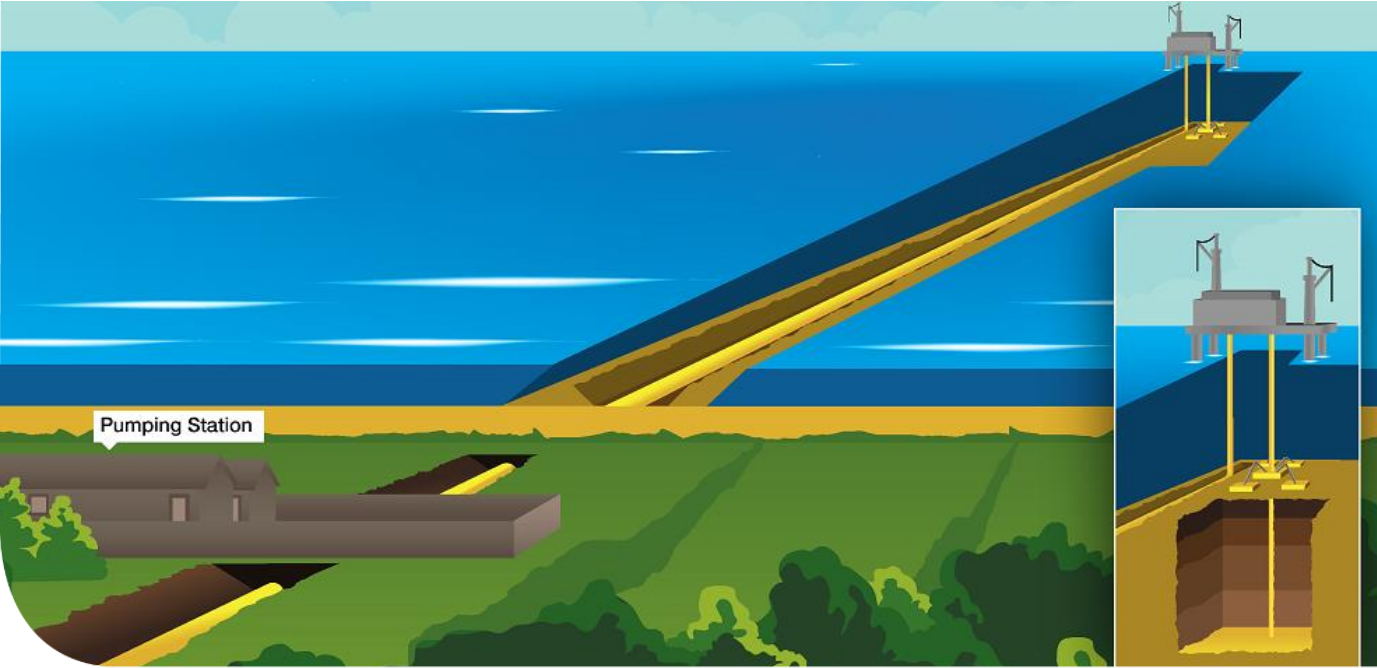




**WHITE
ROSE**

**K33: Pipeline Infrastructure and Design
Confirming the Engineering Design
Rationale**

Technical Transport



IMPORTANT NOTICE

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Contents

Chapter	Title	Page
	Executive Summary	i
1	Introduction	2
2	Purpose	3
3	Overview	5
4	Development Consent Order	8
4.1	Development Consent Order Schedule 1	8
4.2	Development Consent Order Works Plan	23
5	Onshore Pipeline Design	24
5.1	PD 8010 Part 1 Code of Practice Report	24
5.1.1	System and Safety	24
5.1.1.1	Public Safety and Protection of the Environment	24
5.1.1.2	Design Factor	25
5.1.2	Route Selection	26
5.1.3	Mechanical Integrity	26
5.1.3.1	Process Conditions	27
5.1.3.2	Wall Thickness	27
5.1.3.3	Corrosion Allowance	27
5.1.3.4	Restrained Pipeline Combined Stress	27
5.1.3.5	Stability	28
5.1.3.6	Spanning	28
5.1.3.7	Upheaval Buckling Assessment	28
5.1.3.8	Fatigue	28
5.1.3.9	Ovality	28
5.1.3.10	Road Crossings	29
5.1.3.11	Bending	29
5.1.3.12	Expansion and Flexibility	29
5.1.3.13	Anchor Blocks	30
5.1.3.14	Trenchless Crossings	30
5.1.3.15	Hydrotesting	30
5.1.3.16	Cover	31
5.1.4	Corrosion Management	31
5.1.4.1	External Coatings	31
5.1.4.2	Cathodic Protection (CP)	31
5.2	Pipe Laying and Routing Study	32
5.2.1	Development Consent Order	32
5.2.2	Construction Report	33
5.2.3	Code of Construction Practice	33
5.2.4	Works Plans	34
5.2.5	Crossing Schedule	34
5.2.6	Crossing Techniques	34

6	Offshore Pipeline Design	35
6.1	PD 8010 Part 2 Code of Practice Report	35
6.1.1	Health Safety and Assurances	35
6.1.1.1	Health Safety and the Environment	35
6.1.1.2	Quality Assurance	36
6.1.1.3	Design, Construction and Commissioning Assurance	36
6.1.1.4	Operation and Abandonment	36
6.1.1.5	Plans and Drawings	36
6.1.2	Design – System and Safety	36
6.1.2.1	Categorisation of Fluids	37
6.1.2.2	Pipeline Process Design	37
6.1.2.3	Public Safety and Protection of the Environment	37
6.1.2.4	Route Selection	37
6.1.3	Design – Mechanical Integrity	37
6.1.3.1	Design Criteria	37
6.1.3.2	Loads	38
6.1.3.3	Strength	38
6.1.3.4	Stability	40
6.1.3.5	Spanning	40
6.1.3.6	Pipeline and Cable Crossings	40
6.1.3.7	Leak Detection	41
6.1.4	Design – Landfalls Risers and Tie-ins	41
6.1.4.1	Landfall	41
6.1.4.2	Risers and Tie-ins	41
6.1.4.3	Subsea Connections and Valves	42
6.1.4.4	Protection	42
6.1.4.5	Pipeline Shutdown Systems	42
6.1.5	Design Materials and Coatings	42
6.1.5.1	Linepipe Selection	43
6.1.5.2	PIG Traps	43
6.1.5.3	Insulation Joints	43
6.1.5.4	Coatings	43
6.1.6	Corrosion Management	43
6.1.6.1	Internal Corrosion	44
6.1.6.2	External Corrosion	44
6.1.7	Construction – Fabrication and Installation	44
6.1.8	Construction – Testing	44
6.2	Offshore Pipeline Design Reports	44
6.2.1	Hydraulic Analysis	45
6.2.2	Route Selection	45
6.2.2.1	Kilometre Points	46
6.2.2.2	Route Description	46
6.2.2.3	Offshore Proposed Route	48
6.2.3	Geohazards	48
6.2.3.1	Slope Failure	49
6.2.3.2	Anchor Scarring	49
6.2.3.3	Trawl Scarring	49
6.2.3.4	Ridges, Berms, Boulders and Rock Out-crops	49
6.2.3.5	Sediment Mobility	49

6.2.3.6	Faults _____	50
6.2.3.7	Seismicity _____	50
6.2.3.8	Soil Liquefaction _____	51
6.2.3.9	Cliff and Beach Erosion _____	51
6.2.4	Shore Approach _____	54
6.2.4.1	Cofferdam/Open-Cut Trench _____	54
6.2.4.2	Trenchless Installation _____	55
6.2.4.3	Cross Profiles _____	56
6.2.4.4	Pipeline Installation _____	56
6.2.4.5	Pull-in Loads _____	56
6.2.4.6	Winch Spread/Anchor _____	58
6.2.5	Crossings _____	58
6.3	Mechanical Integrity _____	58
6.3.1	Design Criteria _____	58
6.3.1.1	Strength _____	59
6.3.2	Global Buckling Analysis _____	60
6.3.2.1	Pipeline Upheaval Buckling _____	60
6.3.2.2	Offshore Lateral Buckling _____	61
6.3.3	Stability Analysis _____	61
6.3.4	Riser and Spool-piece Analysis _____	62
6.3.5	Structure Outline Design _____	62
6.3.5.1	Fabrication and Installation _____	62
6.3.5.2	Testing _____	62
6.3.6	Material Selection and Corrosion Reports _____	62
6.3.6.1	Internal Corrosion _____	63
6.3.6.2	External Corrosion _____	63
6.3.7	Cathodic Protection Requirements _____	63
7	Operation Maintenance and Integrity Management	64
7.1	Inspection _____	64
7.2	PIG Operations _____	65
7.3	Maintenance _____	65
7.4	Repair _____	65
7.5	Spares _____	66
8	Onshore Pumping Facility Design	67
8.1	Pump and drive design _____	67
8.1.1	Basic Design Scope for Pumps _____	67
8.1.2	CO ₂ Service _____	67
8.1.3	Mechanical Seals _____	68
8.1.4	Pump Turndown _____	68
8.1.5	Lubrication _____	68
8.1.6	Pump Type _____	69
8.1.7	Monitoring _____	69
8.1.8	Pump Skids _____	69
8.2	Control and instrumentation design _____	69
8.2.1	Control _____	69
8.2.1.1	Process Control System _____	70
8.2.2	Monitoring _____	71
8.2.3	Control _____	71

8.2.4	Measurement and Protection _____	71
8.2.5	Control and Communication _____	72
8.3	Electrical design (high and low voltage) _____	73
8.3.1	General Design Requirements _____	73
8.3.1.1	General _____	73
8.3.1.2	Design Life _____	74
8.3.1.3	Electromagnetic Compatibility _____	74
8.3.1.4	Site Service Conditions _____	74
8.3.1.5	Design Temperatures _____	75
8.3.2	General Engineering and Design Criteria _____	75
8.3.2.1	Electrical System _____	75
8.3.2.2	Voltage Levels, Frequency and Neutrals _____	76
8.3.2.3	System Variations _____	77
8.3.2.4	Voltage Drop _____	77
8.3.2.5	Hazardous Area Classification _____	77
8.3.2.6	Ingress Protection _____	79
8.3.3	Design Calculations and Studies _____	79
8.3.3.1	General _____	79
8.3.4	Electrical Equipment _____	80
8.3.4.1	General _____	80
8.3.4.2	Battery Rooms & Cabinets _____	81
8.3.4.3	Motors _____	81
8.3.4.4	Variable Speed Drive Systems _____	82
8.3.4.5	Standardisation of Equipment and Materials _____	83
8.4	Civil design _____	83
8.4.1	Site _____	83
8.4.1.1	Site Layout and Topography _____	83
8.4.2	General Design _____	83
8.4.2.1	Layout _____	83
8.4.2.2	Appearance _____	83
8.4.2.3	Scale _____	83
8.4.2.4	Access _____	84
8.4.3	Layout and Landscaping _____	84
8.4.4	Appearance _____	86
8.4.5	Pump Houses _____	86
8.5	Formal Process Safety Assessment _____	87
8.5.1	Formal Workshops _____	87
8.5.1.1	Pumping Station HAZID Workshop _____	87
8.5.1.2	Pumping Facility HAZOP Workshop _____	88
8.5.1.3	SIL Workshop _____	88
8.5.1.4	ENVID Workshop _____	89
8.5.1.5	Safety Action Management System Register _____	89
8.5.1.6	3D Model Review _____	90
8.5.1.7	Additional HAZOP Workshop (Onshore Transport) _____	90
9	Glossary _____	91
10	Nomenclature and Jargon _____	93

Key Words

Key Work	Meaning or Explanation
Capture	Collection of CO ₂ from power station combustion process or other facilities and its process ready for transportation
Carbon	An element, but used as shorthand for its gaseous oxide, carbon dioxide CO ₂ .
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
Design Rationale	An explicit documentation of the reasons behind decisions made when designing a system or an artefact.
Development consent order	Also known as a DCO, it is a statutory instrument granted by the Secretary of State to authorise the construction and development of a Nationally Significant Infrastructure Project
Key knowledge	Information that may be useful if not vital to understanding how some enterprise may be successfully undertaken
Transport	Removing 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 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 to 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 document provides a summary description of the pipeline infrastructure and design and confirms the engineering design rationale.

It may be noted that the route of the Onshore Pipeline Route Plans is provided in the Appendix to KKD K.35.

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 CCS Project (the WR Project).

CPL has entered into an agreement (the 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 (KKDs). This document is one of these KKD's and its specific purpose is summarised below.

2 Purpose

Firstly this document provides a description of each work area up to the jurisdictional boundary of the low mean water mark of the onshore infrastructure, as shown in the Appendix to KKD K35 Pipeline Route Plans, by presenting the Development Consent Order (DCO) Schedule 1 “Authorised Development” works and descriptions.

It also provides a PD 8010 Code of Practice Report for the onshore and offshore pipeline; including, where appropriate:

- pipeline design codes and specifications;
- pressure protection systems;
- pipe selection including specified minimum yield strength;
- wall thickness and corrosion allowance;
- Cathodic Protection (CP);
- pipelay method;
- fatigue;
- proximity assessment;
- hydrotesting; and
- pipeline inspection requirements (utilising Pipeline Inspection Gauges (PIGs)).

In addition this document provides the following to confirm the engineering design rationale:

- for the onshore pipeline and pipeline installations:
 - project management
 - design management
 - investigations and surveys
 - pipeline design
 - installation design
 - formal process safety assessments
- for the onshore pumping facility:
 - project management
 - design management
 - Investigations and surveys
 - preliminary pump design
 - Pump and drive design
 - control and instrumentation design
 - electrical design (high and low voltage)
 - Civil design
 - formal process safety assessments
- for the offshore pipeline and subsea infrastructure:
 - pipeline design reports, which include:
 - hydraulic analysis
 - route selection
 - geohazard identification study

- shore approach
- crossings
- mechanical
- Lateral buckling analysis
- stability analysis
- riser and spool-piece analysis
- structure outline design
- material selection and corrosion reports
- CP requirements.

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 CO₂ transportation and storage network in the Yorkshire and Humber area. Figure 3.1 below gives a geographical overview of the proposed CO₂ 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 2 million tonnes of CO₂ per year, some 90% of all CO₂ emissions produced by the plant. The by-product CO₂ from the Oxy Power Plant (OPP) would be compressed and transported via an export pipeline for injection into an offshore saline structure (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 CO₂ concentration. This allows the CO₂ 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

Marker 6: Well Head/Injection Point.

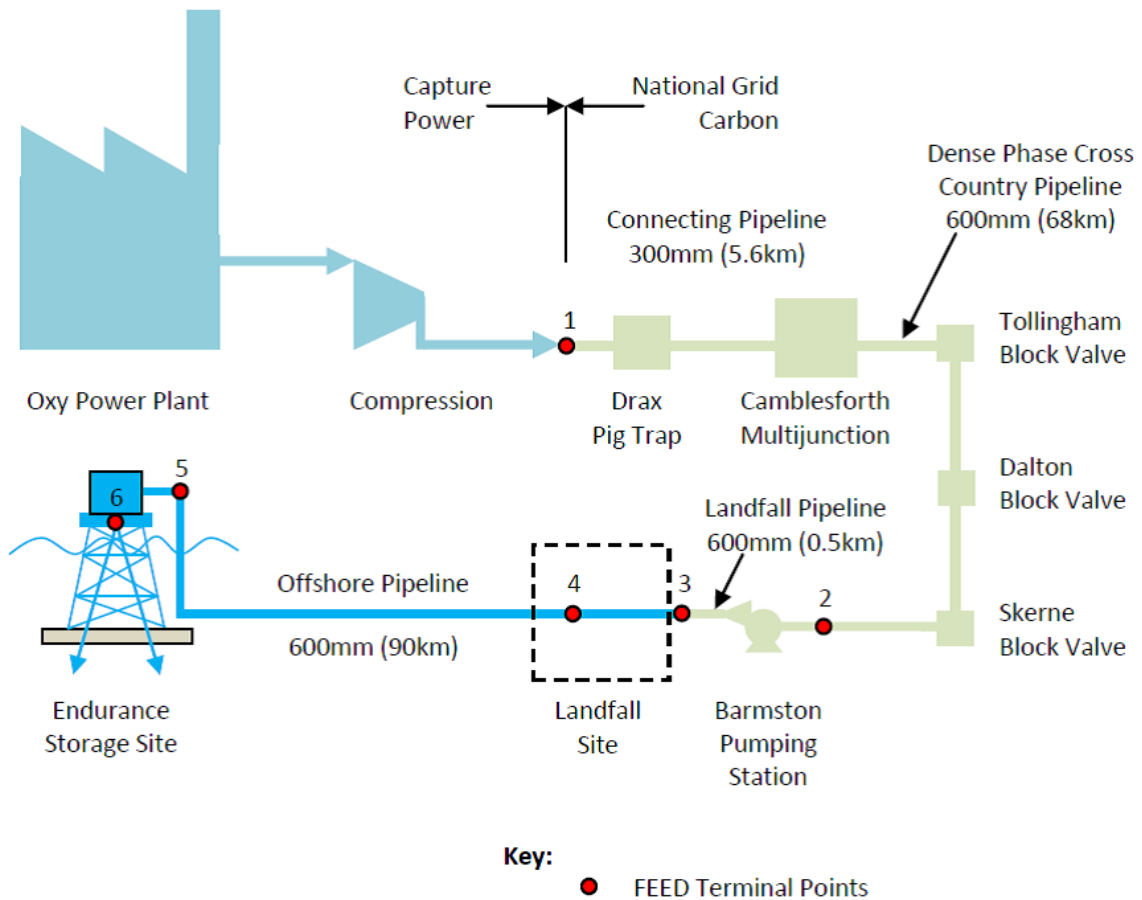


Figure 4.2 Markers:

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

NGCL have taken the strategic investment decision to design the transportation and storage system for future expansion beyond the initial First Load CO₂ supply. The intention would be 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 Bramston

to the Normally Unmanned Installation (NUI) are 600mm 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.

