarised in Table 5.5.

Table 5.5: 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, affects hydraulic efficiency, may increase the size of the two phase region and may cause corrosion problems within the well tubing when contacting saline water
N_2	Decreases density and viscosity, more so than O_2. Expansion of the phase envelope, may increase the size of the two phase region and affects hydraulic efficiency
H_2	Decreases density and viscosity, more so than N_2 and raises saturation pressure and affects hydraulic efficiency
Ar	Decreases density and viscosity, similar to N_2. Hydraulic efficiency is affected and may increase the size of the two phase region

Various carbon capture technology CO_2 product stream compositions were also studied:

- pre-combustion CO_2 product streams demonstrated the greatest divergence from the phase envelope of pure CO_2 when compared to other technologies, due to the high levels of H_2 in the composition;
- the addition of impurities within the CO_2 stream will affect the hydraulic efficiency of the offshore transportation system; and
- for a given flow rate, the pressure drop within the pipeline increased, meaning that a greater upstream pressure was required.

At the storage site, the mass flow injected to the wells will be reduced, for a given differential pressure between the offshore pipeline and reservoir, when the CO_2 stream contains additional impurities. Storage capacity may be impacted by non-condensable components occupying space.

The increase of impurities expands the phase envelope. In particular non-condensable components such as hydrogen, increases the possibility of moving to two-phase conditions; a region with gas and liquid coexisting; reducing the operational area for the pipeline, restricting pipeline operations, which in turn can reduce the operating range for emitters in order to keep out of the two-phase region. Operating within the two-phase region is to be avoided due to the high likelihood of operational instability.

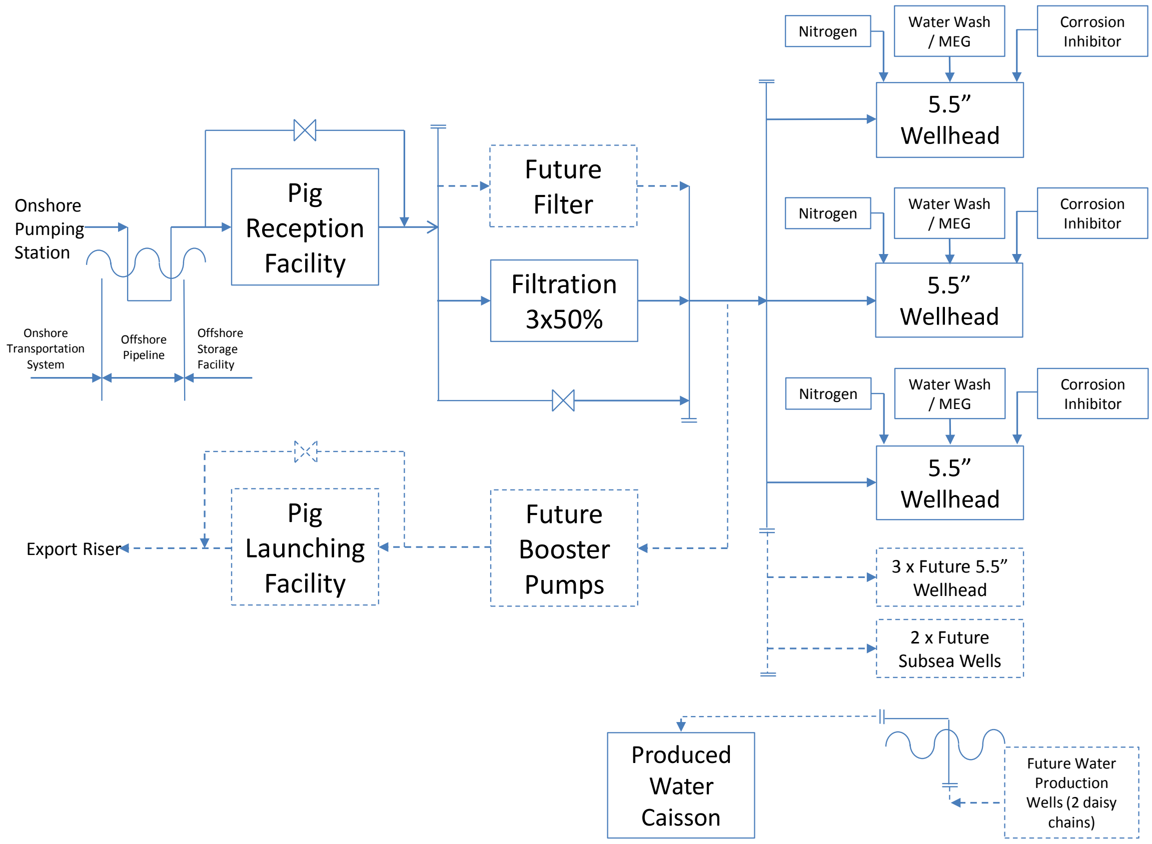
6 Storage and Process Description

6.1 Overview

The section describes the equipment required to inject and transfer CO_2 to other installations and describes the utilities required to support the process and maintain the wells.

A high level schematic of the offshore storage process is shown below.

Figure 6.1: Schematic of Proposed CO_2 Storage System



The equipment required at the offshore storage site is described in the following sections.

6.2 Major Equipment and Vendor Package Selection

Since the storage facility is located offshore and is normally unmanned, major equipment and interconnecting pipework has been selected to minimise space, reduce weight and to allow equipment to be operated locally, when manned, or remotely when unmanned. The facility is designed for a 40-year life.

Additional space and weight allowance has been incorporated into the design to accommodate future demand, when CO_2 flow rates increase and to allow infrequent operations such as water wash of wells (when isolated from the main process). Equipment has been designed with redundant capacity to achieve the desired availability targets of the end-to-end transportation and storage chain as well as the 40 year design life.

6.3 CO_2 Import Facilities

Dense phase CO_2 will arrive at the platform through the 600mm ND (24in) import riser equipped with a riser Emergency Shut Down Valve (ESDV) and maintenance valve. A pressure indicator and temperature indicator will be available upstream and downstream of the riser ESDV for leak testing purposes. The pressure indicator will also be used to monitor the pipeline pressure both in steady state and whilst pressuring the facility through the upstream bypass valve.

Thermal relief valves will be required between valves, where the potential exists to trap an inventory of CO_2 and subject it to a change in ambient conditions and/or solar gain which can cause thermal expansion of the trapped CO_2 inventory.

All ball valves will be self-venting (within the cavity) to avoid thermal expansion of the trapped CO_2 inventory. Valves will be full bore and the temperature indicator is non-intrusive to permit PIG operations.

The total CO_2 mass arriving at the platform is computed by measuring the flow rate (using orifice type meters) at each injection well together with the associated pressure and temperature.

A 600mm Pipeline Inspection Gauge (PIG) launcher and receiver will be provided at the outlet from the Barmston pumping facility and on the platform, respectively, to allow intelligent PIG operations of the offshore pipeline for inspection and monitoring purposes.

The PIG launchers and receivers will be designed in accordance with PD-8010 and be of sufficient dimensions to fit an Intelligent pipeline Inspection Device (IID), also known as an intelligent PIG. The IID will inspect the pipeline for internal and external corrosion and damage.

The geometry of the pipeline and topsides piping will be compatible with running IIDs; having a minimum bend radii of three times the outside diameter (3D) included in the tie-in spool pieces and pipework. At branched connections, guide bars will be incorporated where the diameters exceeds 25% of the pipeline diameter to ensure effective and safe PIG operations.