4 Development Consent Order

Under UK registrations a Development Consent Order (DCO) is required.

4.1 Development Consent Order Schedule 1

SCHEDULES

SCHEDULE 1

Articles 2 and 4

AUTHORISED DEVELOPMENT

A nationally significant infrastructure project as defined in sections 14 and 21 of the 2008 Act and associated development within the meaning of section 115 of the 2008 Act comprising the works described below.

In the District of Selby in the County of North Yorkshire and in the East Riding of Yorkshire—

Work No. 1A – A carbon dioxide pipeline inspection facility at Drax, to be known as the Drax PIG Trap, including the following works and structures—

- (a) construction and/or installation of above and below ground piping, piping bridles and bypasses, insulation joints, valves, actuators, vents, analysers, meters and filtration;
- (b) construction and/or installation of a PIG trap reception and insertion area including associated hard standing, pipe supports, instrument building and associated photo voltaic cells, hard standing for temporary generator, backfilled pits and chambers, gated security fence and cameras, pedestrian access, satellite dish, troughs, trays, ducting, drainage and drainage attenuation, internal vehicular access routes, turning areas, pedestrian areas, post and rail fencing and landscape screening;
- (c) electrical and instrumentation construction and/or installation including instrumentation, electrical cables, earthing protection, electricity and communications kiosks, satellite dish, control and telecommunications cables, utilities and utility metering, intruder detection systems and closed circuit television;
- (d) works, including pipes, to enable a tie in to the White Rose carbon capture and storage project adjacent to Drax power station, Selby; and
- (e) extensions of those parts of the carbon dioxide pipeline comprised in Work No. 3A, the CP facility comprised in Work No. 1B and an access road which link to elements within this Work No. 1A.

Work No. 1B – A CP facility including a transformer rectifier kiosk with control cabinet and junction box surrounded by a post and rail fence; anode canisters, electrical and CP cables, utility meter and cabling; and CP test posts and aerial markers.

Work No. 2A – A temporary pipeline store and office area including temporary—

- (a) office, welfare and security facilities;
- (b) power supplies and temporary lighting;
- (c) enclosures;
- (d) pipe, equipment and fittings storage;
- (e) plant storage;
- (f) fabrication area;
- (g) waste storage areas;
- (h) spoil storage areas;

- (i) internal haul roads;
- (j) access parking; and
- (k) water management areas.

Work No. 3A – A carbon dioxide pipeline from Drax PIG Trap (Work No. 1A) to Pear Tree Avenue (Work No. 3B), approximate chainage 1592 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable) save where the pipeline rises to interface with the Drax PIG Trap (Work No. 1A).

Work No. 3B – A carbon dioxide pipeline from and beneath Pear Tree Avenue, approximate chainage 1592 metres, to Carr Lane (Work No. 3C), approximate chainage 2313 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 3C – A carbon dioxide pipeline from and beneath Carr Lane, approximate chainage 2313 metres, to Main Road (Work No. 3D), approximate chainage 2972 metres, laid in trench, in sleeves or by trenchless methods (save beneath the open drain/ditch adjacent to the disused railway embankment at approximate chainage 2478 metres where it must be laid by trenchless methods); such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 3D – A carbon dioxide pipeline from and beneath Main Road, approximate chainage 2972 metres, to Church Dike Lane (Work No. 3E), approximate chainage 3933 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 3E – A carbon dioxide pipeline from and beneath Church Dike Lane, approximate chainage 3933 metres, to Brickhill Lane (Work No. 3F), approximate chainage 4713 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 3F – A carbon dioxide pipeline from and beneath Brickhill Lane, from approximate chainage 4713 metres to A645 (Work No. 3E), approximate chainage 5298 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 3G – A carbon dioxide pipeline from and beneath A645, approximate chainage 5298 metres, to Camblesforth Multi-Junction (Work No. 4A), approximate chainage 5630 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable) save where the pipeline rises to interface with the Camblesforth Multi Junction (Work No. 4A).

Work No. 4A – A carbon dioxide pipeline multiple inspection facility at Camblesforth, to be known as the Camblesforth Multi-junction, including the following works and structures—

- (a) construction and/or installation of above and below ground piping, piping bridles and bypasses, insulation joints, valves, actuators and vents;

- (b) construction and/or installation of up to 5 PIG trap reception and insertion areas including associated hard standing, pipe supports, instrument building and associated photo voltaic cells, hard standing for temporary generator, backfilled pits and chambers, gated security fence, pedestrian access, satellite dish, troughs, trays, ducting, drainage and drainage attenuation, internal vehicular access routes, turning areas, pedestrian areas, post and rail fencing and landscape screening;
- (c) electrical and instrumentation construction and/or installation including instrumentation, electrical cables, earthing protection, electricity and communications kiosks, satellite dish, control and telecommunications cables, utilities and utility metering, intruder detection systems and closed circuit television; and
extensions of those parts of the carbon dioxide pipeline comprised in Work No. 3G and Work No.5A, the CP facility comprised in Work No. 4B and the road comprised in Work No. 4C which link to elements within this Work No. 4A.

Work No. 4B – A CP facility including a transformer rectifier kiosk with control cabinet and junction box surrounded by a post and rail fence; anode canisters, electrical and CP cables, utility meter and cabling; and CP test posts and aerial markers.

Work No. 4C – A road from A645 / Wade House Lane junction up to and including the carbon dioxide facility at Camblesforth Multi-junction (Work No. 4A) including any splays, gates, fencing, drainage, drainage attenuation and interceptors, piped culverts, utilities, associated ducting, landscape works and CP apparatus including buried CP groundbeds and anodes, buried electrical wiring and ducts and test posts.

Work No. 4D – A temporary pipeline store and office area including temporary–

- (a) office, welfare and security facilities;
- (b) power supplies and temporary lighting;
- (c) enclosures;
- (d) pipe, equipment and fittings storage;
- (e) plant storage;
- (f) fabrication area;
- (g) waste storage areas;
- (h) spoil storage areas;
- (i) internal haul roads;
- (j) access parking; and
- (k) water management areas.

CAMBLESFORTH TO TOLLINGHAM

Work No. 5A – A carbon dioxide pipeline from Camblesforth Multi-junction (Work No. 4A) to the A645, approximate chainage 5984 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable) save where the pipeline rises to interface with the Camblesforth Multi-junction (Work No. 4A).

Work No. 5B – A carbon dioxide pipeline from and beneath the A645, approximate chainage 5984 metres to Church Dike Lane (Work No. 5C), approximate chainage 7458 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 5C – A carbon dioxide pipeline from and beneath Church Dike Lane, approximate chainage 7458 metres, to Barmby Road (Work No. 5D), approximate chainage 11,089 metres, laid in trench, in sleeves or by trenchless methods (save beneath the true clean bottom of the River Ouse where it must be laid by trenchless methods); such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers (other than beneath the River Ouse, where the pipeline is to be not less than 3.5 metres below its true clean bottom), streams, open drains, canals or dykes but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 5D – A carbon dioxide pipeline from and beneath Barmby Road, approximate chainage 11,089 metres, to the A63, Hull Road (Work No. 5E), approximate chainage 12,969 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 5E – A carbon dioxide pipeline from and beneath the A63, Hull Road, approximate chainage 129,69 metres, to Brind Lane (Work No. 5F), approximate chainage 15,252 metres, laid in trench, in sleeves or by trenchless methods (save beneath the Howden to Wressle railway line where it must be laid by trenchless methods); such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers, not less than 2 metres below public highways or not less than 4 metres below the underside of the railway sleepers comprised in the Howden to Wressle railway line where applicable).

Work No. 5F – A carbon dioxide pipeline from and beneath Brind Lane, approximate chainage 15,252 metres, to the B1228, Wood Lane (Work No. 5G), approximate chainage 16,603 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 5G – A carbon dioxide pipeline from and beneath the B1228, Wood Lane, approximate chainage 16,603 metres, to the A614, Holme Road (Work No. 5H), approximate chainage 20,737 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 5H – A carbon dioxide pipeline from and beneath the A614, Holme Road, approximate chainage 20,737 metres, to Bursea Lane (Work No. 5I), approximate chainage 23,217 metres, laid in trench, in sleeves or by trenchless methods (save beneath the bed of the River Foulness where it must be laid by trenchless methods); such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways and the true clean bottom of the River Foulness where applicable).

Work No. 5I – A carbon dioxide pipeline from and beneath Bursea Lane, approximate chainage 23,217 metres, to Drain Lane (Work No. 5J), approximate chainage 24,757 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 5J – A carbon dioxide pipeline from and beneath Drain Lane, approximate chainage 24,757 metres, to Tollingham Block Valve (Work No. 6A), laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable) save where the pipeline rises to interface with Tollingham Block Valve (Work No 6A).

Work No. 6A – A carbon dioxide pipeline isolation facility at Tollingham, to be known as the Tollingham Block Valve, including the following works and structures—

- (a) construction and/or installation including above and below ground piping, piping bridles and bypasses, insulation joints, valves, actuators and vents;
- (b) construction and/or installation including pipe supports, instrument building and associated photo voltaic cells, hard standing for temporary generator, backfilled pits and chambers, gated security fence and cameras, pedestrian access, satellite dish, troughs, trays, ducting, drainage and drainage attenuation, internal vehicular access routes, turning areas, pedestrian areas, post and rail fencing and landscape screening;
- (c) electrical and instrumentation construction and/or installation including instrumentation, electrical cables, earthing protection, satellite dish, control and telecommunications cables, utility metering, intruder detection systems and closed circuit television; and
- (d) extensions of those parts of the carbon dioxide pipeline comprised in Work No. 5J and Work No.8A, the CP facility comprised in Work No. 6B and the road comprised in Work No. 6C which link to elements within this Work No. 6A.

Work No. 6B – A CP facility including a transformer rectifier kiosk with control cabinet and junction box surrounded by a post and rail fence; anode canisters, electrical and CP cables, utility meter and cabling; and CP test posts and aerial markers.

Work No. 6C - A road from Skiff Lane up to and including the carbon dioxide facility at Tollingham Block Valve (Work No. 6A) including any splays, gates, fencing, drainage, drainage attenuation and interceptors, piped culverts, electricity kiosk, utilities, associated ducting, landscape works and CP apparatus including buried CP groundbeds and anodes, buried electrical wiring and ducts, test posts and above ground transformer rectifier with cabinet and guard rail.

Work No. 6D – A temporary pipeline store and office area including temporary—

- (a) office, welfare and security facilities;
- (b) power supplies and temporary lighting;
- (c) enclosures;
- (d) pipe, equipment and fittings storage;
- (e) plant storage;
- (f) fabrication area;
- (g) waste storage areas;
- (h) spoil storage areas;
- (i) internal haul roads;
- (j) access parking; and
- (k) water management areas.

Work No. 7 – A temporary pipeline store and office area to be known as Tollingham Construction Compound including temporary—

- (a) office, welfare and security facilities;
- (b) power supplies and temporary lighting;
- (c) enclosures;
- (d) pipe, equipment and fittings storage;
- (e) plant storage;

- (f) fabrication area;
- (g) waste storage areas;
- (h) spoil storage areas;
- (i) internal haul roads;
- (j) access parking;
- (k) vehicle maintenance area including washing facilities; and
- (l) water management areas.

TOLLINGHAM TO DALTON

Work No. 8A – A carbon dioxide pipeline from Tollingham Block Valve (Work No. 6A) to Skiff Lane, approximate chainage 26,010 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable) save where the pipeline rises to interface with the Tollingham Block Valve (Work No. 6A).

Work No. 8B – A carbon dioxide pipeline from and beneath Skiff Lane, approximate chainage 26,010 metres, to Lock Lane (Work No. 8C), approximate chainage 27,238 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 8C – A carbon dioxide pipeline from and beneath Lock Lane, approximate chainage 27,238 metres, to Sands Lane (Work No. 8D), approximate chainage 29,025 metres, laid in trench, in sleeves or by trenchless methods (save beneath the bed of the disused Market Weighton Canal where it must be laid by trenchless methods); such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways or the beneath the true clean bottom of the disused Market Weighton Canal where applicable).

Work No. 8D – A carbon dioxide pipeline from and beneath Sands Lane, approximate chainage 29,025 metres, to Cliffe Road (Work No. 8E), approximate chainage 32,750 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 8E – A carbon dioxide pipeline from and beneath Cliffe Road, approximate chainage 32,750 metres, to the A1034 Sancton Road (Work No. 8F), approximate chainage 34,547 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 8F – A carbon dioxide pipeline from and beneath the A1034 Sancton Road, approximate chainage 34,547 metres, to the A1079 Arras Hill (Work No. 8G), approximate chainage 36,283 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 8G – A carbon dioxide pipeline from and beneath the A1079 Arras Hill, approximate chainage 36,283 metres, to Kiplingcotes Lane (Work No. 8H), approximate chainage 39,393 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the

true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 8H – A carbon dioxide pipeline from and beneath Kiplingcotes Lane, approximate chainage 39,393 metres, to Kiplingcotes Road (Work No. 8I), approximate chainage 40,231 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 8I – A carbon dioxide pipeline from and beneath Kiplingcotes Road, approximate chainage 40,231 metres, to Kiplingcotes Race Course Road (Work No. 8J), approximate chainage 40,600 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 8J – A carbon dioxide pipeline from and beneath Kiplingcotes Race Course Road, approximate chainage 40,600 metres to Park Road (Work No. 8K), approximate chainage 41,370 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 8K – A carbon dioxide pipeline from and beneath Park Road, approximate chainage 41,370 metres, to Holme Wold Road (Work No. 8L), approximate chainage 43,264 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 8L – A carbon dioxide pipeline from and beneath Holme Wold Road, approximate chainage 43,264 metres to Dalton Block Valve (Work No. 9A), laid in trench, in sleeves or by trenchless methods; all to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable) save where the pipeline rises to interface with Dalton Block Valve (Work No. 9A).

Work No. 9A – A carbon dioxide pipeline isolation facility at Dalton to be known as the Dalton Block Valve including the following works and structures—

- (a) construction and/or installation including above and below ground piping, piping bridles and bypasses, insulation joints, valves, actuators and vents;
- (b) construction and/or installation including pipe supports, instrument building and associated photo voltaic cells, hard standing for temporary generator, backfilled pits and chambers, gated security fence and cameras, pedestrian access, satellite dish, troughs, trays, ducting, drainage and drainage attenuation, internal vehicular access routes, turning areas, pedestrian areas, post and rail fencing and landscape screening;
- (c) electrical and instrumentation construction and/or installation including instrumentation, electrical cables, earthing protection, satellite dish, control and telecommunications cables, utility metering, intruder detection systems and closed circuit television; and
- (d) extensions of those parts of the carbon dioxide pipeline comprised in Work No. 8L and Work No.10A, the CP facility comprised in Work No. 9B and the road comprised in Work No. 9C which link to elements within this Work No. 9A.

Work No. 9B – A CP facility including a transformer rectifier kiosk with control cabinet and junction box surrounded by a post and rail fence; anode canisters, electrical and CP cables, utility meter and cabling; and CP test posts and aerial markers.