Manual venting facilities for the PIG receiver will be provided and connected to the CO_2 vent stack. A mechanical interlocked valve system will be provided to ensure the correct valve sequencing takes place in order to protect personnel carrying out the PIG operations.

Table 6.1 below provides the design and operating conditions of the CO_2 import facilities.

Table 6.1: CO_2 Import Facilities Design and Operating Conditions

Equipment	Design Conditions		Operating Conditions (Notes 3, 4 & 5)	
	Pressure (barg)	Temperature (min / max) (°C)	Pressure (min / max) (barg)	Temperature (min / max) (°C)
Riser	182 (Note 1)	-46 / 50	90 / 182	1 / 20
PIG Receiver (03-VE35006-D200)	200 (Note 2)	-46 / 50	90 / 182	1 / 20

Notes:
1. Maximum Allowable Operating Pressure (MAOP) is 182barg. The maximum incidental pressure is 10% above this value; 200barg.
2. PIG Receivers are covered under PD-8010-2; however parts of the receiver (end closures) will be designed to PD5500. The whole receiver is designed under PD5500 (for testing purposes) with a design pressure set at the maximum incidental pressure of the offshore pipeline of 200barg.
3. Minimum operating pressure is set to ensure CO_2 remains within the dense phase throughout the transportation system.
4. Maximum operating pressure is set to the MAOP of the pipeline.
5. Normal operating pressure range is between 100barg and 161barg (maximum reservoir pressure with impurities at Year 5 flow rates).

6.4 CO_2 Processing and Injection Facilities

6.4.1 Filtration

Prior to injection, CO_2 is routed to fine filters which are installed to filter out fine particulate matter from the dense phase CO_2 in order to avoid the risk of reservoir blockages. The maximum permitted particulate size is ≤5 microns.

The proposed phasing of the equipment is as follows:

- Year 1: three 50% offshore storage facility CO_2 fine filters with 5.7MTPA capacity each;
- Year 10: one offshore storage facility future CO_2 fine filter with 5.7MTPA capacity.
  Note that the configuration will become four 33.3% filters at year 10.

The filters will be operated remotely using motorised valves with limit switches allowing selection of which filters are in service. A remotely monitored differential pressure indicator will be provided to indicate when filter cartridge require replacement.

The filters will be provided with a bypass, which may be used for pipeline/platform depressurising purposes or in future operation when the platform is used as a pumping station and the downstream injection facility has its own fine filters. Filters will be installed horizontally with quick opening end closures to allow quick cartridge replacement with simple mechanical handling. The quick opening end closures will be fitted with mechanical safety devices to ensure that the filter is fully depressurised before the closure can be opened.

To ensure that the flow within the CO_2 transportation system is uninterrupted, when taking a filter out of service for maintenance, the Integrated Control and Safety System (ICSS) will be designed with a software valve interlock. This ensures that a filter can only be taken offline when another filter is brought on stream; this also prevents inadvertent closure of a filter locally or remotely from the Supervisory Control And Data Acquisition (SCADA) system. Note that the SCADA is a system operating with coded signals over communication channels to provide control of remote equipment.

Manual venting facilities will be provided from the filters connected to the CO_2 vent stack which will be used during maintenance periods. The filters are depressurised by draining dense phase CO_2 from low points to the platform vent; removal of liquid/dense phase fluid prevents formation of solids within the vessels.

A single pressure relief valve, set at 200barg, will be provided to protect filters against overpressure. Due to the filter sparing configuration, multiple relief devices are not required. Future pressure relief valve inspections may be planned to coincide with cartridge replacement.

6.4.2 CO_2 Injection Manifold

After flowing through the filters, CO_2 flows into the 600mm ND (24in) manifold. A connection to the future CO_2 booster pumps will be provided upstream of the manifold. Remote temperature and pressure monitoring facilities are installed in the manifold. Pressure monitoring is used for pipeline backpressure control at the choke valves to ensure the pipeline remains in dense phase; above 90barg at all times. In addition, a low pressure trip is employed which will shut in the well in the event of controller or choke valve failure that could lead to lower than desirable pressures in the manifold (and hence the transportation network).

At first load (year 1), the manifold will have three connections to the injection wells. Additional space will be allowed for the following future connections:

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

Manual venting facilities from each wellhead connection will be provided. These are connected to the CO_2 vent stack. The manifold will be depressurised by draining dense phase CO_2 from low points as depressurising through the liquid phase minimises boiling of liquids and cold temperatures/formation of solids.

6.4.3 CO_2 Injection Wells

From the manifold, CO_2 will flow to the first load platform injection wells. Following future expansion, the CO_2 will also flow to additional platform injection wells or the future subsea wells. Each platform injection well inlet arrangement is provided with:

- an orifice plate for metering (outputs from the meters are corrected using pressure and temperature measurement);
- relief valves to protect piping from overpressure in the event of thermal expansion (closed in conditions);
- a corrosion inhibitor injection point; and
- a motor actuated choke valve with downstream pressure and temperature measurement.

A metering accuracy of ±2.5% will be selected. The corrected value will be recorded within the ICSS and in the future will be used to control the flow rate to the wellheads, whilst manifold pressure will be controlled by varying the variable speed drives of the future CO_2 booster pumps, which will be transporting surplus CO_2 to future storage sites.

Further downstream, pressure and temperature measurements will be taken for each well.

The well bay will contain six well slots:

- three for the initial first load; and
- three spare well slots for future platform CO_2 injection wells or re-drills.

Injection wells will be designated as follows:

Table 6.2: Wells Numbering and Features

Well Number	First Load/ Future	Platform/ Subsea Well	Well Tubing Diameter (inch)	Maximum Flowrate (MTPA)
26-AA10001-D200 (P5W2)	First Load	Platform	5.5	2.6 (Note 1)
26-AA10002-D200 (P5W1)	First Load	Platform	5.5	2.6 (Note 1)
26-AA10003-D200 (P5W3)	First Load	Platform	5.5	2.8 (Note 1)
26-AA10004-D200	Future	Platform	5.5	2.6 (Notes 1 and 2)
26-AA10005-D200	Future	Platform	5.5	2.6 (Notes 1 and 2)
26-AA10006-D200	Future	Platform	5.5	2.6 (Notes 1 and 2)
n/a	Future	Subsea	n/a	n/a
n/a	Future	Subsea	n/a	n/a

Notes:

1. Selected at year 5-10 winter conditions (full flow generic composition case) with maximum offshore pipeline operating pressure of 182barg and a reservoir pressure of 171barg ;
2. Future wells (5.5in) are assumed to have the same configuration and a maximum flow rate equivalent to P5W1/2 wells.

The platform will be provided with well trees and well head for each well. Each of these will be provided with the following:

- actuated sub-surface safety valve;
- lower master valve;
- actuated upper master valve;
- swab valve;
- actuated wing valve;
- annulus connections for pressure monitoring, sampling and venting. Vents are connected to the CO_2 vent stack;
- connections for flowing wellhead pressure measurement;
- down hole pressure and temperature measurement;
- isolation valves for wash water/MEG; and
- isolation valves for nitrogen.

Each platform well will be provided with breakout spools on the flow line connection.