Work No. 9C – A road from Lund Wold Road up to and including the carbon dioxide facility at Dalton Block Valve (Work No. 9A) including any splays, gates, fencing, drainage, drainage attenuation and interceptors, piped culverts, electricity kiosk, utilities, associated ducting, landscape works and CP apparatus including buried CP groundbeds and anodes, buried electrical wiring and ducts and test posts.

Work No. 9D – A temporary pipeline store and office area including temporary—

- (a) office, welfare and security facilities;
- (b) power supplies and temporary lighting;
- (c) enclosures;
- (d) pipe, equipment and fittings storage;
- (e) plant storage;
- (f) fabrication area;
- (g) waste storage areas;
- (h) spoil storage areas;
- (i) internal haul roads;
- (j) access parking; and
- (k) water management areas.

DALTON TO SKERNE

Work No. 10A – A carbon dioxide pipeline from Dalton Block Valve (Work No. 9A) to Lund Wold Road (Work No. 10B), approximate chainage 45,909 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable) save where the pipeline rises to interface with the Dalton Block Valve (Work No. 9A).

Work No. 10B – A carbon dioxide pipeline from and beneath Lund Wold Road, approximate chainage 45,909 metres, to Middleton Road (Work No. 10C), approximate chainage 46,874 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 10C – A carbon dioxide pipeline from and beneath Middleton Road, approximate chainage 46,874 metres, to the B1248 Lund Road (Work No. 10D), approximate chainage 47,913 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 10D – A carbon dioxide pipeline from and beneath the B1248 Lund Road, approximate chainage 47,913 metres, to Middleton Road (Work No. 10E), approximate chainage 48,823 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 10E - A carbon dioxide pipeline from and beneath Middleton Road, approximate chainage 48,823 metres to unnamed road from Bracken Lane to Burnbutts Lane (Work No. 10F), approximate chainage 50,921 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or

dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 10F – A carbon dioxide pipeline from and beneath unnamed road from Bracken Lane to Burnbutts Lane, approximate chainage 50,921 metres, to Burnbutts Lane (Work No. 10G), approximate chainage 51,349 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 10G – A carbon dioxide pipeline from and beneath Burnbutts Lane, approximate chainage 51,349 metres, to Southburn Road (Work No. 10H), approximate chainage 54,681 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 10H – A carbon dioxide pipeline from and beneath Southburn Road, approximate chainage 54,681 metres, to the A164, Beverley Road (Work No. 10I), approximate chainage 54,964 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 10I – A carbon dioxide pipeline from and beneath the A164, Beverley Road, approximate chainage 54,964 metres, to Jenkinson Lane (Work No. 10J), approximate chainage 55,172 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 10J – A carbon dioxide pipeline from and beneath Jenkinson Lane, approximate chainage 55,172 metres, to Ricklepits (Work No. 10K), approximate chainage 57,185 metres, laid in trench, in sleeves or by trenchless methods (save beneath the Drifffield to Hutton Cranswick railway line where it must be laid by trenchless methods); such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers, not less than 2 metres below public highways or not less than 4 metres below the underside of the railway sleepers comprised in the Drifffield to Hutton Cranswick railway line where applicable).

Work No. 10K – A carbon dioxide pipeline from and beneath Ricklepits, approximate chainage 57,185 metres, to Skerne Block Valve (Work No. 11A), laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable) save where the pipeline rises to interface with Skerne Block Valve (Work No. 11A).

Work No. 11A – A carbon dioxide pipeline isolation facility at Skerne, to be known as the Skerne Block Valve, including the following works and structures—

- (a) construction and/or installation of above and below ground piping, piping bridles and bypasses, insulation joints, valves, actuators and vents;
- (b) construction and/or installation of pipe supports, instrument building and associated photo voltaic cells, hard standing for temporary generator, backfilled pits and chambers, gated security fence and cameras, pedestrian access, satellite dish, troughs, trays, ducting, drainage and drainage attenuation, internal vehicular access routes, turning areas, pedestrian areas, post and rail fencing and landscape screening;

- (c) electrical and instrumentation construction and/or installation including instrumentation, electrical cables, earthing protection, satellite dish, control and telecommunications cables, utility metering, intruder detection systems and closed circuit television; and
- (d) extensions of those parts of the carbon dioxide pipeline comprised in Work No. 10K and Work No.13A, the CP facility comprised in Work No. 11B and the road comprised in Work No. 11C which link to elements within this Work No. 11A.

Work No. 11B – A CP facility including a transformer rectifier kiosk with control cabinet and junction box surrounded by a post and rail fence; anode canisters, electrical and CP cables, utility meter and cabling; and CP test post and aerial markers.

Work No. 11C – A road from Main Street up to and including the carbon dioxide facility at Skerne Block Valve (Work No. 11A) including any splays, gates, fencing, drainage, drainage attenuation and interceptors, piped culverts, electricity kiosk, utilities, associated ducting, landscaping works and CP apparatus including buried CP groundbeds and anodes, buried electrical wiring and ducts and test posts.

Work No. 11D – A temporary pipeline store and office area including temporary—

- (a) office, welfare and security facilities;
- (b) power supplies and temporary lighting;
- (c) enclosures;
- (d) pipe, equipment and fittings storage;
- (e) plant storage;
- (f) fabrication area;
- (g) waste storage areas;
- (h) spoil storage areas;
- (i) internal haul roads;
- (j) access parking; and
- (k) water management areas.

Work No. 12 – A temporary pipeline store and office area, to be known as the Driffeld Construction Compound, including temporary—

- (a) office, welfare and security facilities;
- (b) power supplies and temporary lighting;
- (c) enclosures;
- (d) pipe, equipment and fittings storage;
- (e) plant storage;
- (f) fabrication area;
- (g) waste storage areas;
- (h) spoil storage areas;
- (i) internal haul roads;
- (j) access parking;
- (k) vehicle maintenance area including washing facilities; and
- (l) water management areas.

SKERNE TO PUMPING STATION

Work No. 13A - A carbon dioxide pipeline from Skerne Block Valve (Work No. 11A) to the B1249, Frodingham Road (Work No. 13B), approximate chainage 60,990 metres, laid in trench, in sleeves or by trenchless methods (save beneath the beds of the River Hull and the Driffield Canal where it must be laid by trenchless methods); such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways or the true clean bottom of the River Hull and the Driffield Canal where applicable) save where the pipeline rises to interface with the Skerne Block Valve (Work No. 11A).

Work No. 13B – A carbon dioxide pipeline from and beneath the B1249, Frodingham Road, approximate chainage 60,990 metres, to Main Street (Work No. 13C), approximate chainage 64,982 metres, laid in trench, in sleeves or by trenchless methods (save beneath the beds of the Nafferton Highland Spring Drain, White Dike and Kelk Beck where it must be laid by trenchless methods); such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways and the true clean bottom of the Nafferton Highland Spring Drain, White Dike and Kelk Beck where applicable).

Work No. 13C – A carbon dioxide pipeline from and beneath Main Street, approximate chainage 64,982 metres, to Gransmoor Road (Work No. 13D), approximate chainage 68,618 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No. 13D – A carbon dioxide pipeline from and beneath Gransmoor Road, approximate chainage 68,618 metres, to the A165, Bridlington Road (Work No. 13E), approximate chainage 71,453 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable).

Work No 13E – A carbon dioxide pipeline from and beneath the A165, Bridlington Road, approximate chainage 71,453 metres, to Barmston Pumping Station (Work No. 14A), laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface (or not less than 1.7 metres below the true clean bottom of rivers, streams, open drains, canals or dykes, but excluding land drains, culverts or sewers and not less than 2 metres below public highways where applicable) save where the pipeline rises to interface with Barmston Pumping Station (Work No. 14A).

PUMPING STATION

Work No. 14A – A carbon dioxide pumping facility at Barmston, to be known as the Barmston Pumping Station, including the following works and structures—

- (a) temporary working area for constructing the Barmston Pumping Station including temporary—
 - (i) office, welfare and security facilities;
 - (ii) power supplies and temporary lighting;
 - (iii) enclosures;
 - (iv) pipe, equipment and fittings storage;
 - (v) plant storage
 - (vi) fabrication area;
 - (vii) waste storage areas;
 - (viii) spoil handling and storage areas;
 - (ix) internal haul roads;
 - (x) access and parking; and

- (xi) water management areas;
- (b) water supply works, foul drainage provision, surface water management system and culverting;
- (c) construction and/or installation of two PIG trap reception and insertion areas including above and below ground piping, piping bridles and bypasses, filtration, meters, analysers, pumping facility bypass, insulation joints, actuators, vents and vent stacks, valves (including non-return valves, emergency shutdown valves and recycle valves), coolers, chillers, monoethylene glycol (MEG) tank and water tank;
- (d) construction and/or installation of pipe supports, local and remote instrument building and associated photo voltaic cells, control and domestic building, stores areas, workshops, pump houses, air and nitrogen building, substation, switchroom, variable speed drive containers, metering buildings, analyser building, associated bottle store and hard standing hard standing for temporary generator, backfilled pits and chambers, gated security fence and cameras, pedestrian access, lighting columns, satellite dish, weather station, troughs, trays, ducting, internal vehicular access routes, turning areas, pedestrian areas, pond, post and rail fencing and landscape screening, planting and earthworks;
- (e) construction and/or installation of instrumentation, electrical cables, earthing protection, satellite dish, control and telecommunications cables, utility metering, intruder detection systems and closed circuit television, electrical cables, CP facility including a transformer rectifier kiosk, anode canisters, electrical and CP cables, utility supplies, meters and cabling, earthing protection, backfilled pits and chambers, electricity and communications kiosks, control and telecommunications cables, troughs, trays, ducting, drainage and drainage attenuation; and
- (f) extensions of those parts of the carbon dioxide pipeline comprised in Work No. 13E and Work No. 15A and the road comprised in Work No 14B which link to elements within this Work No.

Work No. 14B – A CP facility including a transformer rectifier kiosk with control cabinet and junction box surrounded by a post and rail fence; anode canisters, electrical and CP cables, utility meter and cabling; and CP test posts and aerial markers.

Work No. 14C – Modifications to Sands Road between A165, Bridlington Road and Sands Road track; modification of junction between Sands Road tarmac road and Sands Road track; upgrading Sands Road track between junction with Sands Road tarmac road and access to Barmston Pumping Station; and a road from Sands Road track up to and including the Barmston Pumping Station (Work No. 14A) including any splays, gates, fencing, drainage, drainage attenuation and interceptors, piped culverts, utilities, associated ducting and landscape screening.

Work No. 14D – A temporary pipeline store and office areas including temporary—

- (a) office, welfare and security facilities;
- (b) power supplies and temporary lighting;
- (c) enclosures;
- (d) pipe, equipment and fittings storage;
- (e) plant storage;
- (f) fabrication area;
- (g) waste storage areas;
- (h) spoil storage areas;
- (i) internal haul roads;
- (j) access parking;
- (k) vehicle maintenance area including washing facilities; and
- (l) water management areas.

LANDFALL

Work No. 15A – A carbon dioxide pipeline from Barmston Pumping Station (Work No. 14A) to a landfall drive shaft (Work No. 15B), approximate chainage 73,094 metres, laid in trench, in sleeves or by trenchless methods; such pipeline to be not less than 1.2 metres below ground surface save where the pipeline rises to interface with the Barmston Pumping Station (Work No. 14A).

Work No. 15B A carbon dioxide pipeline from a landfall drive shaft comprised in this Work No. 15B to mean low water spring tide (which has the same meaning as that given in Schedule 10 (deemed marine licence under Part 4 (marine licensing) of the Marine and Coastal Access Act 2009), approximate chainage 73,568 metres, laid by trench in sleeves or by trenchless methods (save beneath the cliffs where it must be laid by trenchless methods); such pipeline to be not less than 1.2 metres below ground surface; and which may include the following works and structures—

- (a) temporary working areas including temporary—
 - (i) office, welfare and security facilities;
 - (ii) power supplies and temporary lighting;
 - (iii) workshops and stores;
 - (iv) materials and pipe, equipment and fittings storage;
 - (v) water tanks;
 - (vi) control cabin;
 - (vii) waste storage areas;
 - (viii) spoil handling and storage areas, spoil separators and settlement lagoons;
 - (ix) de-watering systems and water management areas;
 - (x) generators and switchgear;
 - (xi) air receivers and compressors;
 - (xii) oil store;
 - (xiii) drive shaft, slip trench;
 - (xiv) drilling rig, anchor blocks, slip trench;
 - (xv) crane working areas;
 - (xvi) reception pit / tie-in pit;
 - (xvii) access to the drive shaft/ drilling rig and reception area/ beach and parking;
- (b) construction and installation of the pipeline under the cliffs by trenchless methods which may include the installation of a concrete sleeve drive shaft and tunnel; backfilling of permanent structures not less than 1.2 metres below ground surface; and temporary works including tunnel boring/pipeline drilling, reception pit, hydraulic rams, rollers and brackets and winch;
- (c) construction and installation of pipeline within the inter tidal zone which may include cofferdams and temporary works including crane working areas, raised causeway, channel dredging, shallow bottomed barge, winch, reception/tie-in pit and spoil storage.

FURTHER ASSOCIATED DEVELOPMENT

In connection with the above Work Nos. further associated development within the Order limits consisting of—

- (a) in relation to Work Nos. 1A, 4A, 6A, 9A, 11A and 14A site preparation works, site clearance (including fencing, vegetation removal and creation of new footpaths), earthworks (including soil stripping and storage) and site levelling;

- (b) in relation to Work Nos. 1A, 4A, 6A, 9A and 11A establishment of site construction compounds, storage areas, temporary vehicle parking, construction fencing (including perimeter enclosure and security fencing), construction related buildings, welfare facilities, construction lighting, haulage roads, fabrication areas, waste storage areas, spoil storage area, access, parking and water management areas;
- (c) installation of wires, cables, conductors, pipes and ducts;
- (d) in relation to Work Nos. 3A, 3B, 3C, 3D, 3E, 3F, 3G, 5A, 5B, 5C, 5D, 5E, 5F, 5G, 5H, 5I, 5J, 8A, 8B, 8C, 8D, 8E, 8F, 8G, 8H, 8I, 8J, 8K, 8L, 10A, 10B, 10C, 10D, 10E, 10F, 10G, 10H, 10I, 10J, 10K, 13A, 13B, 13C, 13D, 13E, 15A and 15B pipeline construction works including—
 - (i) surveying and setting-out;
 - (ii) breaking-through, site clearance (including vegetation removal) and establishment of temporary working area;
 - (iii) installation of demarcation fencing/stockproof fencing/heras fencing or similar;
 - (iv) pre-construction drainage;
 - (v) topsoil stripping;
 - (vi) levelling and benching;
 - (vii) archaeological surveys and watching brief;
 - (viii) pipe stringing, pipe bending, end preparation, front end welding, back end welding, fabrication welding, pipeline coating, pipeline trench excavation, disruption or fragmentation of rock (including by mechanical means), dewatering activities, trenchless crossings, lower and lay, sand padding, backfilling, pipeline tie-ins, re-grading of soil, post construction drainage, cross-ripping and reinstatement of topsoil, internally swab and gauge pipeline test sections;
 - (ix) filling, testing and dewatering test sections;
 - (x) reinstating test locations;
 - (xi) removing demarcation fencing;
 - (xii) reinstating boundary walls, hedges, and fencing;
 - (xiii) final gauge plate and calliper surveys;
 - (xiv) drying and commissioning pipelines;
 - (xv) demobilisation from site; and
 - (xvi) works to enable power supplies;
- (e) works to remove or alter the position of apparatus including mains, sewers, drains and cables which do not give rise to any materially new or materially different significant effects from those assessed in the environmental statement;
- (f) in relation to Work Nos. 1A, 3A, 3B, 3C, 3D, 3E, 3F, 3G, 4A, 5A, 5B, 5C, 5D, 5E, 5F, 5G, 5H, 5I, 5J, 6A, 8A, 8B, 8C, 8D, 8E, 8F, 8G, 8H, 8I, 8J, 8K, 8L, 9A, 10A, 10B, 10C, 10D, 10E, 10F, 10G, 10H, 10I, 10J, 10K, 11A, 13A, 13B, 13C, 13D, 13E, 14A, 15A, 15B the location of aerial markers, field boundary markers and CP apparatus including CP test posts and sacrificial anodes;
- (g) landscaping and other works to mitigate any adverse effects of the construction, maintenance or operation of the authorised development which do not give rise to any materially new or materially different significant effects from those assessed in the environmental statement;
- (h) works for the benefit or protection of land affected by the authorised development which do not give rise to any materially new or materially different significant effects from those assessed in the environmental statement;
- (i) works required for the strengthening, improvement, maintenance or reconstruction of any streets;

- (j) the carrying out of street works pursuant to article 10 (*street works*), works to alter the layout of streets pursuant to article 11 (*power to alter layout, etc., of streets*) and the alteration or removal of road furniture;
- (k) ramps, means of access, provision of footpaths, bridleways, cycleways and footpath linkages;
- (l) works for the decommissioning (including removal and demolition), restoration and aftercare of the authorised development which fall within the scheme approved pursuant to paragraph 22 (*decommissioning*) of Schedule 3 (*requirements*);
- (m) installation of drainage, drainage attenuation and land drainage including outfalls; and
 - (iv) such other works, including working sites, storage areas and works of demolition, as may be necessary for the purposes of or in connection with the construction or operation of the authorised development and which do not give rise to any materially different effects from those assessed in the environmental statement.