The CO_2 injections wells will be hard piped to receive:

- water wash from a temporary water wash skid loaded onto the platform laydown area with an ESDV for each individual wellhead. MEG for hydrate control from storage and injection pumps is injected into the same line; during normal operation, the wash water ESDV will be closed and a soft safety interlock with the respective wing valve will be provided; and
- nitrogen from quads loaded onto the platform laydown area will be used to create a gas cap after water wash operations. Note that a quad is a manifold pack holding cylinders connected to one outlet.

Space will be allowed for connections to future subsea wells inside the site, except from the manifold connections to the platform injection wells described above. The two future manifold connections for subsea injection wells will tie-in to two pre-installed 400mm ND (16in) risers. Each riser is capable of 6MTPA (60% of total Endurance injection capacity). It is envisaged that an ESDV will be provided upstream of each riser. Upstream of the ESDVs, flow orifices will be installed; the flow will be corrected by temperature and pressure measurements. The subsea well choke valve will be modulated by a manifold pressure controller, controlling the CO_2 flow rate injected into the subsea wells.

Deck space will be allowed for two temporary 400mm ND (16in) future PIG launchers close to the 400mm ND (16in) risers. The PIG launchers will be specified to accommodate IIDs. Two spare J-tubes will also be pre-fitted for control and power supply to the future CO_2 subsea injection wellheads within the storage site.

Table 6.3 presents the design and operating conditions of the CO_2 processing facilities.

Table 6.3: CO_2 Processing Facilities Design and Operating Conditions

Equipment	Design Conditions		Operating Conditions	
	Pressure (barg)	Temperature (min / max) (°C)	Pressure (min / max) (barg)	Temperature (min / max) (°C)
Inlet Filters	200 (Note 1)	-46 / 50	90 / 182 (Note 2)	1 / 20
Manifold	200 (Note 1)	-46 / 50	90 / 182 (Note 2)	1 / 20
Risers for Subsea Tiebacks	182 (Note 1)	-46 / 50	90 / 182	1 / 20
PIG Launchers for Subsea Tiebacks	200 (Note 3)	-46 / 50	0 / 182	1 / 20

Notes:

1. A design pressure of 200barg is applicable to ASME B31.3 pipework sections only. The offshore pipeline and risers are designed in line with PD-8010-2. Pipeline design pressure (MAOP = 182barg) is the pressure at which calculations are based on for the pipeline. The maximum incidental pressure is 10% above this value; 200barg.
2. Minimum operating pressure is set to ensure CO_2 remains within the dense phase throughout the transportation system. Maximum operating pressure is set the maximum allowable operating pressure of the pipeline. Normal operating pressure range is between 100barg and 133barg.
3. PIG receivers are covered under PD-8010-2; however parts of the receiver (end closures) will be designed to PD5500. The whole receiver is designed under PD5500 (for testing purposes) with a design pressure set at the maximum incidental pressure of the offshore pipeline of 200barg.

6.5 Future CO_2 Export Facilities

During first load no CO_2 will be exported and all of the 2.68MTPA will be injected in the Endurance reservoir. At year 10, CO_2 will be transported onwards through the hub platform to other CO_2 storage sites. The first load facilities are designed to facilitate this future expansion. A connection downstream of the CO_2 filters and upstream of the manifold will be provided for future CO_2 export. CO_2 will be routed to the three 50% variable speed offshore CO_2 booster pumps to increase the pressure to 182barg. Pumps will be sized for the full flow arriving to the platform (8.5MTPA each).

A pump recycle line will be provided to allow pump proving (for the very first pump start-up at commissioning, or post overhaul for maintenance). The recycle line will route CO_2 to the future CO_2 booster pumps recycle cooler which is a shell and plate exchanger designed to cool the full flow of one pump against seawater. A cooler will be required to ensure that the pipework design temperature is not exceeded during the recycle operation. The temperature of the CO_2 will be controlled by regulating the seawater flow rate through the exchanger. Seawater exiting the exchanger is discharged overboard through the produced water caisson.

Downstream of the offshore CO_2 booster pumps, the CO_2 will flow to the pre-fitted 600mm ND (24in) export riser. Deck space will be allowed for the offshore storage facility future PIG launcher. The PIG launcher will be specified to accommodate IIDs. Future offshore pipeline overpressure will be protected using an offshore storage facility High Integrity Pressure Protection System (HIPPS) and an ESDV valve will be provided upstream of the riser.

One spare J-tube will be pre-fitted for control and power supply to future satellite CO_2 injection wells outside the storage site. Two spare J-tubes will be pre-fitted for power supply cable from shore for future Offshore CO_2 Booster Pumps. A manual vent will be provided for venting the PIG Launcher (from a low point to prevent formation of solids within the piping). An additional venting connection routed to the vent stack will be located upstream of the riser.

Manual venting facilities for the pumps will be provided on their discharge. These will be connected to the CO_2 vent stack. Draining of dense phase CO_2 from low points prevents formation of solids within the pipework. Temperature and pressure monitoring facilities will be provided on the discharge of the pumps.

Table 6.4 presents the design and operating conditions of the CO_2 export facilities.

Table 6.4: CO_2 Export Facilities Design and Operating Conditions

Equipment	Design Conditions		Operating Conditions	
	Pressure (barg)	Temperature (min / max) (°C)	Pressure (min / max) (barg)	Temperature (min / max) (°C)
Offshore Future CO_2 Booster Pumps	281.5	-46 / 50	144 / 182	1 / 27
Offshore Storage Facility Future PIG Launcher	281.5 (Note 4)	-46 / 50	0 / 182	8 / 27
Offshore Future CO_2 Booster Pumps Recycle Cooler	281.5	-46 / 50	122 / 130 5 / 7 (Note 1)	35 / 24 19 / 26 (Note 1)
Export Riser	256 (Notes 2 and 3)	-46 / 50	182	1 / 27

Notes:

1. Operating conditions of the offshore future CO_2 booster pumps recycle cooler are provided for the shell inlet/outlet and plate inlet/outlet respectively.
2. The riser is designed for the full shut in head of pumps regardless of the HIPPS employed. The pressure break on the pipeline to 1500# (Maximum allowable operating pressure of the pipeline is 182barg) is expected to be outside of the platform safety zone to satisfy the HSE requirements.
3. The export riser and pipeline is designed in line with PD-8010-2. Pipeline design pressure (MAOP = 256barg) is the pressure at which calculations are based on for the pipeline. The maximum incidental pressure is 10% above this value; 281.5barg.
4. PIG launchers are covered under PD-8010-2 code; however parts of the launcher (end closures) may be designed to PD5500. The whole launcher is designed under PD5500 (for testing purposes) with a design pressure set at the maximum incidental pressure of the offshore pipeline of 281.5barg.

6.6 Produced Water Facilities

Up to eight water production wells may be installed in phases over the design life. Water production from the aquifer is not required for the first load CO_2 injection rates. Two 400mm ND (16in) water production well risers are pre-fitted in the platform. One ESDV will be provided in each future incoming line. The risers will allow two daisy chain tie backs from water production wells to the hub platform. Each daisy chain will be capable of flowing 662m^3/h, with a maximum tubing head pressure of 50barg at each well head.

Flow indication will be provided to measure the quantity of water that is discharged overboard. A sample connection will be installed to allow operations to analyse the well stream prior to routing overboard. An analysis unit is also specified to monitor the CO_2 content of the incoming stream as breakthrough of CO_2 could lead to corrosion issues and degradation of the topsides pipework.

Although the water production pressure at this stage is unknown and therefore feasibility of PIG operations the produced water flow line is unknown (however the maximum allowable tubing head pressure is 30barg), it is a requirement of the basis of design that additional deck space will be allowed for two temporary 400mm ND (16in) future PIG receivers. The PIG receivers will be specified to accommodate IIDs. Additionally, deck space will be provided for a future header joining the two water lines with the pre-fitted produced water discharge caisson. Two pre-fitted J-tubes for control and power supply for future water production wells will also be pre-installed.

Table 6.5 presents the design and operating conditions of the produced water facilities.

Table 6.5: Produced Water Facilities Design and Operating Conditions

	Design Conditions		Operating Conditions	
	Pressure (barg)	Temperature (min/max) (°C)	Pressure (min/max) (barg)	Temperature (min/max) (°C)
Import Risers	45.5 (Note 1)	-10 / 90	0 / 30	4 / 65
Produced Water Discharge Caisson	3	-10 / 90	Atmospheric (ATM)	4 / 65

Notes:

1. The future water production pipelines and risers are designed in line with PD-8010-2 code. Pipeline design pressure (MAOP = 45.5barg) is the pressure at which calculations are based on for the pipeline. The maximum incidental pressure is 10% above this value; 50barg.

6.7 Utilities

Utilities will be provided to support the operation of the facility and carry out intermittent maintenance activities on the wells.

6.7.1 Seawater

Seawater will be provided in a single pass, once through, system with discharge overboard through the produced water caisson. Two 100% seawater lift pumps will be installed in the seawater lift caissons and will supply the following users during initial load:

- seawater to the temporary water wash skid (1000m^3/day; intermittent use); and
- platform utility water (for deck wash down; intermittent use).

In future additional seawater will be supplied to the future CO_2 booster pumps recycle cooler for cooling purposes. This duty will require larger seawater pumps. Seawater piping/header and caissons will be initially oversized for future demand to permit easier installation of larger seawater pumps in the future.

An anti-marine fouling system will be installed within the caissons to protect the seawater lift pumps.

Prior to distribution, seawater from the pumps will be filtered in the seawater lift pumps filter to a maximum size of 400 microns. The delivery pressure from the seawater lift pumps will be maintained using back pressure control at each pump minimum flow control valve. This will ensure that sufficient pressure is available to overcome system hydraulics when supplying seawater to the wash water service tank and future CO_2 booster pumps recycle cooler. Remote monitoring of the filters will be provided to indicate when filter changeover is required.

The seawater lift pumps will be provided with a vent/vacuum breaker at the top of the riser to prevent surge/water hammer upon pump start-up, and prevent vacuum conditions forming as the seawater drains down the riser when the pump is stopped. Similarly, there will be an air release valve / auto vent valve at the seawater system high point to prevent surge/water hammer and vacuum conditions forming in the system.

Table 6.6 presents the design and operating conditions of the seawater lift facilities.

Table 6.6: Seawater Lift Facilities Design and Operating Conditions

Equipment	Design Conditions		Operating Conditions	
	Pressure (barg)	Temperature (min/max) (°C)	Pressure (barg)	Temperature (°C)
Seawater Pumps	15	-10 / 50 (Note 1)	0 / 10	4 / 19
Seawater Lift Caisson	3	-10 / 50	ATM	4 / 19
Seawater Lift Pumps Filter	15	-10 / 50 (Note 1)	5 / 7	4 / 19

Notes:

2. Design temperature set at black body limit and matches all process and utility systems. The temperature limit for 25%Cr super duplex stainless steel in seawater service is 30°C. The maximum operating temperature foreseen at the outlet of the future CO_2 booster pumps recycle cooler is 26°C.

6.7.2 Water Wash

Water wash injection will be used to avoid halite build up when CO_2 injection is shut in. The injection rate will be 1000m^3/day for a duration of seven days per year per well. The water wash injection pressure will be 146barg to 182barg. The coarse filtered seawater from the seawater lift pumps is filtered, chemically treated and pumped in the temporary water wash package prior to injection into the wells. The water wash package will be rented from drilling service contractors and lifted to a laydown area by crane; probably as multiple skids to enable crane lift. The high level temporary skid design includes:

- filters;
- chemical injection and storage;
- water injection pumps; and
- integral diesel power generation.

The seawater lift and diesel connections to the water wash package and the water wash connections to the wells will be hard piped up to the laydown area with appropriate isolation valves provided. Flexible hoses will connect to the skid to the isolation valves. A high pressure hose will be required from the discharge of the package to the connection at the package boundary.

Table 6.7 presents the design and operating conditions of the water wash facilities.

Table 6.7: Wash Water Facilities Design and Operating Conditions

Equipment	Design Conditions		Operating Conditions	
	Pressure (barg)	Temperature (°C)	Pressure (barg)	Temperature (°C)
Water Wash Package	200 (Note 1)	-10 / 50	0 / 182	4 / 19

Notes:
1. Design pressure quoted at the outlet of the injection pumps. Equipment (wash water filters and wash water service tank) supplied with seawater is aligned to the seawater design pressure of 15barg.

Two modes of flow control selection will be made available to operations to allow for full variation of the operating regime:

- before and after water wash injection, a 57wt% MEG solution will be injected for hydrate inhibition. A recycle line will be provided from the package outlet to the wash water service tank, which will allow a small quantity of water to feed forward under ratio control. This will ensures that the correct MEG concentration. After MEG injection, nitrogen will be injected to provide a gas cap on the well; and
- during wash water injection, wash water flow (41.7 m^3/h) will be measured and controlled by a wash water flow controller.

6.7.3 MEG Storage and Injection

Hydrates can form in the well tubing when cold CO_2 contacts directly with formation water or seawater from the water wash. MEG at 57%wt will be required to prevent hydrate formation in the CO_2 injection wells; injected before the initial start-up and before and after water wash injection.

The MEG storage tank will contain MEG at a concentration of 90wt%. The storage tank capacity will be sufficient to inject MEG for the maintenance of one platform well; this comprises the displacement of the entire well twice, before and after water wash injection. When depleted, MEG will be loaded to the tank from a boat through the MEG filter. Differential pressure indication across the filter will be available with a high pressure alarm to alert operations when internals may require replacement. Local and remote level indication will be provided with level alarms and trips to allow stock management, monitoring of loading operations and pump protection.

The MEG injection pumps will provide a constant volumetric flow rate of MEG (4 m^3/h) which is diluted with the water wash to 57wt% before being injected into the wells. MEG injection will take approximately four hours. Upstream of the pumps, an ESDV will shut on low flow to protect the pump. Downstream of the pumps, an ESDV will shut on high pressure to protect the temporary wash water package and system due to the elevated pumps shut in pressure. The injection pumps' motors will be provided with a variable speed drive for smoother start up and lower starting current.

A low flow trip will be provided on the MEG supply line, which will stop the wash water pumps and close the wash water ESDV, preventing water being injected to the well without MEG which would lead to potential hydrate formation.

Table 6.8 presents the design and operating conditions of the MEG storage and injection facilities.

Table 6.8: MEG Storage and Injection Facilities Design and Operating Conditions

Equipment	Design Conditions		Operating Conditions	
	Pressure (barg)	Temperature (min/max) (°C)	Pressure (barg)	Temperature (min/max) (°C)
MEG Storage Tank	0.07 + Liquid Head (LH)	-10 / 50	ATM	-3 / 20
MEG Injection Pumps	200	-10 / 50	0 –91	-3 / 20
MEG Filter	10	-10 / 50	5	-3 / 20

6.7.4 Biofouling Control Package

The biofouling package will prevent fouling in the:

- seawater lift pumps;
- seawater lift caissons; and
- produced water caisson.