4.2 Development Consent Order Works Plan

The Work Plans scheduled in Table 4.1 below are provided in KKD K35 Appendix: Supporting Documents for Onshore Pipeline Route Plan.

Table 4.1: Schedule 2 Plans – Part 1, Works Plans

Document Number	Title of Drawing
10-2574-GND-01-05-0030	LOCATION KEY PLANS – WORKS PLANS
10-2574-GND-01-05-0031	WORKS PLANS - Sheet 1 of 25
10-2574-GND-01-05-0032	WORKS PLANS - Sheet 2 of 25
10-2574-GND-01-05-0033	WORKS PLANS - Sheet 3 of 25
10-2574-GND-01-05-0034	WORKS PLANS - Sheet 4 of 25
10-2574-GND-01-05-0035	WORKS PLANS - Sheet 5 of 25
10-2574-GND-01-05-0036	WORKS PLANS - Sheet 6 of 25
10-2574-GND-01-05-0037	WORKS PLANS - Sheet 7 of 25
10-2574-GND-01-05-0038	WORKS PLANS - Sheet 8 of 25
10-2574-GND-01-05-0039	WORKS PLANS - Sheet 9 of 25
10-2574-GND-01-05-0040	WORKS PLANS - Sheet 10 of 25
10-2574-GND-01-05-0041	WORKS PLANS - Sheet 11 of 25
10-2574-GND-01-05-0042	WORKS PLANS - Sheet 12 of 25
10-2574-GND-01-05-0043	WORKS PLANS - Sheet 13 of 25
10-2574-GND-01-05-0044	WORKS PLANS - Sheet 14 of 25
10-2574-GND-01-05-0045	WORKS PLANS - Sheet 15 of 25
10-2574-GND-01-05-0046	WORKS PLANS - Sheet 16 of 25
10-2574-GND-01-05-0047	WORKS PLANS - Sheet 17 of 25
10-2574-GND-01-05-0048	WORKS PLANS - Sheet 18 of 25
10-2574-GND-01-05-0049	WORKS PLANS - Sheet 19 of 25
10-2574-GND-01-05-0050	WORKS PLANS - Sheet 20 of 25
10-2574-GND-01-05-0051	WORKS PLANS - Sheet 21 of 25
10-2574-GND-01-05-0052	WORKS PLANS - Sheet 22 of 25
10-2574-GND-01-05-0053	WORKS PLANS - Sheet 23 of 25
10-2574-GND-01-05-0054	WORKS PLANS - Sheet 24 of 25
10-2574-GND-01-05-0055	WORKS PLANS - Sheet 25 of 25

5 Onshore Pipeline Design

5.1 PD 8010 Part 1 Code of Practice Report

NGCL has complied with the primary design code, *PD 8010 Part 1: Steel Pipelines on Land*, paying particular attention to the key aspects of the pipeline design:

- system and safety;
- route selection;
- mechanical integrity; and
- corrosion management.

Where the primary design code offers no definitive guidance on design criteria, an alternative guideline or code has been used:

Table 5.1: Pipeline Design Codes and Specifications

Code/Specification	Name
BS PD 8010 Part 1	Pipeline Systems – Part 1: Steel Pipelines on Land Code of Practice
ASCE ALA	Guidelines for the Design of Buried Steel Pipe
API RP 1102	Steel Pipelines Crossing Railroads and Highways
IGEM TD/1 Edition 5	Steel Pipelines and Associated Installations for High Pressure Gas Transmission
15589-1	Cathodic Protection of Pipeline

5.1.1 System and Safety

NGCL has applied a rigorous approach to the routing of the proposed pipelines to ensure the individual and societal risks posed by the pipelines comply with the requirements of the Health and Safety Executive (HSE) risk framework and UK pipeline codes, and are as low as reasonably practicable as defined by the Health and Safety at Work Act 1974. To do this NGCL have followed the principles of, and the requirements specified in *PD 8010 Part 1*.

The individual and societal risks along the pipelines have been evaluated by an independent consultancy and are well within the accepted risk criteria applied by UK safety legislation being classed as broadly acceptable by the HSE.

5.1.1.1 Public Safety and Protection of the Environment

The primary design code requires service classification according to hazard potential.

Dense phase CO₂ has been classified as category E. This is the most conservative selection and has the definition “*Flammable and/or toxic fluids that are gases at ambient temperature and atmospheric pressure conditions and are conveyed as gases and/or liquids*”.

5.1.1.2 Design Factor

Pipeline design is governed by ‘design factors’. The design factor is used to control the level of stress in a pipeline and is defined as the ratio of the hoop stress to the Specified Minimum Yield Stress (SMYS) of the pipe material.

Where hoop stress is the stress in a pipe wall, acting circumferentially in a plane perpendicular to the longitudinal axis of the pipe and produced by the pressure of the fluid in the pipe. The SMYS is an indication of the minimum stress a pipe may experience that will cause plastic (permanent) deformation.

The design factor is inversely proportional to the risk of pipeline failure and therefore is assigned in relation to the location of the pipeline and the substance being carried. Design factors for the pipeline are reduced from the maximum according to the proximity of the pipeline to people and the hazardous nature of the transported fluid. The design factor is dependent on class locations of which there are three:

Table 5.2: Classification of Location in Relation To Population Density

Location Class	Description
1	Areas with a population density less than 2.5 persons per hectare
2	Areas with a population density greater than or equal to 2.5 persons per hectare and which may be extensively developed with residential properties, schools and shops and so on
3	Central areas of towns and cities with a high population and building density, multi-storey buildings, dense traffic and numerous underground services

The primary design code states that:

- Category E substance pipelines, in location class 1 and 2 areas, should not normally exceed a design factor of 0.72 and 0.3 respectively;
- the location class 2 design factor may be increased to a maximum of 0.72 provided that it can be justified, by risk analysis, carried out as part of a safety evaluation for the pipeline for a statutory authority; and
- routing through location class 3 areas should be avoided for category E substances.

TP-13 to Barmston

For the TP-13 to Barmston onshore pipeline route NGCL have selected nominal wall thicknesses by carrying out a Quantitative Risk Assessment (QRA) with the following results:

Table 5.3: TP-13 to Barmston Wall Thicknesses

Route Location	Wall Thickness (mm)
12" NPS – TP-13 to Camblesforth	11.9
12" NPS – TP-13 to Camblesforth Crossings Location	17.05
24" NPS – Camblesforth to Barmston Inlet	19.1

Note: A 17.05mm section of 12" crossing pipe is included for passing the Drax Read School

Note that a separate QRA for the onshore pipeline section downstream of Barmston and the offshore pipeline section is being undertaken by NGCL.

Barmston to Landfall

For the Barmston to landfall onshore pipeline route a conventional population density assessment has been carried out during FEED to determine design factors resulting in:

- a maximum design factor of 0.72;
- a conservative design factor of 0.5 for the pipeline within the facility fence line, using IGEM TD/1; and
- a design factor of 0.6 for the pipeline outside the fence line; this aligns with the stipulated design factor for the landfall section according to PD 8010 Part 1.

NGCL have selected the following nominal wall thicknesses:

Table 5.4: Barmston to Landfall

Route Location	Wall Thickness (mm)
24" NPS – Barmston PIG Launcher to ESD Valve	34.93
24" NPS – Barmston ESD Valve to Fence Line	26.97
24" NPS – Barmston Fence Line to Landfall	22.23

5.1.2 Route Selection

The primary design code requires the route to be selected based on safety, environmental, technical and economic considerations.

NGCL have been through a DCO process to agree a centreline for the pipeline with the governing authorities. The centreline is subject to a limit of deviation, where only route changes within this limit are permitted during the design process.

The route is mainly agricultural and is selected to:

- avoid centres of population;
- minimise the number of major crossings (combined crossings are used where practicable); and
- avoid areas liable to landslip, subsidence or other instability.

5.1.3 Mechanical Integrity

The mechanical integrity design of the onshore pipeline is in accordance with the primary design code and aims to deliver the safe, efficient and reliable operation of the pipeline by considering the following:

- process conditions;
- wall thickness;
- corrosion allowance;
- restrained pipeline combined stress;
- stability;
- spanning;
- upheaval buckling assessment;
- fatigue;
- ovality;

- road crossings;
- bending;
- expansion and flexibility;
- anchor blocks;
- trenchless crossings;
- hydrotesting; and
- cover.

5.1.3.1 Process Conditions

The primary design code stipulates that the Maximum Allowable Operating Pressure (MAOP); the maximum pressure at which a pipeline system is allowed to operate, would not exceed the design pressure and that the Maximum Incidental Pressure (MIP); the maximum pressure which a gas system can experience during a short time, would not exceed the design pressure by more than 10%.

From TP-13 to the Barmston inlet, the pipeline design pressure of 135barg is equal to the MAOP.

From the Barmston outlet to the landfall the pipeline design pressure of 182barg is equal to the MAOP.

5.1.3.2 Wall Thickness

Mainline onshore pipeline wall thicknesses have been selected as described in Section 5.1.1.2 (Design Factor).

As the primary design code does not provide guidance on the selection of a design factor for pipework within the compound of facilities, the technical standard IGEM/TD/1 *Steel Pipelines and Associated Installations for High Pressure Gas Transmission* published by the Institution of Gas Engineers and Managers (IGEM) provided a conservative estimate of 0.5. This result accorded with the value indicated by the American Society of Mechanical Engineers (ASME) Code B31.8. The appropriate primary (thin wall) code has been used to determine wall thickness.

5.1.3.3 Corrosion Allowance

The onshore pipeline section will include both coating and CP and therefore does not require corrosion allowance in accordance with the primary code.

5.1.3.4 Restrained Pipeline Combined Stress

The primary code stipulates calculation of hoop, longitudinal and combined stresses for fully restrained (buried) and straight pipe.

Calculations have been carried out using the Von Mises Criterion for the full design temperature and pressure range.

All pipelines sizes are compliant with the code for the process design conditions; the resultant combined stresses are less than 90% of the SMYS.

5.1.3.5 Stability

The primary design code stipulates that stability should be by design.

One cause of instability is a high level of groundwater. A practical solution is an application of concrete; it provides both sufficient buoyancy control and mechanical protection.

However, no concrete coating is specified at this stage of the design, as water courses are mainly installed using trenchless techniques and service ditches which do not require concrete coating. Buoyancy measures may be required when areas are regarded to be boggy during construction.

5.1.3.6 Spanning

Spanning is the term applied to the lengths of pipe between supports. The primary design code states that spanning should be controlled to ensure the pipeline is not subject to excess forces or stresses.

For an onshore buried pipeline, with a well compacted and consolidated trench, spanning is not a credible design case as the soil provides constant support along its length.

5.1.3.7 Upheaval Buckling Assessment

The primary design code stipulates an upheaval buckling assessment where consideration will be given to the variability of design parameters, out of straightness and resultant stresses.

An upheaval buckling assessment has been carried out to determine the propensity of the pipelines to undergo this failure mode. Vertical force and bending stress has been assessed for a range of vertical trench imperfection heights (up to 300mm) in conjunction with conservative (submerged) soil density.

Onshore buried pipeline sizes do not exhibit a tendency to undergo upheaval buckling with the minimum cover of 1.2 m.

Resultant force direction and local bending stress have been assessed with pass criteria for both.

5.1.3.8 Fatigue

A fatigue assessment has been carried out based on the *IGE/TD/1* method for constant pressure fluctuations. Fatigue occurs as a result of periodic increases (application of stress) and decreases (removal of stress) in operating pressures.

The results provide a design life in excess of 40 years based on the fatigue cycle of design pressure to 90barg.

5.1.3.9 Ovality

Ovality is a condition in which a circular pipe forms an ellipse, usually as the result of external forces. According to the primary code ovality needs to be avoided.

NGCL have used the guidelines in *ASCE ALA: Guidelines for the Design of Buried Steel Pipe* as well as conservative assumptions to demonstrate that the expected ovality is within acceptable limits.

This includes checks for ovality displacement driven through wall bending stress and ring buckling failure mode; all are within allowable limits.

5.1.3.10 Road Crossings

The primary design code stipulates a maximum design factor of 0.3 for a pipeline containing a category E substance at major and minor road crossings unless a risk analysis, as part of a safety evaluation, can justify a design factor of up to 0.72 to the statutory authority.

Wall thicknesses have been selected using the appropriate primary code for use at road crossings.

Loadings at road crossings have been evaluated in accordance with *API RP 1102: Steel Pipelines Crossing Railroads and Highways*. All crossing pipeline sizes are within the allowable loading limits set out by the primary design code.

5.1.3.11 Bending

There are three methods of bending which can be used:

- induction bending;
- field cold bending; and
- elastic bending.

Induction bending is a controlled means of bending pipes through the application of local heating using high frequency induced electrical power. The process causes wall thickening on the inner part of the bend and thinning on the outer. Induction bend thinning at the outer radius of the bend has been considered in accordance with the primary design code and mother pipe thickness has been recommended.

Field cold bending is a means of bending pipes, along the pipeline route, using special pipe bending machines, to a relatively gentle radius of 40 x Diameter (40D). The primary design code permits field cold bending at a radius of 40D when using pipe intended for straight lengths, this has therefore been selected by the project.

Elastic bending is a means of bending pipes using the natural elastic property of the pipe to achieve the change in direction of the pipeline route. Elastic bending is permitted by the primary design code on the condition that it is proven by stress analysis and also that the bending stress does not exceed 85% of SMYS. A minimum allowable bending radius of 1000 x Diameter (1000D) has been selected, in accordance with stress analysis, which meets the 85% SMYS criteria and is also included as a load in the assessment of restrained pipe combined stress.

5.1.3.12 Expansion and Flexibility

The primary design code requires expansion and flexibility analysis to ensure that the design has sufficient flexibility and that system forces and stresses are acceptable. A flexibility analysis has been carried out:

- which verifies stress compliance for partially restrained sections of pipeline at facility approaches; and
- addresses the interface with the Above Ground Installations (AGIs).

All pipeline sections were found to be compliant with the primary code.

5.1.3.13 Anchor Blocks

Anchor blocks are reinforced concrete blocks cast around a straight piece of pipe, designed to restrain the pipe against longitudinal movement. Calculations for anchor blocks are required by the primary design code to include the effects of pipe/soil friction that restrains movement.

An expansion and flexibility analysis has been completed showing that displacements at the Endurance platform PIG trap and the associated stresses are acceptable.

5.1.3.14 Trenchless Crossings

Trenchless crossing involves subsurface construction work that requires few trenches or no continuous trenches. The primary design code allows trenchless crossings techniques. Different types of trenchless crossing techniques are outlined in Section 5.2.5 Crossing Schedule, the key elements to be considered are:

- safety aspects of excavations, proposed crossings and the technique;
- location of buried services and buried objects;
- soil/ground, and nature and type of terrain; and
- accuracy of the technique in line, level and direction.

In addition environmental aspects have been considered in order to appraise and select the following trenchless crossing techniques:

Table 5.5: Trenchless Crossing Techniques

Crossing	Trenchless Crossing Techniques
River Ouse	Horizontal Directional Drill (HDD)
Howden to Wressle Railway	Microtunnel
River Foulness	HDD
River Hull and Driffield Canal	Microtunnel
Driffield to Hutton Railway	Microtunnel
Landfall	Microtunnel

5.1.3.15 Hydrotesting

Hydrotesting is the process by which the pipeline is pressure tested to a predefined pressure above the operating design pressure of the pipeline.

The primary design code stipulates that following completion of construction and backfill it is essential that pipelines are subject to comprehensive inspection and assessment to confirm their integrity. This is generally confirmed by pressure testing.