The package will consist of copper and aluminium anodes housed within steel frameworks located in the caissons (below the pumps if applicable). An electrical current will be fed from the control package transmitter/rectifier resulting in the production of copper ions (which are a deterrent for marine growth). By regulating the current, the level of copper dosing will be adjusted.

The biofouling package will be automatically activated upon starting the seawater lift pump, however a small current will be maintained at all times in order to protect the bottom of the caisson and seawater lift pump when the pump is not in use.

6.7.5 Service and Potable Water

Since the facility will be normally unattended, fresh service water will be supplied by tote tanks. The quantity of tote tanks to be provided per visit is based on the water requirement to meet the daily demands of the personnel forced to stay overnight for one night (12 people at 300l/d). The fresh water will be used for sanitary washing, such as flushing toilets, shower, washing hands, and so on, and for supply to safety showers and eye wash. The number and locations of safety showers and eye wash will be defined during the detailed design. Potable (drinking) water will be brought on-board in bottles by the visiting crew.

6.7.6 Sewage

The facility will be normally unmanned and likely to be visited by personnel during dayshift hours; overnight stays will only happen as an emergency measure. Using these assumptions, a toilet with an integral macerator will be provided within the emergency overnight accommodation with a 4in nominal bore discharge overboard sewage line (sized to accommodate additional solids) instead of a waste water caisson.

6.7.7 Chemical Injection

Depending on the well materials selection, provision for permanent corrosion inhibitor injection facilities may be required particularly at the base of the well where CO_2 contacts saline water, until the saline water in the near wellbore region is displaced. Corrosion inhibitor will be brought to the platform in tote tanks which will be placed on the weather deck. Corrosion inhibitor will flow to the chemical injection packages by gravity and then injection pumps will inject into the wellheads upstream of the choke valves.

Two corrosion inhibitor packages are envisaged, one for the platform CO_2 injection wellheads and one for the future subsea CO_2 injection wells. The initial package will contain two pumps, supplying the first three wellheads. An additional pump will be installed, in future, to supply corrosion inhibitor to the future wellheads.

The packages will contain injection rate control devices, and discharge relief valves at the outlet of the pumps. Space and connections for a separate dedicated chemical injection package will be provided for future CO_2 subsea injection wells because the flow rate and pressure requirements are likely to differ from the platform wells. Table 6.9 presents the design and operating conditions of the chemical injection facilities.

Table 6.9: Chemical Injection Facilities Design and Operating Conditions

Equipment	Design Conditions		Operating Conditions	
	Pressure (barg)	Temperature (min/max) (°C)	Pressure (barg)	Temperature (°C)
Chemical Injection Packages	200	-10 / 50	-	-

6.7.8 Diesel System

Diesel is used for the following:

- platform crane;
- TEMPSC;
- water wash facilities ; and
- diesel generators on the platform.

6.7.8.1 Pedestal Crane Diesel Storage Tank

The pedestal crane diesel storage tank storage capacity will be sufficient for at least 155 days of unmanned operation. Therefore, it is envisaged that filling of the tank will be coordinated with the occasions when the platform is manned for maintenance (once every three months). The tank will be equipped with high and low level alarms in order to warn operations to stop filling or make arrangements to fill the tank. A low level trip will be provided for pump protection.

The tank will have a low drain point to draw off any water present in the diesel that has settled in the bottom of the tank. A connection will be provided to drain the water via a flexible hose to a tote tank.

6.7.8.2 Diesel Transfer Pumps

The diesel transfer pumps will supply diesel to the diesel service tank, the wash water package and the crane day tank filling point. The diesel will also be used for periodic re-fuel of the TEMPSC. The pumps will be electric motor driven positive displacement diaphragm pumps (two 100% in a duty/standby configuration) operated in gap control based on the level reading in the service tank. They are sized for a nominal 1 m^3/h with 2bar differential pressure. The pumps will be manually started and stopped when necessary and have a pressure regulated spill back to the pedestal crane diesel storage tank. High pressure trips will stop the pumps on high discharge pressure and isolate the pumps by closing the two ESDVs.

6.7.8.3 Diesel Service Tank

The diesel service tank will have a working capacity of 11.9 m^3. An overflow line will drain back to the pedestal crane diesel storage tank. The diesel service tank will supply diesel to the day tanks inside the power generation packages and provide buffer capacity should diesel supply be interrupted. Each generator day tank will be refilled from the diesel service tank by gravity.

Table 6.10 presents the design and operating conditions of the diesel facilities.

Table 6.10: Diesel Facilities Design and Operating Conditions

Equipment	Design Conditions		Operating Conditions	
	Pressure (barg)	Temperature (min/max) (°C)	Pressure (min/max) (barg)	Temperature (min/max) (°C)
Crane Pedestal Diesel Storage Tank	0.07 + LH (Note 1)	-10 / 50	ATM	-3 / 20
Diesel Transfer Pumps	6	-10 / 50	0 / 2	-3 / 20
Diesel Service Tank	0.07 + LH (Note 1)	-10 / 50	ATM	-3 / 20

Notes:
1. Liquid head of water

6.7.9 Power Generation

Three off 100kW diesel generator packages will provide electrical supply to the platform. The generators will be self-contained units with their own dedicated diesel day tanks which are supplied by the diesel service tank. The overflow from each generator day tank will drain back to the pedestal crane diesel storage tank.

The diesel generators will be configured for operation such as two will be running and one will be standby to meet the total electricity generation requirement. These will be remotely started and stopped.

In the event that power generation fails, a UPS system will provide emergency power only to the necessary units vital for safe operation (ICSS, telecoms, obstruction lights) for a period of 72 hours.

Note that the future CO_2 booster pumps will be powered by an electric subsea cable from shore.

6.7.10 Nitrogen

The nitrogen package will consists of a sixteen cylinders quad loaded onto the platform laydown area to provide nitrogen for:

- CO_2 injection wells water wash activities and start-up activities; and
- Commissioning and maintenance purposes such as PIG trap and filter purging.

A 16 cylinder quad will provide enough nitrogen to create the gas cap twice by raising the tubing head pressure to 40barg, using a pressure regulator valve, following water wash activities. This will limit flashing across the choke valve upon restart, which could cause low temperatures leading to potential hydrate formation or possible sublimation of CO_2.

An ESDV will be provided at the manifold outlet of the package to protect against overpressure due to control valve failure.

6.7.11 Wellhead Hydraulic Power Unit

The hydraulic power unit, which is part of the wellhead control panel, will supply hydraulic power to the topsides wells and valves. Additional space will be provided to allow future expansion of the hydraulic power unit to accommodate the maximum number of platform wells; which is six. The system will be configured with two low pressure pumps and two high pressure pumps, each set in an auto duty/standby arrangement.

6.7.12 Drains

Diesel from the crane pedestal storage tank, diesel service tank and day tanks in the power generation packages along with MEG from the MEG storage tank will be collected in the drains header, which will be connected to a facility to offload the drains to a tote tank. Rodding points will be provided to allow operations to clear blockages as required.