Pressure testing a pipeline has the following benefits:

- it establishes the existence of a margin of safety against failure at operational pressure conditions; and
- it demonstrates the strength and leak tightness prior to commissioning.

The type and level of test pressure should be selected according to the proposed operation of the pipeline where a standard or high level test is permitted. A high level test provides increased assurance by subjecting the pipeline to higher test pressures to demonstrate that any remaining defects are too small to cause failure at the operating design pressure, allowing a safety margin for defect growth during service.

NGCL have selected a high level pressure test where the primary code requirements are:

- minimum test pressure: pressure that generates a hoop stress of 90% SMYS; and
- maximum test pressure: pressure that generates a hoop stress of 105% SMYS.

The pipeline stresses have been calculated at these test pressures and are within acceptable limits.

The allowable elevation changes between the minimum and maximum test pressures have also been determined and far exceed the elevation changes along the pipeline.

5.1.3.16 Cover

The primary design code defines minimum depths of cover of the pipeline.

Minimum pipeline cover through different terrain and under crossings is defined to encompass situations where greater depth of cover represents lesser risk to third party interference or natural interference such as natural risks such as scour of a riverbed in the case of river crossings.

The design has selected minimum depths of cover that are at least equal to or greater than that defined by the primary code through all specified terrain and at crossings.

5.1.4 Corrosion Management

5.1.4.1 External Coatings

The primary design code states that the external coatings of the linepipe should possess suitable mechanical and electrical properties in relation to pipe size, environment and operating conditions.

NGCL have specified a factory Fusion Bonded Epoxy (FBE) external coating of the onshore pipeline and a compatible FBE field joint coating. All buried pipeline fittings and valves will be coated using a modified high build epoxy coating containing glass fibre to meet the primary code requirements.

5.1.4.2 Cathodic Protection (CP)

CP is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell.

The primary design code states that CP should be installed for a buried pipeline to mitigate against external corrosion and coating defects.

CP will be continuous wherever possible and be of the sacrificial anode or impressed current anode methods. The sacrificial anode method of protection connects the metal to be protected to a more easily corroded sacrificial metal to act as the anode. The sacrificial metal then corrodes instead of the protected metal. The impressed current anode method of protection supplies current from a DC power source to a buried pipe using an inert electrode buried in the ground, the pipe becomes the cathode and the auxiliary electrode the anode.

With possible exceptions of crossing points, the onshore pipeline system is buried and consequently would require CP in conjunction with the external coating system to ensure that the pipeline is adequately protected. The CP system will be impressed current and would be broken into pipeline sections and above ground installations where the pipe transitions the ground level.

A CP philosophy has been detailed in which will be designed, installed and commissioned using the CP specification in accordance with the primary design code.

5.2 Pipe Laying and Routing Study

A pipe laying and routing study has been undertaken by NGCL for the onshore transportation package including:

- a pipeline installation report; inclusive of key construction consents;
- indicative construction programme;
- pipeline installation construction;
- linear pipeline construction techniques;
- special crossings by third party operator;
- depths of cover;
- access and temporary working area requirements;
- environmental mitigation measures (working hours, noise and dust, emissions and waste); and
- pipeline construction phase strategy in terms of number of sections and contractors.

5.2.1 Development Consent Order

The pipe laying and routing study has been submitted as part of the DCO:

- *Part 7.5 Code of Construction Practice* including indicative construction programme, environmental mitigation measures and pipeline construction phase strategy;
- *Part 7.6 Construction Report* including key construction consents, pipeline installation construction, linear pipeline construction techniques, special crossings, depths of cover and access and temporary working area requirements; and
- *Part 2.3 Works Plans* using scale 1:2500.

The DCO Schedule 1 and Works Plans submitted are shown in Chapter 4 and the Works Plans are shown in the Appendix to K35 – Pipeline Route Plans.

5.2.2 Construction Report

The pipe laying and routing study makes reference to the construction report which includes detailed information of the following:

- Consents management strategy;
- construction overview;
- construction of pipelines;
- special crossing methods;
- limits of deviation;
 - Vertical limits of deviation; and
- general pipeline construction methodology
 - Temporary construction compounds.

5.2.3 Code of Construction Practice

The pipe laying and routing study makes reference to the code of construction practice report which includes detailed information of the following:

- indicative construction programme;
- general site operations
 - working hours
 - construction site layout and good housekeeping
 - fencing
 - lighting and visual intrusion
 - security
 - welfare
 - temporary living accommodation
 - clearance of site on completion;
- Health and Safety
 - regulatory overview
 - emergency contacts and procedures
 - unexploded ordnance
 - radiation emissions;
- Noise and vibration
 - objective
 - noise emissions
 - control measures
 - vibration
 - monitoring;
- Air quality
 - objective
 - air emissions
 - control measures; and
- Disposal of waste and contaminated materials
 - objective
 - waste management
 - contaminated land

- control measures.

5.2.4 Works Plans

The pipe laying and routing study makes reference to the works plans which include detailed plans of the works including road, rail and third party crossings. They are drawn to scale 1:2500 with a scale bar clearly marked on each plan. See the Appendix to K35 for copies.

5.2.5 Crossing Schedule

The pipe laying study also includes a preliminary crossing schedule identifying crossings where obstructions are encountered, providing grid references for each crossing, road, ditch and service crossings.

Trenchless crossings are confirmed for:

- River Ouse;
- Howden – Wressle Railway;
- River Foulness;
- Driffield – Hutton Cranswick Railway; and
- River Hull and Driffield Canal.

5.2.6 Crossing Techniques

Trenchless crossing techniques are explained with an indication of the method that may be adopted for each crossing, likely techniques are:

Table 5.6: Trenchless Crossing Techniques

Heading Left	Heading Right
Open Cut	Once underground services have been identified and exposed, and if the ground conditions are favourable, open cut techniques can be utilised using an array of different excavating machinery when crossing minor roads and ditches.
Auger Bore	Best used for non-major highway crossings, ditch crossings, minor river and canal crossings. Ground conditions dictate where this technique can be best utilised.
Microtunnel	Commonly used to cross infrastructure such as railway lines, major rivers and major highways such as motorways. The microtunnel is a crossing technique that performs well in a variety of ground conditions and gives the best guarantee of little or no settlement. The technique is very accurate and by increasing the depth of such high risk crossings the possibility of settlement is reduced even further.
Horizontal Directional Drilled	Used for long crossings such as rivers and multiple crossings where trenching or open excavation is not feasible. It gives a good degree of accuracy but due to over cutting of the tunnel a small amount of settlement can be experienced.
Direct Pipe	Utilises a tunnel boring machine with interchangeable cutting bits which can deal with a variety of ground conditions.
Grundoram	A technique suited to soft ground conditions where a pneumatic piston drives the pipe from a pit at one side of the crossing to a receiving pit at the other side of the crossing.

Alternative crossing techniques will be identified in preferential order as the crossing technique stated may not be the final selected technique due to seasonal groundwater levels affecting crossing technique and the availability of contractor specific plant and equipment.

6 Offshore Pipeline Design

6.1 PD 8010 Part 2 Code of Practice Report

NGCL have complied with the primary design code *PD 8010 Part 2: Subsea Pipelines* paying particular attention to the key aspects of the pipeline design:

- Health Safety and Assurances;
- Design – System and Safety;
- Design – Mechanical Integrity;
- Design – Landfalls, Risers and Tie-ins;
- Design – Materials and Coatings;
- Design – Corrosion Management;
- Construction – Fabrication and Installation;
- Construction – Testing;
- Pre-commissioning and Commissioning; and
- Operation, Maintenance and Integrity Assurance Management.

Where the primary design code offers no definitive guidance on design criteria, an alternative guideline has been used. The following design codes and specifications (Table 6.1) have been used for detailed analysis, calculations and design criteria:

Table 6.1: Pipeline Design Codes and Specifications

Code/Specification	Name
BS PD 8010 Part 2	Pipeline Systems – Part 2: Subsea Pipelines Code of Practice
BS EN ISO 15589-2	Petroleum, Petrochemical and Natural Gas Industries - Cathodic Protection of Pipeline Transportation Systems Part 2: Offshore Pipelines
DNV-RP-F105	Free Spanning Pipelines, February 2006
IGEM TD/1 Edition 5	Steel Pipelines and Associated Installations for High Pressure Gas Transmission

6.1.1 Health Safety and Assurances

6.1.1.1 Health Safety and the Environment

A Hazard Identification (HAZID) workshop has identified all causes and potential consequences of credible hazards associated with the offshore transport assets, system and operation of the offshore transport system scope of design. Recommended safeguards and risk reduction measures to prevent, control and mitigate hazards throughout the project lifetime have been identified.

An offshore Environmental impact Identification (ENVID) workshop has identified the risk events or issues that could lead to an environmental consequence or legislative non-compliance. Design and safeguards have been identified to mitigate, prevent or control the impact of the environmental risk events identified.

An environmental philosophy has been developed that establishes the project criteria for facility design, installation, operability, and reliability. The philosophy provides key environmental requirements applicable to the project, interprets the environmental legislation, codes and standards applicable to the UK and the project.

6.1.1.2 Quality Assurance

A project quality plan has been developed for FEED, certified in accordance with the requirements of *ISO 9001:2008* by LRQA (certificate no. 4004777) for the 'Provision of a range of engineering consultancy, design, project management and subsea operations support services to the oil and gas process industries.'

The quality plan makes reference to:

- ISO 9001:2008 Guidelines for Quality Management Systems; and
- ISO 10005:2005 Guidelines for Quality Plans.

A quality assurance matrix has been established to detail the quality planning arrangements established for the project and to track the status as the project progresses.

6.1.1.3 Design, Construction and Commissioning Assurance

An offshore design basis establishes the design methodology for the offshore pipeline covering the key design components contained within Section 6 of *PD 8010 Part 2* and pertains to the pipeline design information addressed in Clauses 5 to 9 of *PD 8010 Part 2*.

6.1.1.4 Operation and Abandonment

The operating philosophy for the offshore storage facility has been developed which includes information on the start-up, normal/steady state operation, shut down and non-routine activities such as well intervention, PIG operations and maintenance. This work would be further developed during the detailed design stage to ensure compliance with *PD 8010 Part 2*.

Note that pipeline abandonment will be developed in a future design phase.

6.1.1.5 Plans and Drawings

The offshore routing has been developed based on information provided in the offshore survey performed during September to October 2013. The routing has been developed taking into account seabed features and existing/future assets.

The key routing and layout drawings detail:

- overall field layout;
- White Rose CCS wellhead platform approach;
- Barmston beach approach;
- offshore alignment sheets; and
- offshore crossing drawings.

6.1.2 Design – System and Safety

The subsea pipeline limits of applicability, according to *PD 8010 Part 2* is the tie-in at the onshore and offshore pipeline interface, located at the landfall on Barmston beach, to the PIG receiver located on the wellhead platform.

The design life of the pipeline system is 40 years and design conditions for pipeline design are given in the offshore design basis.

6.1.2.1 *Categorisation of Fluids*

The primary design code requires service classification according to hazard potential.

Dense phase CO₂ has been classified as category E. This is the most conservative selection and has the definition “*Flammable and/or toxic fluids that are gases at ambient temperature and atmospheric pressure conditions and are conveyed as gases and/or liquids*”.

6.1.2.2 *Pipeline Process Design*

Process steady state analysis and transient analysis have been performed.

The MAOP is identical to the system design pressure of the offshore pipeline of 182barg for a Lowest Astronomical Tide (LAT) of +6.84m.

6.1.2.3 *Public Safety and Protection of the Environment*

Consideration has been given to public safety during the design process by following the relevant design codes and applying location specific safety values as defined in *PD 8010 Part 2*.

A project environmental philosophy has been developed which provides an outline of key environmental requirements applicable to the project and interprets environmental legislation, codes, and standards applicable to the UK and the project.

An environmental risk matrix was performed which identifies potential environmental concerns, impact and mitigation/prevention/control considered in the design of the offshore system.

6.1.2.4 *Route Selection*

The offshore routing is within the initial survey corridor, and routing design is covered in detail in the offshore infrastructure report which has taken into account route selection based on safety, environmental, technical and economic considerations as required by *PD 8010 Part 2*. Consideration has been given to the proximity of existing and future assets in the routing layout in addition to seabed features.

6.1.3 *Design – Mechanical Integrity*

6.1.3.1 *Design Criteria*

Process Conditions

The pipe and components are designed for an MAOP of 182barg with a LAT of +6.84m.

The subsea flanges are rated to minimum class 1500 for sufficient pressure ratings of the pipeline system. Pipeline wall thicknesses have been selected to withstand the MAOP for pressure containment accounting

for manufacturing tolerances. The maximum expected CO₂ fluid temperature in the offshore pipeline has been determined and temperature profiles have been used in pipeline design calculations.

High Integrity Pressure Protection System (HIPPS) is provided to protect the offshore pipeline from CO₂ booster pump pressures at the Barmston pumping station. An Emergency Shut Down Valve (ESDV) is located at the pumping station at Barmston for shutdown and isolation of the offshore pipeline and an ESDV is located at the offshore facility on the wellhead platform.

Pressure Design of Pipeline and Pipeline Components

Nominal pipe thickness has been selected using standard pipe sizes as in *ASME B36.10M-2004: Welded and Seamless Wrought Steel Pipe* and the linepipe manufacturing tolerances are as *BS EN ISO 3183: Petroleum and Natural Gas Industries - Steel Pipe for Pipeline Transportation Systems*, it takes into consideration the minimum required wall thickness at bends accounting for wall thinning at the outer radius; in accordance with *PD 8010 Part 2* the expected bend thinning is estimated to be approximately 9.1% for 5 x Diameter induction bends.

Minimum wall thicknesses have been calculated using *PD 8010 Part 2* for stress based design, to satisfy pressure containment, collapse, propagation buckling and local buckling.

Note that reeling criteria have not been considered since reel-lay is not achievable given the pipeline diameter for the offshore pipeline wall thickness including riser and tie-in spool.

6.1.3.2 Loads

Loads are considered dependant on the analysis performed and the load conditions in accordance with *PD 8010 Part 2*. Loads conditions are indicated within individual design reports.

6.1.3.3 Strength

The pipeline is designed in compliance with *PD 8010 Part 2*, to ensure that the selected wall thickness is appropriate for all the load conditions and combinations that can be expected throughout the life of the pipeline.

Design Factors

Design factors (Table 6.2) are applied to hoop stress when calculating the wall thickness or pressure values:

Table 6.2: Design Factor

Hoop Stress		Equivalent Stresses Resulting From Functional and Environmental or Accidental Loads		Equivalent Stresses Arising From Construction or Hydrotest Loads	
Riser/Landfall	Seabed Including Tie-in	Riser/Landfall	Seabed Including Tie-in	Riser/Landfall	Seabed Including Tie-in
0.6	0.72	0.72	0.96	1.0	1.0

Source: PD 8010 Part 2: Subsea Pipelines

A landfall factor of 0.6 for hoop stress and 0.72 for equivalent stress, apply from the onshore/offshore tie-in interface to 1.3km offshore where there is an approximate water depth of 7.5m (LAT). The remaining pipeline and spool use a factor of 0.72 for hoop stress and 0.96 for equivalent stress. All conditions prior to operation of the pipeline use equivalent stress factors of 1.0.

Stress Based Design

Hoop, longitudinal and combined stresses have been calculated, for fully restrained and straight pipe, using the thin wall formula in accordance with *PD 8010 Part 2*.

Stress check calculations have been carried out using the Von Mises Criterion for the full design temperature and pressure range. The pipeline is compliant with the code for the process design conditions and all integrity checks have been performed using stress-based design checks.

Expansion analysis has been performed using strain-based equations to determine the location of the Virtual Anchor Points (VAP) from the wellhead platform end of the pipeline which determined the 'active' length to calculate the magnitude of pipeline end expansion. The calculations account the MAOP and thermal loads in the pipeline and the cumulative resistance force between the pipeline and seabed. Leak test conditions were also assessed.

The tie-in spool design is flexible enough to absorb end expansion loads and prevent excess transfer of loads into the riser, this uses the end expansion previously calculated. The tie-in spool design accounts for flexibility and stress intensification caused by fittings including bends by using AutoPIPE stress software.

Strain Based Design

Strain-based design may be considered for the offshore pipeline design in future design stages.

Buckling assessment has been performed in accordance with *PD 8010 Part 2*, accounting for nominal wall thickness, ovality and the weight contribution of concrete coating excluding the coating stiffness contribution.