7 Operation and Control

7.1 Normal Operation

7.1.1 Operating Envelope

CO_2 is compressed into dense phase (liquid) for ease and practicality when transporting it between capture and storage offshore. The pressure-temperature diagram for CO_2 defines the approximate 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 platform. Key process conditions of the CO2 are listed in Table 7.1 below:

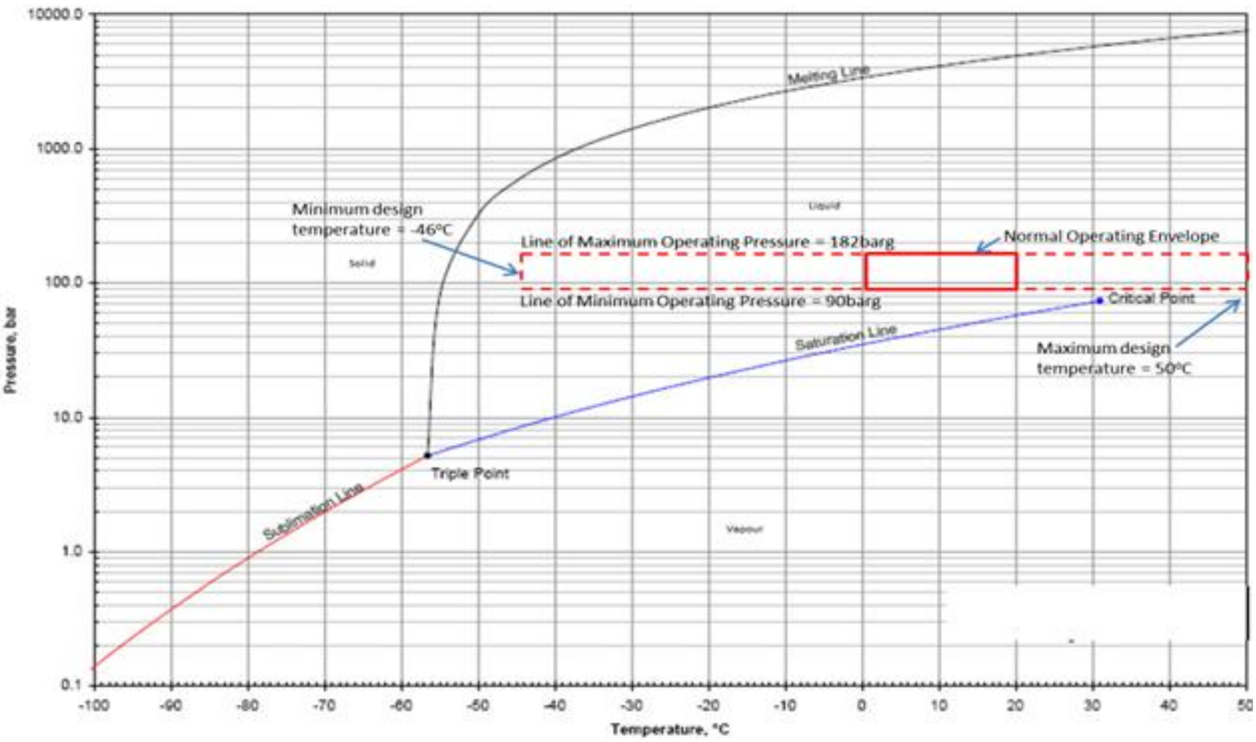
Table 7.1: Pure CO_2 Key Process Parameters

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

In order to keep the CO_2 inventory in the dense phase at all times, it is important to maintain the operating pressure significantly above the critical pressure. The operating temperature is selected below the critical temperature, but within the pipeline design temperature range (0°C to 20°C) along the entire transportation route.

Figure 7.1 displays the design and operating envelope of the Offshore Transport and Topside platform facility at the storage site for pure carbon dioxide. The operating range marked in solid red rectangle is shown for the CO_2 with impurities in the worst case scenario for full 17.0MTPA flow. The lower horizontal line of minimum operating pressure provides a margin over the critical point, which will be affected by impurities in the CO_2 flow.

Figure 7.1: Pure CO_2 Pressure Temperature Diagram with Operating Envelope



The onshore transportation system, operating in bypass mode, without the onshore CO_2 booster pumps, in the early years of operation or with the onshore CO_2 booster pumps, will operate over a range of flow rates; this will necessitate a range of discharge pressures to provide 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. Over time, the pressure of the reservoir will increase as CO_2 is injected down hole. The onshore CO_2 booster pumps will be limited to a maximum discharge pressure of 182barg in order to safeguard the containment integrity of the offshore pipeline and storage site. Ultimately the pipeline backpressure is controlled using the choke valves at the wellhead in conjunction with injection manifold master pressure controller at the platform. Future booster CO_2 pumps will compress the CO_2 up to 182barg to transport it outside the storage site.

7.1.2 Process Control

The offshore installation is designed for unmanned operation. The process control system will be part of the ICSS located at the offshore storage facility, which is a user friendly, proven and reliable system consisting of control facilities provided to the operator through Human Machine Interface (HMI) at the offshore storage facility local equipment room (when manned) and at the NGCL remote control centre (when platform is unmanned), which enables the operator to monitor and control the process parameters during start-up, normal operation and shutdown.

7.2 Abnormal Operation

As Drax will be the first captured CO_2 provider to the end-to-end transportation and storage system, there is a requirement for it to demonstrate its flexibility. For up to 100 days per year, Drax will operate at a reduced production rate, with a proposed minimum flow rate of 0.58MTPA (65,800 kg/h) for 10% of the year, approximately 37 days.

Drax OPP is also required to prove ramp rates (the rate at which a generating unit can change load), for the 75% to 100% range, which are set at 2% per minute of the design flow rate of 305,374 kg/h, which is 6,107 kg/h/minute. There is limited linepack availability within the system so it is expected that these flow rates and frequencies will also be seen at the offshore storage facility. Note that linepack is the mass of CO_2 in this case, occupying the volume of a section or entire pipeline at the given pressure and temperature.

In the event that process parameters fall outside of the normal operating range, alarms are provided, where necessary, to alert operations to take action before an event may escalate. If the event escalates further, shutdown action is taken.

7.3 Normal Start-up/Shutdown

Start-up may be from a pressurised or depressurised state, depending on the circumstances of the preceding shutdown. After a shutdown where possible, the stagnant system should be retained in a pressurised state for the ease of the restart. In the case of maintenance activities, the isolated system or equipment items will require isolation and complete depressurisation.

At the inlet to the pipeline transportation system, any out of specification CO_2 will be vented at the power plant site until all the specification criteria are met this ensures that only in specification CO_2 will arrive to the offshore storage site.

A normal shutdown, such as a planned shutdown will ramp down at a planned rate to a zero flow rate. Any equipment requiring maintenance intervention will be isolated and depressurised following the correct venting procedure.

7.4 Operation Manual

Operating procedures will be developed during detailed design to cover all operational aspects including:

- start-up;
- normal operation;
- abnormal operation; and
- controlled and emergency shutdowns.

The procedures will include a hierarchy of operation, responsibility, communication procedures and protocols.

8 Venting Philosophy

8.1 Venting Objectives

Safety, process, operating and maintenance reasons require venting of CO_2 from the entire end-to-end transportation and storage system. Venting large volumes of high concentration (≥ 96 vol%) high pressure CO_2 into the atmosphere has health, safety and environmental implications. All these factors impact the engineering design of the whole T&S system.