The following have been tested for a range of seabed imperfection heights to assess both the integrity of the pipeline and the propensity of the pipe to buckle and identify mitigation methods:

- local buckling;
- propagation buckling; and
- restrained pipe buckling due to axial compressive forces.

Brittle fracture during normal operation or in blowdown conditions will be avoided by the selection of materials which have adequate low temperature toughness.

A fatigue assessment for the pipeline system has been performed at the design stage and simplified fatigue criteria carried out, based on a daily allowable pressure (stress) range during the pipeline design life and with an allowable frequency for a depressurisation down to 90barg from MAOP.

This provides a design life in excess of 40 years. A more detailed fatigue assessment will be performed once the number of cycles for operation, shut down and start-up are known.

6.1.3.4 Stability

The stability of the offshore pipeline system on the seabed over the lifetime of the pipe has been considered, in all design conditions, with consideration given to both lateral and vertical stability. Environmental, soil conditions and marine growth have also been considered.

The required concrete weight coating to ensure a stable pipeline has been determined using the 2D force-balance method.

Pre-lay and post-lay trenching has been considered in areas where an excessive concrete coating is required to ensure pipeline stability. Trenching inhibits sideways movement and reduces hydrodynamic loads (loads that result from water flowing against and around a rigid structural element).

6.1.3.5 Spanning

Free spanning in the pipeline, where the seabed sediments have been eroded under lengths of the pipe, may occur as a consequence of an uneven seabed and local scouring due to flow turbulence and instability. Free spans along the route have been determined in an on-bottom roughness analysis using Sage Profile 2D and static analyses have been performed with the maximum allowable equivalent stresses to *PD 8010 Part 2*.

6.1.3.6 Pipeline and Cable Crossings

A minimum separation of 0.3m will be achieved between pipeline and cable crossings by using separation mattresses with a thickness of 0.3m.

Consideration has been given to the 1100mm (44") Langed pipeline. Mattress protection will allow sufficient clearance between the Langed pipeline and the bottom of the 600mm CCS pipeline.

Consideration has also been given to the two High Voltage Direct Current (HVDC) cables planned for the Forewind wind turbine array areas in the Dogger Bank Zone. If they are laid prior to the pipeline, they will be trenched and buried with protection mattresses laid over the cable location to ensure a minimum separation from the CCS pipeline. If they are laid after installation of the CCS pipeline, the pipeline will be in a trenched section and the HVDC cables will be laid over a pre-lay mattress to ensure that the minimum separation is met.

To avoid interference of CP systems there will be no anodes over crossings, instead double anodes can be placed prior to and after the crossing, if necessary.

Crossing angles will be as close to 90 degrees as feasible. However, the crossing angle of the Dogger Bank cable crossing may be as acute as 12 degrees; in this case additional protection mattresses will be laid to account for pipe lay tolerances for such a long crossing.

To protect the pipeline from trawler gear interaction, rocks will be laid at the crossings.

Buckling at the crossing and free spans prior to rock dumping has been assessed.

6.1.3.7 Leak Detection

A project gas leak detection and control philosophy has been developed which defines the design approach and minimum functional requirements for the fixed CO₂ detection and alarm system.

The fixed CO₂ detection systems will consider a combination of acoustic leak detection, infrared point detection and open path detection.

6.1.4 Design – Landfalls Risers and Tie-ins

The location is in close proximity to the pumping station, allowing access for direct pull-in to the beach following beach preparation works.

6.1.4.1 Landfall

The extent of the landfall is from the onshore/offshore tie-in location on the beach to sufficient water depth offshore where surf and inter-tidal waves have limiting effect.

The near shore has shallow water depths so may require a shallow water vessel or a large dredged channel to gain access for performing the shore pull.

Stabilisation and pipeline burial requirements have been determined with routing and survey information. The near shore on-bottom stability has been performed in accordance with PD 8010 Part 2 as have safety factors in the landfall zone resulting in increased pipeline wall thickness.

The recommended solution for the construction and installation of the pipeline at the landfall is a trench with a cofferdam located at the tie-in with the onshore pipeline on the beach. The offshore pipeline will be pulled ashore from an offshore shallow water lay barge via twin linear winches.

6.1.4.2 Risers and Tie-ins

A preliminary riser and tie-in spool design has been prepared which takes into account:

- pipeline end expansion for operation and leak test conditions;
- upper bound and lower bound soil sensitivities;
- mattress loads; and
- environmental loading.

Vortex induced vibration of the riser has been assessed in addition to the spool stability and equivalent stress checks have been performed according to PD 8010 Part 2.

Loads on riser supports, guides and flanges have been extracted for support design and flange capacity checks. The design is considered preliminary at FEED stage as platform layout and orientations are ongoing. Installation loads, platform movements and seismic loads would be considered in the next design phase.

6.1.4.3 Subsea Connections and Valves

PIG Operations

A 600mm Pipeline Inspection Gauge (PIG) launcher will be provided at the Barmston outlet of the pumping facility and a 600mm PIG receiver will be provided on the wellhead platform to allow the operation of intelligent PIGs 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 Intelligent pipeline Inspection Device (IID), also known as an intelligent PIG.

All changes of internal diameter will be tapered to allow smooth running of the PIGs.

Flanged Connections

Flanges will be selected based on the pressure ratings of the systems in accordance with the flange specification and data sheet.

Flange loads on the tie-in spool and riser have been determined in the spool and riser analysis and the acceptability of the loads would be confirmed with flange manufacturers.

6.1.4.4 Protection

A study has been performed to determine the required protection for the assets where pipeline protection requirements and mitigations cover possible causes of damages given in PD 8010 Part 2, including trawl gear impact, trawl pull over and trawl hooking.

Further investigation, such as the following, is required to determine if additional protection is required:

- level of fishing intensity from trawling;
- if major shipping channels pass the route and anchor protection is required; and
- the effect of seismic activity.

6.1.4.5 Pipeline Shutdown Systems

A HIPPS is provided to protect the offshore pipeline from CO₂ booster pump pressures at the Barmston pumping station.

ESDVs are located at the pumping station at Barmston and at the offshore facility on the wellhead platform, for shut down and isolation of the offshore pipeline.

6.1.5 Design Materials and Coatings

Detailed assessment of selected materials and coatings for the CO₂ pipeline has been performed. The primary approach to the mitigation of internal corrosion of the offshore pipeline, riser and tie-in spool is to ensure that dense phase CO₂ stream remains dry (free of water) throughout.

6.1.5.1 Linepipe Selection

The selected material for the linepipe is carbon steel of L450MO grade to BS EN ISO 3183. The manufacturing method is Longitudinal Submerged Arc Welding (SAWL).

6.1.5.2 PIG Traps

The offshore platform PIG launchers and receivers (traps) are in accordance with the offshore platform PIG launchers and receivers specification and data sheet.

6.1.5.3 Insulation Joints

To prevent interference with corrosion control a welded prefabricated three piece union, called a monolithic insulating joint, will be used for electrical isolation of differing CP systems in accordance with the specification and data sheet.

6.1.5.4 Coatings

The line pipe is to be concrete coated for hydrodynamic stability and protection; the anti-corrosion coating shall be compatible with the application of the concrete weight coating (CWC). A fusion-bonded Epoxy, single layer anti-corrosion coating would therefore be selected.

As mentioned above, CWC may be required for stability purposes; typically concrete densities range from 1800 kg/m³ to 3450kg/m³. The “28-day minimum compressive strength” is assumed as 35N/mm². The concrete coating shall not be less than 45mm as per PD 8010-2 recommendation.

Use of high density concrete coating (3450kg/m³) has a higher cost implication due to costs associated with increasing iron ore content to achieve the required density. Optimisation is recommended to assess the costing of trenching the full route and minimising CWC versus an exposed pipe with high density CWC.

Reducing the weight of the concrete coating, to allow the pipe to be laid over greater seabed imperfection heights without overstressing the pipe, should reduce the amount of seabed rectification required. Currently the 145mm CWC and 25.4mm steel Wall Thickness (WT) would result in a significant amount of pre-trenching required in the section of the route which passes through the sand wave, estimated at 270 000 tonnes. This could be reduced by almost half to 150 000 tonnes if consideration is given to using 85mm CWC and 25.4mm WT i.e. using DNV-RP-F109 Stability Method or further development of pipe-soil interaction models.

6.1.6 Corrosion Management

Corrosion mechanisms of the pipeline have been reviewed and mitigation methods determined, these are detailed in the material selection report. These include assessment of:

- Internal corrosion:
 - CO₂ corrosion;
 - dense phase CO₂ corrosion;
 - oxygen corrosion;
 - hydrogen sulphide corrosion/cracking;

- hydrates; and
- presence of impurities; and
- External corrosion:
 - differential corrosion;
 - microbiologically influenced corrosion;
 - stress corrosion cracking; and
 - galvanic attack.

6.1.6.1 Internal Corrosion

Internal corrosion is not expected as the pipeline is to be operated dry (free of water) and be protected by a high integrity water monitoring and shutdown protection system. All water introduced after laying for pre-commissioning will be treated and inhibited.

6.1.6.2 External Corrosion

The primary external corrosion control strategy will be the use of high quality factory and field applied coatings with the CP system as the secondary but essential, mandatory, protection system. The external coating of the linepipe would be factory FBE with compatible FBE field joint coating.

CP of the offshore pipeline will be provided by indium activated aluminium alloy bracelet sacrificial anodes (Aluminium-Zinc-Indium) designed in accordance with BS EN ISO 15589-2.

The design life of the CP system will be 40 years.

6.1.7 Construction – Fabrication and Installation

A high level philosophy for planning, alignment and co-ordination of the engineering, procurement, installation and construction activities has been developed in the offshore pipeline installation and constructability philosophy.

6.1.8 Construction – Testing

Technical requirements related to the flooding, cleaning, gauging, strength testing, leak testing and pre-commissioning of the offshore pipeline facilities are given in the offshore pipeline flooding, cleaning, gauging, testing and pre-commissioning specification.

6.2 Offshore Pipeline Design Reports

A high level philosophy for planning, alignment and co-ordination of the engineering, procurement, installation and construction activities has been developed.

Technical requirements related to the flooding, cleaning, gauging, strength testing, leak testing and pre-commissioning of the pipeline facilities are given in the pre-commissioning specification.

These design reports determine the required minimum wall thicknesses for the landfall, offshore pipeline, spool and riser in accordance with PD 8010 Part 2, as well as global buckling and fatigue analyses to demonstrate the pipeline's fitness for purpose and predict the pipeline limitations for typical scenarios.

Note that reeling criteria has not been considered as reel-lay is not achievable given the pipeline diameter for the offshore pipeline wall thickness including riser and tie-in spool.

6.2.1 Hydraulic Analysis

The pipeline test pressures vary depending on the location within the system and wall thickness, therefore the pipeline would be hydrostatically tested to 239.7barg at a LAT of +6.84m and leak tested to 200.2barg at a LAT of +6.84m; these are associated with the lowest wall thickness along the route.

Hydrotesting and leak testing would be performed in accordance with PD 8010 Part 2:

- after installation of the offshore pipeline is complete and trenching is complete, the pipeline will be flooded, cleaned, gauged and hydrostatically strength tested, to ensure integrity of the offshore pipeline;
- the tie-in spool and riser would be cleaned, gauged and hydrostatically strength tested onshore after fabrication;
- following completion of the offshore activities the pipeline will be tied into the riser at wellhead platform via a tie-in spool and a tied into the onshore pipeline at the landfall; and
- pre-commissioning activities will be performed on the pipeline system and include system leak test, dewatering/swabbing, drying and air or Nitrogen packing.

6.2.2 Route Selection

The following criteria were considered in the route selection and design:

- minimisation of the pipeline route length and intersection points, ensuring that the selected route remains within the surveyed route corridor, whilst still satisfying other route criteria;
- avoidance of the seabed features and crossings, where possible including pockmarks, abandoned wells and drilling cuttings piles;
- optimisation of the approaches to shore and to the wellhead platform;
- consideration of the construction vessel limitations and pipeline installation methods including initiation, lay down and crossing requirements;
- minimisation of the environmental impact and seabed disturbance due to pipeline installation and operation activities, when possible;
- minimisation of the number (and extent) of subsea pipeline and cable crossings and avoidance of crossing within the route curve, when possible;
- consideration of a minimum clearance distance of 50m from any (isolated) abandoned/suspended well, when possible;
- consideration of a minimum distance of 30m from any existing flow line, cable, umbilical or subsea structure;
- avoidance, when practical, of any seabed obstructions or features such as boulders, debris, wrecks, rocky outcrops, unstable slopes, ridges, depressions, debris, pockmarks; and
- minimisation of the length, footage or area of tie-in arrangement, as practically as possible, taking into account existing subsea facilities, installation constraint, riser arrangement.

6.2.2.1 Kilometre Points

Kilometre Points (KPs) are measurements used to describe the route in relation to its distance from the beach tie-in. The value of KP is 0 at the interface between the onshore and offshore pipeline on the beach tie-in and increases in proportion to the distance from the tie-in in the direction of product flow.

The offshore route passes through blocks 41 and 42 of the south North Sea. The route also passes through 42/28a Wollaston Field which is currently owned by Perenco UK Ltd.

An initial near shore survey was performed between November 2012 and March 2013 for the first 15.3km, 1km wide from the beach at Barmston. An offshore route survey was performed in September and October 2013 covering 88.6km of a 1km wide offshore corridor.

The pipeline key route co-ordinates are as shown in Table 6.3 below:

Table 6.3: Key Route Coordinates

Location	KP (km)	Easting (m)	Northing (m)
Onshore/Offshore Tie-in Point (beach)	0	289 478.02	5 991 627.67
2 x Dogger Bank Crossings	TBC (1)	TBC (1)	TBC (1)
Langeled Crossing	37.603	326 840.72	5 995 016.67
Pipeline Tie-in at Platform	88.349	366 851.34	6 012 732.10
White Rose CCS Platform	-	366 882.00	6 012 790.00

1. The Dogger Bank High Voltage Direct Current cables are not yet installed.

6.2.2.2 Route Description

Landfall

The landfall location is north of Barmston, on the Holderness coast, on a sandy beach with low sedimentary cliffs set back from a narrow beach. The cliffs are subject to erosion and the pipeline should be buried to sufficient depth to prevent erosion impacting the integrity of the pipe or the trench.

The interface between the offshore and onshore is at the tie-in point. This will be located at the first joint pulled into shore to enable separation of testing for the offshore and onshore pipeline sections.

The pipe-lay start-up will either be at the landfall or a shallow water tie-in separating the landfall installation from the offshore.

Offshore

The route from the shore approach to the lay down at the wellhead platform has been surveyed using sonar with reference to KP distances, land/seabed features and water depth

Obstructions and features have been identified; the most notable are summarised as follows:

- the presence of areas of sub-cropping boulder clay in the near shore area consists of high to ultra-high strength clay which may cause difficulty in dredging. Sonar contacts from the survey indicated that a significant number of boulders occur near shore between KP 1.100 to and KP 1.580 and between KP 8.735 and KP 15.211 with average heights of approximately 0.6m and a maximum height of 1.2m;
- boulders are avoided where feasible and the nearest boulder occurs 10m from the proposed main route. Touchdown monitoring is recommended, where the profile of the underwater pipeline extending between the pipe laying vessel and the seabed is monitored. Monitoring in this section will avoid laying over boulders particularly in trenched sections of the route;
- an area of 10.5km by 7km is designated for the crossing of two HVDC Dogger Bank cables which have a depth contour ranging from 10m to 40m. The Dogger Bank cables may not be present prior to installation of the CCS pipeline. In this area the route heads in an easterly direction towards the wellhead platform;
- trawl scars are visible from KP 26.380, and become intensive from KP 33.415 to KP 38.100, crossing the survey area with a predominant east to west orientation. These scars are indicative of intensive trawling activity in the area;
- from KP 27.755 to KP 29.759 the proposed route crosses a shallow channel. This feature has a very minor topographic relief, with a maximum depth of 1.6m below the local seabed;
- the second crossing is the existing Langed pipeline which is at KP 37.603, after which the route turns north east;
- an unknown magnetic anomaly crosses the proposed route corridor at approximately KP 46.349 and should be investigated further to determine if another crossing is required;
- from approximately KP 46.400 to the end of the proposed main route the seabed topography is dominated by the presence of large sand waves. The presence of these sand waves is also responsible for a significant increase in general seabed gradients across the survey corridor. Gradients of up to 6.0° are observed associated with sediment ripples which cover the larger scale sand waves. Gradients of between 10° and 12° are recorded associated with the crests of sand waves. The maximum recorded gradient along the proposed route is 15.2° recorded at the crest of a sand wave at KP 82.549; and
- A number of sonar contacts, boulders and lobster crab pots are found along the route and should be visually inspected to ensure these do not impact the pipeline route, otherwise sweeping of the route may be required.

6.2.2.3 Offshore Proposed Route

The offshore section of the proposed route starts at the onshore/offshore tie-in point at KP 0 with an easterly heading of 80.74°, through the Dogger Bank crossing area, until KP 17.730 followed by a 5000m radius bend, the length of the bend is 685m.

After the first bend the pipeline has a change of direction to a heading of 88.59°, at KP 18.415, for a length of 20347m, until KP 38.762. Then there is another 5000m radius bend, the length of this bend is 5273m.

After the second bend the pipeline has a change of direction to a north-north-east heading of 28.17° (at KP44.035) for a length of 2161m (until KP46.196). Then there is another 5000m radius bend, the length of this bend is 759m where the pipeline route passes through the Wollaston Field.

After the third bend the pipeline has a change of direction to a heading of 36.86° (at KP 46.955) for a length of 16068m (until KP63.023), the pipeline runs in almost parallel with the Langede pipeline route. Then there is another 5500m radius bend, the length of this bend is 7490m.

After the fourth bend the pipeline has a change of direction to an east-south-east heading of 114.89° (at KP70.513) for a length of 7485m (until KP77.998). Then there is another 5500m bend, the length of this bend is 4785m.

After the fifth bend the pipeline has a change of direction to an east-north-east heading of 65.04° (at KP82.783) for a length of 1409m (until KP84.192). Then there is another 5500m bend, the length of this bend is 2396m.

After the sixth bend, the final pipeline heading is at an easterly direction of 90.00° (at KP86.588) and has a length of 1761m. This heading is maintained up to the tie-in location at KP 88.349.

The lay down will be at the wellhead platform.

6.2.3 Geohazards

A geohazard is a geological state that may lead to widespread damage or risk. The following geohazards along the offshore route were assessed:

- slope failure;
- anchor scar;
- trawling;
- ridges, berms, boulders and rock out-crops;
- sediment mobility;
- faults;
- soil liquefaction;
- cliff and beach erosion; and
- munitions.

6.2.3.1 *Slope Failure*

The largest gradients along the route occur in the near shore section, 37° between KP 0.227 and KP 1.400 and between KP 8.865 to KP 15.211, which are pre-dredged sections of the route. Typical gradients are between 5° and 7°. Slope failure is not expected to occur as the seabed gradient along the route does not have any significant slopes with steep gradients.

6.2.3.2 *Anchor Scarring*

An isolated anchor scar was found at approximately KP 17.764 at 38m water depth in the offshore survey, up to 100mm below the seabed. This section of the route will be trenched.

Further investigation into activities and the presence of shipping channels along the route are recommended to decide whether additional pipeline protection is necessary.

6.2.3.3 *Trawl Scarring*

Intensive trawl scarring is visible along the proposed main route, between KP 26.380 and KP 38.100. The trawl scars cross the proposed main route in numerous places suggesting a prevalence of fishing activity in the area.

Further fishing studies are recommended to determine the level of fishing intensity and type of fishing in the area, if this is deemed high then further pipeline protection is required.

6.2.3.4 *Ridges, Berms, Boulders and Rock Out-crops*

The pipeline route passes through the low point of a series of berms orientated north to south between KP 20.420 and KP 20.740, which must be followed to avoid creating free spans.

Sub-cropping rock and boulders must be avoided or pre-swept, where feasible, to prevent formation of free spans during pipe laying otherwise post-lay rectification is required. Boulders may present a direct obstruction to the pipeline installation techniques. Some boulders may require removal and any areas of outcrops which cannot be pre-swept/dredged may require intervention in the form of rock dumping if unacceptable spans are formed.

6.2.3.5 *Sediment Mobility*

Sand waves and sand ripples occur along the majority of the second half of the offshore route which has the potential to cause scouring for sections of the pipeline which are free spanning. Pre-sweeping or trenching to ensure the pipeline rests on the seabed or below seabed level, where sediment mobility is dominant, will militate against scouring. Regular inspection, maintenance and repair surveys may be required, followed by intervention works when necessary, if low rates of scouring are predicted.

Sediment ripples are observed between KP 18.060 to KP 30.831 and between KP 38.842 to KP 86.760. Sand waves can be observed between KP 46.400 to KP 86.760.

The sediment movement indicates that offshore the net movement is either from the north-west or from the south-east. This results in the sections of pipeline which are resting on the seabed and orientated from south-west to north-east, gaining an accumulation of sand against the pipe. In addition, there is the potential of scouring for sections of the pipeline which are free spanning and for pipeline sections orientated in the same direction as the sediment flow.

Near shore the sediment is predominately transported in a southerly direction along the coastline which over time will potentially change the shape of the coastline. Material from the cliff, fine sands and silts tend to be more mobile and are transported further than coarser sands and gravels. A detailed sediment transport study is recommended to:

- determine the impact on the pipeline and the trench: and
- assess how the seabed changes over time to decide suitable dredged depths and lengths.

6.2.3.6 Faults

A number of fault lines within the upper cretaceous chalk layers have been detected in the offshore survey but it has not been indicated whether these faults are active.

The majority of faults are near vertical and do not extend vertically into the upper layers of boulder clay. The effects on the fault lines during seismic activities should be investigated further to determine whether slip may occur.

The route passes over the Wollaston field, where significant fault lines occur in the cretaceous chalk layer. Reservoir compaction over time may cause movement of the fault lines and potentially cause subsidence at, and around, the reservoir. Additional strain caused by subsidence would have to be considered in the pipeline design.

6.2.3.7 Seismicity

Information from [UK HSE Offshore Technology Report 2002/005, Seismic Hazard: UK Continental Shelf, Prepared by EQE International Ltd for the Health and Safety Executive](#) indicates that the route is on the northern margin of the Sole Pit Basin, a major seismic region of the southern North Sea. The epicentre of the major Dogger Bank earthquake of 7th June 1931 was close to the route.

Table 6.4 below presents typical peak ground accelerations of the bedrock in the section of the North Sea where the White Rose pipeline is routed.

Table 6.4: Peak Ground Accelerations

Parameter	Value				
PGA (m/s ²)	0.0265g	0.0382g	0.0611g	0.0917g	0.2447g
Exceedance probability	1e-2	5e-3	2.1e-3	1e-3	1e-4
Return Period (Years)	100	200	475	1000	10,000

6.2.3.8 Soil Liquefaction

Seismic activity can cause liquefaction which occurs predominately when soils have low shear strength or lose strength during seismic activity. The soils along the route consist of very loose to medium-dense, slightly silty sand, and clay silty sands. The sand layer generally overlays either boulder clay or chalk. The underlying boulder clay (high shear strength) and chalk make the likelihood of liquefaction low where these layers occur.

The upper layers of sand vary in strength from low to high, along the route and vary in thickness, in some samples sections of sand were found deeper in the stratum. This can lead to a potential of liquefaction in the loose un-cohesive upper layer, this upper layer can be up to 0.5m thick. Further assessment of the soils can determine if liquefaction due to seismic activity is likely to occur.

6.2.3.9 Cliff and Beach Erosion

The cliffs in the beach area are susceptible to erosion, and the pipeline in these areas should be either buried to sufficient depth or protected using covers/rock dumping to account for future coastal erosion at the beach. Erosion of the cliffs will continue until the sea can no longer reach the base of the cliff, however due to the predicted increase in future sea levels there will be continuous erosion of the cliff throughout the pipeline design life.

Cliff erosion in Holderness results in large quantities of sand and mud falling into the sea which is then moved south by wind-driven waves and currents. In calm periods, beach sand builds up against the cliff, but during storms the sand is transferred to sandbars just offshore. The average cliff erosion rates to September 2012 were 1.65m per year at the current landfall location.

The cliff face can be protected by using erosion protection methods such as a rock wall; however this may have an environmental impact and cause greater erosion rates in other areas altering the shape of the coastline. The erosion of the cliff may cause a temporary increase in beach elevation which will eventually erode over time.

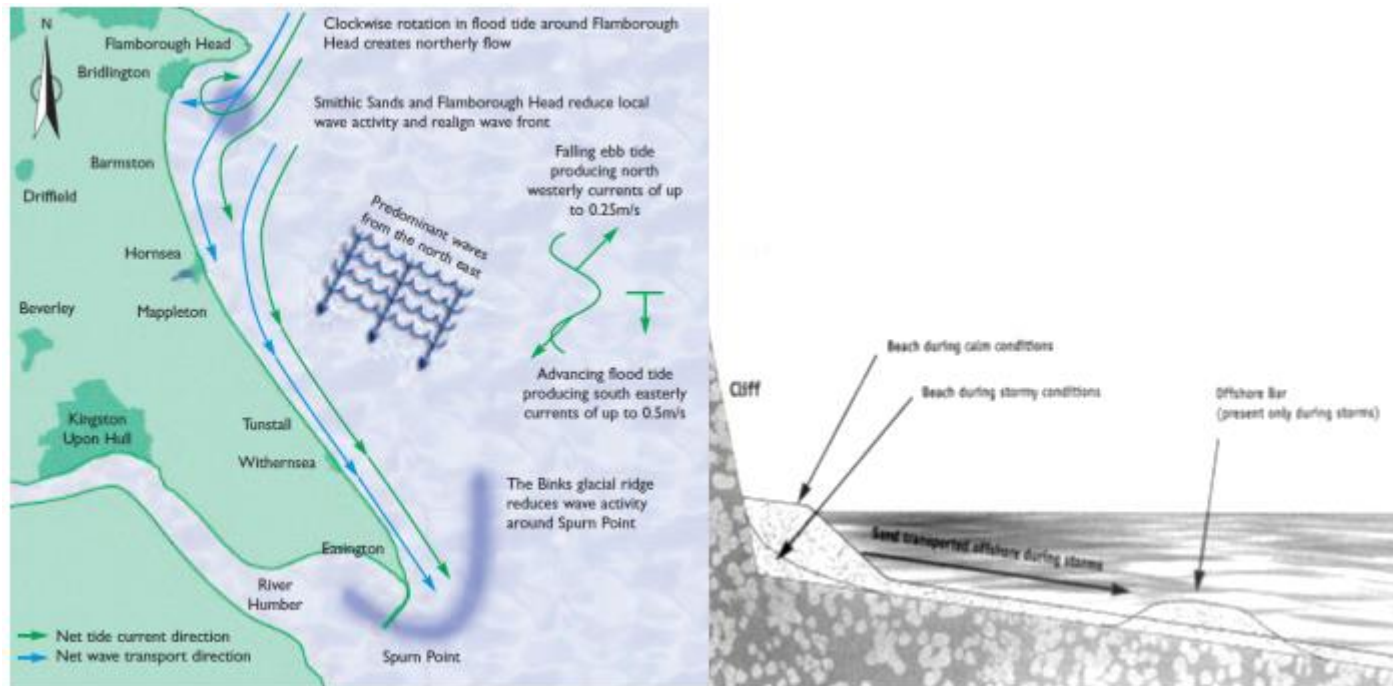
Figure 6.1 overleaf shows the cumulative change in beach elevation from September 2008 to September 2012. Over the four year period the change in the seabed is approximately +/-1.75m; this does not reveal significant alteration in any area in proximity to the landfall location. This beach surface lowering is a consequence of cliff retreat which may be temporarily obscured by seasonal beach growth and erosion. However, longer term shore erosion is a gradual process, and values closer to 0.02m per year may be typical, when also accounting for the sediment due to erosion of the cliff. This equates to total change in seabed elevation of 0.8m over the 40 year design life.

Considering the net erosion of 0.8m over the 40 year design life and a change in the seabed of +/-1.75m due to temporary erosion, the 600mm pipe with a 95mm concrete weight coating would require a minimum trench depth of 4.8m with a 1.45m depth of cover.

The beach is subject to longshore currents that move parallel to shore caused by large swells sweeping into the shoreline at an angle and pushing water down the length of the beach in one direction. Longshore currents can cause problematic issues for dredging activities and stability of the trenches. Protection will be

required to account for erosion of the seabed either by a deep trench, tunnel/bore or protection cover such as rock dumping or culverting.

Figure 6.1: Typical Cliff Erosion Mechanism on Holderness Coast



6.2.4 Shore Approach

The landfall location is based south-east of the proposed pumping station location. The shore approach is a relatively exposed section of the beach with longshore drift and environmental loading at 90° to the pipe. There is no shelter offered to the pipe from natural features. The shore approach consists of a veneer of sand with outcrops of clay silty sand which overlies boulder clay. A chalk layer occurs at much greater depths with outcrops in some locations.

It is considered that near shore, the pipe will be highly unstable if left exposed on the seabed due to environmental conditions so it is recommended that the pipeline is laid in a trench which extends to a water depth of approximately 49m, 27.25km in length from the beach.

The pre-dredged section of the trench is to a water depth of 36m at KP 16.25. The seabed will be excavated to a nominal depth to ensure that sufficient cover remains in the event of sediment movement. Natural backfill will infill the trench and spoils of material placed updrift of the trench will encourage this. To prevent sediment movement uncovering the pipeline, rock dumping will be used in the first kilometre or up to a point where the influence of longshore drift dissipates.

The survey information and metocean data indicates that high tide is up to the cliff face. Works will have to be performed on the cliff to establish access to the beach (if necessary) and create a safe working area above high tide level.

Studies have been performed to evaluate a number of solutions for the design, installation and construction of the landfall, some of which are detailed in the following sections. After consideration of all the results the following recommendations have been made for the:

- a microtunnel, from upstream of the cliff face to the beach for the onshore pipeline section;
- the microtunnel is tied into the offshore pipeline on the beach within a cofferdam; and
- a conventional installation of the offshore pipeline is performed using onshore based linear winch spreads into a sheet piled cofferdam and open-cut trench.

6.2.4.1 Cofferdam/Open-Cut Trench

A cofferdam is required as a trench alone would be insufficient to block infill in the surf zone. A sheet piled cofferdam will be established from the beach and along the coast. To avoid the influence of the longshore currents, a causeway out from the beach will be constructed to enable land-based equipment to perform the works.

Further offshore the cofferdam will lead to a dredged channel. Survey activities identify magnetic anomalies which have not yet been defined. This causes a safety concern for dredging activities as there are potentially unexploded ordnance; further survey is needed before any construction work begins. Wave and current conditions may also cause construction and long term integrity difficulties for a typical cofferdam.

The landfall works involved with a cofferdam and dredging will have a great environmental impact due to the level of disturbance of ground excavations because of the required depth of cover for the buried

landfall pipeline. The ground works may potentially result in accelerating coastal erosion, so in critical areas rock dumping or potential covers will be required to protect against loss of cover.

6.2.4.2 Trenchless Installation

The methods of trenchless installation have been compared.

The direct-pipe method was ruled out early in the considerations as the installation is limited to pipe diameters between 800mm and 1500mm. Instead both HDD and microtunnel were considered to pass through the clay or chalk layers out to a cofferdam on the beach; the HDD could be extended to a pre-dredged section offshore. With HDD, an exit point into a pre-dredged trench would be located outside of the surf zone region where long shore drift is likely to occur and outside of the area where future coastal erosion will cause significant changes to the landscape of the seabed.

The disadvantage of a HDD over a microtunnel is that the soil conditions may cause difficulty in boring causing a collapse of the bore. Boring through boulders and hard geology would also prove difficulty which may necessitate boring another tunnel causing offshore installation delays. No concrete would be present so temporary stabilisation would be required for the pipe string laid offshore for the pull-in.

Micro-tunnelling can bore through harder soil conditions, but has a higher cost implication and longer schedule demands.

The two methods are compared in table 6.5 below:

Table 6.5: Suitability of Trenchless Installation Method for Different Site Conditions

	Site Conditions	Micro-tunnel	HDD
Soil	Cohesive	✓	✓
	Sand	✓	✓
	Gravel	✓	X
	Boulders	✓	X
	Mixed	✓	O
	Rock	✓	✓
Pipe Coating	High Density PE	X	✓
	Steel	O	✓
	Concrete	✓	X
Pipe Nominal Diameter	≤1000mm	O	✓
	≥1200mm	✓	O
	≥2000mm	✓	X
	>3500mm	X	X
Length of section	≤100m	✓	✓
	100m to 500m	✓	✓
	500m to 1200m	✓	✓
	>1200m	O	✓

Note: ✓ = particularly suitable, o = conditionally suitable, X = not suitable.