Venting is required for the following objectives:

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

Care is required when locating vent stacks since CO_2 is heavier than air at atmospheric conditions. Particular attention will be paid to buildings that are either pressurised or air-conditioned and the proximity to buildings or enclosures as the aerodynamic forces around the buildings and any air intakes will impact the safe dispersion of CO_2.

8.2 Venting Scenarios

Detailed procedures will be developed to cover all venting scenarios:

- to support start-up;
- out-of-specification CO_2;
- to depressurise the system;
- for thermal relief;
- for maintenance activities;
- during commissioning; and
- during a chain shutdown.

These scenarios are detailed in the proceeding subsections.

8.2.1 Venting to Support Start-up

Venting at locations other than the OPP is not expected during start-up providing the system components remain filled with on-specification CO_2. However, starting the full chain after maintenance may require venting to return to CO_2 service; this is covered below.

8.2.2 Venting Out-of-specification CO_2

The CO_2 product leaving the OPP is analysed and monitored to detect impurities such as O_2, NO_X and SOX. Currently there is no executive action at the OPP to vent if out of specification; however facilities do exist. It is not envisaged that out of specification CO_2 will be vented to atmosphere at the onshore transportation system (from TP-13) and the offshore storage facility (to the wellheads). Out of specification

CO_2 should not enter the onshore pipeline, as the system and equipment, such as filters and pumps, are designed for the flow rates and compositions detailed in Section 5. It is observed that certain components like moisture, H_2 and H_2S are not monitored at the OPP (prior to entering the transportation system). It is noted that there is a moisture analyser upstream of the CPL cold box, which is critical for the operation of this system and may provide an early indication for the downstream systems. The need for executive action on detection of off specification components in the CPL export stream is under review.

8.2.3 Venting to Depressurise the System

During maintenance the offshore storage facilities may be fully or partially vented. It is intended that both onshore and offshore pipelines will be isolated and left in a pressurised state.

Depressurisation of the offshore pipeline is considered a rare and abnormal requirement as it is intended that the pipeline systems will be maintained in a pressurised state during the operating lifetime of the full chain.

Depressurisation of the pipelines will be a manual operation and will utilise suitable venting systems and vent stack and will be carried out under a safe system of work.

8.2.4 Venting for Thermal Relief

Thermal relief is required to avoid overpressure conditions that arise when fluid is trapped in a system under rising temperature conditions due to solar gain or a change in ambient conditions. Venting may be used to bring the system back within its operational and design limits. Dense phase CO_2 has a high coefficient of thermal expansion and can create pressure rises in blocked/isolated sections of pipe, pipeline and equipment. Venting arrangements will accommodate the venting of dense CO_2.

Equipment such as isolation valves, small thermal relief valves, valve cavity vents and relief valve bonnets will have small local vents which will be potential sources of fugitive releases of CO_2. All local vents will be routed to a safe location (lowest platform deck at a safe location away from any potential personnel, such as at platform legs which could require inspection).

8.2.5 Venting for Maintenance Activities

The equipment or system under maintenance will need to be vented to remove all CO_2 prior to starting the maintenance activity. Small amounts of CO_2 will be vented from the double-block-and-bleed valve arrangements that are provided to maintain safe isolation from pressurised CO_2 sections. The number and position of the isolation valves used to sectionalise the system for maintenance will be specified to minimise the release of CO_2. Starting the full chain after maintenance may require equipment to be purged with CO_2 for return to normal service. This is anticipated to require venting of small inventories of CO_2.

The venting procedures associated with maintenance activities will be developed during detailed design.

8.2.6 Venting During Commissioning

Prior to commissioning, the offshore transportation system will contain dry air. This dry air fill will require purging with CO_2 exported from the OPP in order to fill the system with in-specification CO_2. Purging will take place through vents on the platform, while the system is being filled with CO_2. Venting will cease when the initial dry air fill is purged from the pipeline. A temporary analyser will be used to monitor the venting stream and confirm that the pipeline has been successfully purged.

8.2.7 Venting During a Chain Shut-Down

Should a situation arise where an element of the full chain is not available for a short period of time; such as the pumping station has tripped and the onshore transportation system has reached its pressure limit, the onshore transportation system operator will have the option of requesting the OPP operator to divert CO_2 from the OPP to the OPP main stack. Otherwise the OPP would need to be switched to air mode or shut down.

The decision to either continue operating the OPP and venting the CO_2 captured or switch to air mode/shut down will be taken in communication with the other operators of the full chain. The decision to vent will be governed by the system conditions, the likelihood of the chain returning to an operational state in a reasonable timeframe and other commercial factors.

8.3 Noise

The noise generated at the vent tip as a result of CO_2 venting operations will require consideration of the occupational health limits.

8.4 Dispersion

An Environmental Impact Assessment (EIA) study is required for permanent vents and should include CO_2 dispersion modelling, which takes into consideration:

- wind direction;
- wind strength;
- the topography of the location; and
- the vent height and orientation.

The venting system will be designed to maximise air mixing at the tip and to ensure that effective vent velocities are maintained in order to promote effective dispersion of CO_2 into the atmosphere.

8.5 Low Temperature

The cooling effects of depressurisation will be taken into account when designing the vent systems for the CO_2 transportation system. Where very low temperatures are predicted, mitigating venting procedures will need to be developed; for example, controlling the time period for venting, thereby pausing the procedure and allowing it to warm up by surrounding air for a period of time before continuing venting.

The venting systems will 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 should be given to the design and location of the vents as a means of mitigating the effects low resultant temperatures, for example, venting from the bottom of a pipe reduces the cooling effect as liquid CO_2 has a lower Joule-Thomson effect than gaseous CO_2. Note that the Joule-Thomson effect describes the temperature change and associated cooling effect of a gas or liquid when it is forced through a valve or porous plug (sudden expansion) while kept insulated so that no heat is exchanged with the environment.

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

9 Safety and Environmental Considerations

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

The large volumes of dense phase CO_2 present hazards not previously considered for a network of pipelines in the UK. Key issues for consideration are the toxicity of CO_2 and its physical properties as the fluid is subjected to changes in process conditions.

9.1 CO_2 Toxicity

The HSE has published a guidance note for harm criteria, defining Dangerous Toxic Loads (DTLs) for CO_2, expressed as Specified Level of Toxicity (SLOT) and Significant Likelihood of Death (SLOD) relationships. SLOT and SLOD can be used to assess the risk potential from CO_2 releases; both are functions of CO_2 concentration and exposure duration.

The individual workspace exposure level of 0.5% (5,000 ppm) for long term exposure; 8 hours Time-Weighted Average (TWA), and 1.5% (15,000 ppm) for short term exposure (15 minutes TWA) will 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.

9.2 CO_2 Physical Properties

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

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

9.3 Detection Measures

A fixed CO_2 detection and alarm system will be provided. The system will form a part of the existing ICSS architecture at the NGCL Control Centre.

The fixed CO_2 detection systems will consider a combination of:

- acoustic leak detection; which detects ultrasonic noise typically at frequencies above 24 kHz with up to 10m coverage radius;
- infrared point detection; for areas where CO_2 gas accumulation or ingress may occur such as enclosures, HVAC inlet at the temporary refuge; and
- open path detection; for areas where CO_2 gas migration may occur.

The infrared point detectors and open path detectors will alarm at two pre-set levels. The alarm set points are shown in Table 9.1.

Table 9.1: Alarm Set Points

Detector Type	High (Alert) (Note 1)	High-High (Action) (Note 2)
Infrared Point Detector	0.5%	1.5%
Open Path Detectors (Note 3)	50,000ppm.m	150,000ppm.m

Notes:
1. Long Term Exposure Limit (LTEL) averaged over 8 hours
2. Short Term Exposure Limit (STEL) averaged over 15 minutes
3. Based on a 10 m path length – to be confirmed as part of PROJECT

The fixed CO_2 detection system will be interfaced with a general alarm system to allow general and abandon facility/platform alarms to be transmitted to personnel, including remotely from the NGCL Control Centre. The alarm system field devices will include sounders and beacons. On confirmed CO_2 gas detection, audible and visual alarms will be initiated. No other executive actions will be initiated.

9.4 Environment

CPL is responsible for the environmental impact assessment for Drax OPP and its associated infrastructure. NGCL is responsible for the onshore and offshore pipelines and the offshore storage site EIA.

10 Glossary

Abbreviations	Meaning
Ar	Argon
ATM	Atmospheric Pressure
bara	Bar Absolute
barg	Bar Gauge
BOC	British Oxygen Company
CCS	Carbon Capture and Storage
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPL	Capture Power Limited
C	Degrees Celsius
DECC	Department of Energy and Climate Change
DIFFS	Deck Integrated Fire Fighting System
DTL	Dangerous Toxic Load
ESD(V)	Emergency Shutdown (Valve)
EOA	Emergency Overnight Accommodation
FEED	Front End Engineering Design
h	hour
HIPPS	High Integrity Pressure Protection System
HP	High Pressure
HPU	Hydraulic Power Unit
HSE	Health & Safety Executive
H_2	Hydrogen
H_2O	Water
H_2S	Hydrogen Sulphide
ICSS	Integrated Control and Safety System
IID	Intelligent Inspection Device
in	inch
IRCD	Injection Rate Control Device
kg/h	Kilograms per Hour
KSC	Contract made between CPL and NGCL
LER	Local Equipment Room
LH	Liquid Head
LOP	Local Operating Procedure
LP	Low Pressure
LPA	Local Planning Authority
LTEL	Long Term Exposure Limit
MAOP	Maximum Allowable Operating Pressure
MEG	Mono Ethylene Glycol
m^3/h	Cubic Metres per Hour
mm	Millimetres
MTPA	Million Tonnes Per Annum

Abbreviations	Meaning
MW	Mega Watt
NACE	National Association of Corrosion Engineers
ND	Nominal Diameter
NGCL	National Grid Carbon Limited
NOx	Nitrogen Oxide (various)
NUI	Normally Unmanned Installation
N_2	Nitrogen
OPP	Oxy Power Plant
O_2	Oxygen
PIG	Pipeline Inspection Gauge
ppm(v)	Parts Per Million (Volume)
PRV	Pressure Relief Valve
SCADA	Supervisory Control And Data Acquisition
SLOD	Significant Likelihood of Death
SLOT	Specified Level of Toxicity
SOL	Safe Operating Limit
SOx	Sulphur Oxide (various)
SO_2	Sulphur Dioxide
STEL	Short Term Exposure Limit
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
THP	Tubing Head Pressure
TP	Terminal Point
TQ	Technical Query
TWA	Time Weighted Average
T&S	Transportation and Storage
UK	United Kingdom
WR	White Rose

11 Nomenclature and Jargon

Term	Explanation
Caisson	A vessel with the bottom end open through which water continuously drains into the sea
Carbon capture	Collection of CO_2 from power station combustion process or other facilities and its process ready for transportation
Daisy chain tie backs	An arrangement where a new subsea tie back is linked to an existing tie back, using excess flow line capacity to reach the platform
Dense Phase	The physical properties of CO_2 can vary according to temperature and pressure. It can be a gas, solid, liquid or can exist in a 'supercritical' state, where it behaves as a gas but has the viscosity of a liquid. The term 'dense phase' refers to CO_2 in either the supercritical or liquid stage
Dry tree	Often called a production tree or Christmas tree. Wellhead device installed at the surface of the well, including casing heads and a tubing head combined to provide surface control of the subsurface conditions of the well
FEED contract	CPL have entered into an agreement with the UK Government's DECC pursuant to which it will carry out, among other things, the engineering, cost estimation and risk assessment required to specify the budget required to develop and operate the White Rose assets
Equations of State	An equation of state is a thermodynamic equation describing the state of matter under a given set of physical conditions which provides a mathematical relationship between two or more state functions associated with the matter, such as its temperature, pressure, volume, or internal energy. Equations of state are useful in describing the properties of fluids, mixtures of fluids and solids
First load	The amount of CO_2 produced during the first year of the CO_2 transportation system
Full chain	The complete process from the capture of the CO_2 at the emitter plant to its injection into the storage reservoir
GERG2008	An equation of state fluid package specified for the HYSYS simulation work, used for modelling CO_2 with impurities Flow Assurance studies.
High Integrity Pressure Protection System	Or HIPPS. A safety instrumented system designed to prevent over-pressurisation of the plant equipment
HYSYS	Oil and gas process simulation software that enables optimisation of conceptual design and operations
Integrated Control and Safety System	Regulates the production process using real-time data acquisition to guarantee the smooth operation of the equipment and ensure environmental and personnel safety
Injection well	Deep subsurface rock formations identified for long-term storage
Inventory	An accounting of the amount of gas discharged into the atmosphere. An inventory usually contains the emission of one or more specific greenhouse gases or air pollutants within a specified time span in a specified place
Jacket	A welded tubular steel frame with tubular chord legs supporting the deck and the topsides in a fixed offshore platform
Joule-Thomson effect	Describes the temperature change of a gas or liquid when it is forced through a valve or porous plug while kept insulated so that no heat is exchanged with the environment
Key Knowledge Deliverable	A series of reports Including this one) issued as public information to describe the flows and processes associated with the overall system. Also referred to as a KKD
Linepack	The volume of gas occupying all pressurised sections of the pipeline network
Nitrogen quads	Manifold pack holding nitrogen cylinders connected to one outlet
Oxy-fuel	A power plant technology which burns fuel in a modified combustion environment with the resulting combustion gases being high in CO_2 concentration which allows the CO_2 produced to be captured without the need for additional chemical separation
PIG operations	An essential maintenance activity that optimises the smooth operation of the pipeline using a Pipeline Inspection Gauge (PIG) to traverses the pipeline to inspect and clean it
PIG launcher/receiver	The PIG enters the line through a PIG trap, which includes a launcher and receiver and is driven by the process gas

Term	Explanation
Phase envelope	The behaviour of a gas at different phases represented as a function of pressure and temperature
Piles	Also called leg piles. Thick lengths of steel inserted in the tubular chord legs of the jacket and penetrate the sea floor up to 100 meters deep to ensure the stability of the whole platform and fix the jacket onto the seabed
Ramp rates	The rate at which a generating unit can change load
Reservoir	Containment in suitable pervious rock formations located under impervious rock formations usually under the sea bed
Supervisory Control And Data Acquisition	Or SCADA. A system operating with coded signals over communication channels to provide control of remote equipment
Sublimes	Transitions directly from vapour to solid
Tie backs	A connection between a new subsea well discovery and an existing subsea well facility
Two-phase	A region with gas and liquid coexisting
White Rose Transport and Storage FEED Project	CPL and NGCL have entered into a key sub-contract agreement where NGCL will perform this project which will meet that part of CPL's obligations under the FEED Contract which are associated with the transport and storage assets