6.2.4.3 Cross Profiles

The near shore approach from KP 0 to KP 3.7 cross profile indicates that:

- at 2m trench depths, the trench walls will consist of a mixture of silty sand and high shear strength clay with calcareous chalk outcrops;
- at 3m trench depths the trench walls will consist of high shear strength clay and boulder clay with calcareous chalk outcrops; and
- at 3m+ trench depths the near shore will provide a stable wall below the sand layer that is susceptible to sediment movement.

Therefore a minimum of 4.8m dredge depth is recommended to account for beach erosion.

From KP 3.7 to KP 9.2 the sand layer becomes dominant in the upper layers increasing to depths of up to 9m. This section may have to be pre-dredged to allow access by the installation vessel due to a small water depth decrease and a plateau profile. Dredging to a depth of 4.8m over this section is recommended.

Beyond KP 9.2, the boulder clay becomes more prevalent for the remainder of the route so dredging to depths of 2m should be sufficient.

The minimum dredging depths to attain a solid seabed, which is less susceptible to mobility, are shown in table 6.6 below:

Table 6.6: Minimum Dredging Depths

KP Range (km)	Trench Depth (m)
0 to 9.2	4.8
9.2 to 16.25	2

Deeper depths may be required if future studies indicate changes to the future landscape of the near shore seabed.

6.2.4.4 Pipeline Installation

Typical shore approach pipeline installation methods include:

- pull ashore from a vessel based winch using a return sheave anchored above the tie in point at the beach;
- pull offshore from an onshore stringing site to a lay down point offshore;
- pull ashore from vessel positioned offshore to an onshore location; and
- HDD installation with pull ashore from a vessel positioned offshore.

6.2.4.5 Pull-in Loads

The required shore pull loads have been determined for the near shore section of the pipeline based on the following assumptions:

- pull-ashore through a cofferdam / open-cut trench;
- the pipeline is empty during pull in;
- seabed axial friction is assumed to be 1.2;
- tow head weight is considered as a single pipe joint;
- pull-in of a short 0.1km dry section of pipe has been considered with an average ground slope angle equal to zero; and
- steel wall thickness and concrete weight coating are assumed constant.

The weight of the offshore pipeline resting on the seabed was considered for two different lengths, 1.2km and 0.8km; a short 0.1km dry section was also considered.

The forces incurred during a typical shore pull-in from a vessel positioned offshore are shown in Figure 6.2 below:

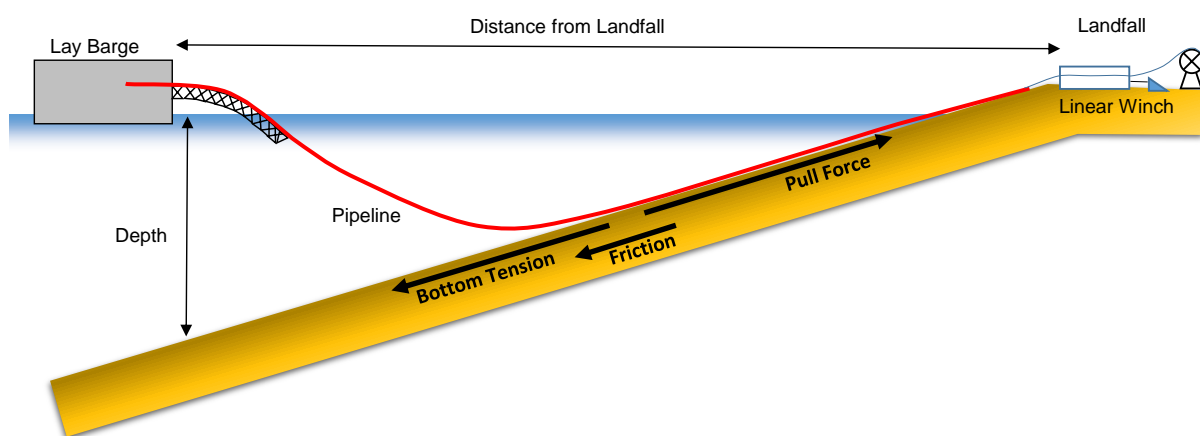


Figure 6.2: Shore Pull Schematic

The pull load, accounting for back tension and the average angle of slope of the seabed, was estimated using the following equation resulting in the figures in Table 6.7 below:

$$P=W \times L \times (\mu + \sin \theta) + F_b$$

Where:

- P = pull in load
- W = empty submerged weight of the pipe (N/m)
- L = length of pipe on seabed being pulled ashore (m)
- μ = axial seabed friction coefficient
- θ = average slope angle
- F_b = lay barge bottom tension.

Table 6.7: Pull in Loads

Offshore Pipeline Length	Buoyancy Tank lift capacity	No. of Flotation Tanks (1)	Onshore Pull-in Load (2)	Offshore Pull-in Load	F _b	Total Pull-in Load
(km)	(Tonne)	(Tonne)	(Tonne)	(Tonne)	(Tonne)	(Tonne)
1.2	-	-	39.23	786.00	13.03	838.26
1.2	4.0	50	39.23	544.67	9.03	592.90
1.2	5.0	50	39.23	484.34	8.03	531.60
0.8	-	-	39.23	525.45	13.03	577.71
0.8	4.0	34	39.23	364.12	9.03	412.38
0.8	5.0	34	39.23	323.78	8.03	371.04

Notes:

1. Assuming buoyancy tank every two pipe joints (24m).
2. Based on a short 0.1km dry section of pipeline lay flat on the ground.

The results show that:

- a minimum pull capacity of 372 tonnes is required for the shore pull considering a pipeline length of 0.8km, using a shallow water barge, with 5 tonne buoyancy tanks every 24m; and
- A minimum pull capacity of 535 tonnes is required for the shore pull considering a pipeline length of 1.2km with buoyancy tanks every 24m.

6.2.4.6 Winch Spread/Anchor

A high capacity winch will be required with a typical footing of 12m by 2m per winch. The winch spread will be located above high tide with fixed piled anchorage to accommodate high loads and soil conditions at the site. The target point for the pipeline pull-in head is KP 0 at the beach, UTM Zone 31, 289 478.02E 5 991 627.67N; a dry location for tie-in from the onshore pipe to the offshore pipeline.

6.2.5 Crossings

Please refer to Section 6.1.3.6 Pipeline and Cable Crossings for a description of the crossing.

6.3 Mechanical Integrity

6.3.1 Design Criteria

Nominal pipe thickness has been selected using standard pipe sizes. Minimum wall thicknesses have been calculated for stress based design, to satisfy pressure containment, collapse, propagation buckling and local buckling. Reeling criteria has not been considered since reel-lay is not achievable given the pipeline diameter.

The wall thickness of finished bends has been selected to provide the minimum required wall thickness at any location of the bend.

The subsea flanges have been rated for sufficient pressure ratings of the pipeline system. Pipeline wall thicknesses have been selected to withstand the MAOP. The maximum expected CO₂ fluid temperature in

the offshore pipeline has been determined and temperature profiles have been used in pipeline design calculations.

The minimum pressure for normal operation is 90barg and the MAOP is 182barg at low tide. A safety margin of 110% of the MAOP has been allowed for the maximum pressure which the system can experience during a short time, limited by safety devices; this gives a MIP of 200barg.

A High Integrity Pressure Protection System (HIPPS) will be provided to protect the offshore pipeline from CO₂ booster pump pressures at the Barmston pumping station. ESDVs will be located at the pumping station at Barmston for shutdown and isolation of the offshore pipeline at the wellhead platform.

6.3.1.1 Strength

The design factors used are compliant with *PD 8010-2 2004: Code of Practice for Pipelines: Subsea Pipelines* now withdrawn and replaced by [PD 8010-2:2015](#).

Hoop, longitudinal and combined stresses, for fully restrained and straight pipe, has been calculated. The thin wall formula has been used to determine hoop stress within the pipe.

Stress check calculations have been carried out using the Von Mises Criterion for the full design temperature and pressure range.

The pipeline is compliant with the code for the process design conditions and all integrity checks have been performed using stress-based design checks.

Expansion analysis has been performed using strain-based equations to determine the location of the virtual anchor points from the wellhead platform end of the pipeline and calculate the magnitude of pipeline end expansion. The calculations account for MAOP and thermal loads in the pipeline and the cumulative resistance force between the pipeline and seabed. Leak test conditions are also assessed.

The end expansion is accounted for in the tie in spool design which is designed to be flexible enough to absorb end expansion loads and prevent excess transfer of loads into the riser.

AutoPIPE stress software has been used to account for flexibility and stress intensification caused by fittings including bends. Stress based integrity checks have not been performed for the offshore pipeline design but may be considered in future design stages.

Buckling assessment has been performed accounting for nominal wall thickness, ovality and the weight contribution of concrete coating, looking at:

- local buckling;
- propagation buckling; and
- restrained pipe buckling due to axial compressive forces.

Upheaval buckling analysis has been performed for a range of seabed imperfection heights to assess both the integrity of the pipeline and the propensity of the pipe to buckle, see Section 6.3.2 Global Buckling Analysis. Any required mitigation methods have been identified.

All selected materials have an adequate low temperature toughness to prevent brittle fracture during normal operation and in blowdown conditions. Note that blowdown is a type of venting which releases natural gas from a pipeline to atmosphere.

A design stage fatigue assessment for the pipeline system has been performed based on a daily allowable pressure (stress) range during the pipeline design life, and an allowable frequency for a depressurisation down to 90barg from MAOP. This provides a design life in excess of 40 years. A detailed fatigue assessment can be performed once the number of cycles for operation, shutdown and start-up are known.

6.3.2 Global Buckling Analysis

Global buckling is one of the most common problems threatening the safe operation of subsea pipelines and can come in the form of upheaval or lateral buckling, triggered by the increasing of temperature and inner pressure.

- Upheaval buckling is the vertical deformation of a, normally buried, pipeline.
- Lateral buckling is the vertical deformation of a, normally surface laid, pipeline.

Preliminary lateral and upheaval buckling analyses were performed to check the integrity of the pipe, to investigate the likelihood of buckling and to determine the required pipeline coating to mitigate upheaval buckling. Results for the minimum and maximum concrete coating are presented in Table 6.8 below:

Table 6.8: Preliminary Concrete Coating Thickness and Properties

Concrete Coating	Thickness (mm)	Density (kg/m ³)
Minimum	95	3450
Maximum	160	3450

6.3.2.1 Pipeline Upheaval Buckling

The pipeline will be buried in some areas, so the susceptibility for upheaval buckling has been analysed with imperfection heights ranging from 0.05m to 0.5m.

For the landfall, the maximum allowable imperfection height during operation is 0.1m; there is a lower allowable stress in this section and a large concrete weight coating. No backfill is required to mitigate upheaval buckling in this section. If using the same SMYS allowance as for the offshore pipeline (96% of SMYS) the landfall pipeline will be overstressed for imperfection heights greater than 0.40m.

For offshore pipeline with a concrete weight coating of 95mm, the maximum allowable imperfection height is 0.1m during hydrotest and 0.3m during operation. No backfill is required to mitigate upheaval buckling in this section.

For offshore pipeline with a concrete weight coating of 115mm, the maximum allowable imperfection height is 0.1m during hydrotest and 0.2m during operation. No backfill is required to mitigate upheaval buckling in this section.

For offshore pipeline with a concrete weight coating of 160mm, the maximum allowable imperfection height at this section is 0.1m during operation because of the large concrete weight coating. No backfill is required to mitigate upheaval buckling in this section.

Sensitivity analyses show that the offshore pipeline, with a wall thickness of 25.4mm and a concrete weight coating of 145mm, has a maximum allowable imperfection height of 0.3m during hydrotest and 0.3m during operation. No backfill is required to mitigate upheaval buckling in this section.

These allowable imperfection heights are considered low. The stress for the pipeline laid on the seabed has been assessed in detail during using on-bottom roughness test.

6.3.2.2 Offshore Lateral Buckling

The landfall is not susceptible to lateral buckling.

The offshore pipeline is not susceptible to lateral buckling during hydrotest, but is susceptible to lateral buckling under design conditions with a concrete weight coating of 95mm and low lateral soil frictions.

The offshore pipeline is not susceptible to lateral buckling when considering maximum operating temperature instead of design temperature.

6.3.3 Stability Analysis

The required concrete weight coating to ensure a stable pipeline has been calculated (Table 6.9), with consideration given to both lateral and vertical stability.

Table 6.9: Selected Concrete Thickness

Section	KP from	KP to	Water Depth Range (m)	Outside Diameter (mm)	Wall Thickness (mm)	Thickness CWC (mm)	Burial Condition
Landfall	0	1.3	0 – 7.5	610	22.23	95 ⁱ	Pre-lay dredged and backfill
Shore approach	1.3	16.25	5.7 – 36.0	610	19.05	95 ⁱ	Pre-lay dredged and backfill
Shallow depth	16.25	27.25 ^{iv}	36.0 – 49.0	610	19.05	115	Post-lay trenched
Flat seabed	27.25	46.49	49.0 – 53.4	610	19.05	160 ⁱⁱ	Exposed
Sand waves	46.49	88.349	49.1 – 61.4	610	25.4 ⁱⁱⁱ	145 ^{ii iii}	Pre-swept

KP: Kilometre Point; the offshore pipeline KPs are defined such that KP '0' is defined at the tie-in point on the beach and continues to the lay down target box at the wellhead platform.

- i. Can be reduced to 80mm from KP0 to KP8.6 if pull-in loads are required to be reduced further.
- ii. For a fully buried pipe (for protection/mitigation against excessive marine growth) concrete requirements would reduce to 75mm from KP27.25 to KP88.349.
- iii. Wall thickness is increased from 19.05mm to 25.4mm as recommended by the on-bottom roughness analysis and CWC reduces from 160mm to 145mm CWC.
- iv. Survey information indicates intensive trawl scarring up to KP 38.1, further fishing studies are recommended to determine if post-lay trench requires extension.

An on-bottom stability analysis has also considered marine growth, environmental and soil conditions.

Pre-lay and post-lay trenching has been considered in areas where the excessive concrete coating is required to ensure pipeline stability.

The allowable span lengths for free-spanning pipe have been assessed for both inline and cross-flow vortex induced vibration. Free spans along the route have been determined in an on-bottom roughness analysis and static analyses have been performed with the maximum allowable equivalent stresses.

6.3.4 Riser and Spool-piece Analysis

A preliminary design for riser and tie in spools has been performed which takes into account pipeline end expansion for operation and leak test conditions, upper bound and lower bound soil sensitivities, mattress loads and environmental loading.

Vortex induced vibration of the riser has been assessed in addition to the spool stability and equivalent stress checks.

Loads on riser supports, guides and flanges have been extracted for support design and for flange capacity checks to be performed.

The design is considered preliminary as wellhead platform layout and orientations are ongoing. Installation loads, platform movements and seismic loads will be considered in the next design phase.

6.3.5 Structure Outline Design

6.3.5.1 Fabrication and Installation

A high level philosophy for planning, alignment and co-ordination of the engineering, procurement, installation and construction activities has been developed.

6.3.5.2 Testing

Technical requirements related to the flooding, cleaning, gauging, strength testing, leak testing and pre-commissioning of the offshore pipeline facilities have been considered in the specification for offshore pipeline flooding, cleaning, gauging, testing and pre-commissioning.

6.3.6 Material Selection and Corrosion Reports

Corrosion mechanisms and mitigation methods have been determined and include an assessment of:

- internal corrosion:
 - CO₂ corrosion
 - dense phase CO₂ corrosion
 - oxygen corrosion
 - hydrogen sulphide corrosion/cracking
 - hydrates presence of impurities; and

- external corrosion:
 - differential corrosion
 - microbiologically influenced corrosion
 - stress corrosion cracking
 - galvanic attack.

6.3.6.1 *Internal Corrosion*

No internal corrosion is expected for the offshore pipeline as the pipeline is operated dry (free of water) and is protected by a high integrity, water monitoring and shut down protection system.

All water introduced after laying for pre-commissioning will be treated and inhibited.

6.3.6.2 *External Corrosion*

The primary corrosion control strategy will be the use of high quality factory and field applied coatings with the CP system as the secondary but mandatory, protection system. The design life of permanent CP systems will be 40 years.

The external coating of the line pipe will be factory fusion bonded epoxy with compatible fusion bonded epoxy field joint coating and the CP will be indium activated aluminium alloy bracelet anodes (Aluminium-Zinc-Indium).

6.3.7 *Cathodic Protection Requirements*

The CP provided by bracelet sacrificial anodes is designed in accordance with *BS EN ISO 15589-2:2014*.

It will be isolated from the onshore impressed current system using an isolation joint.

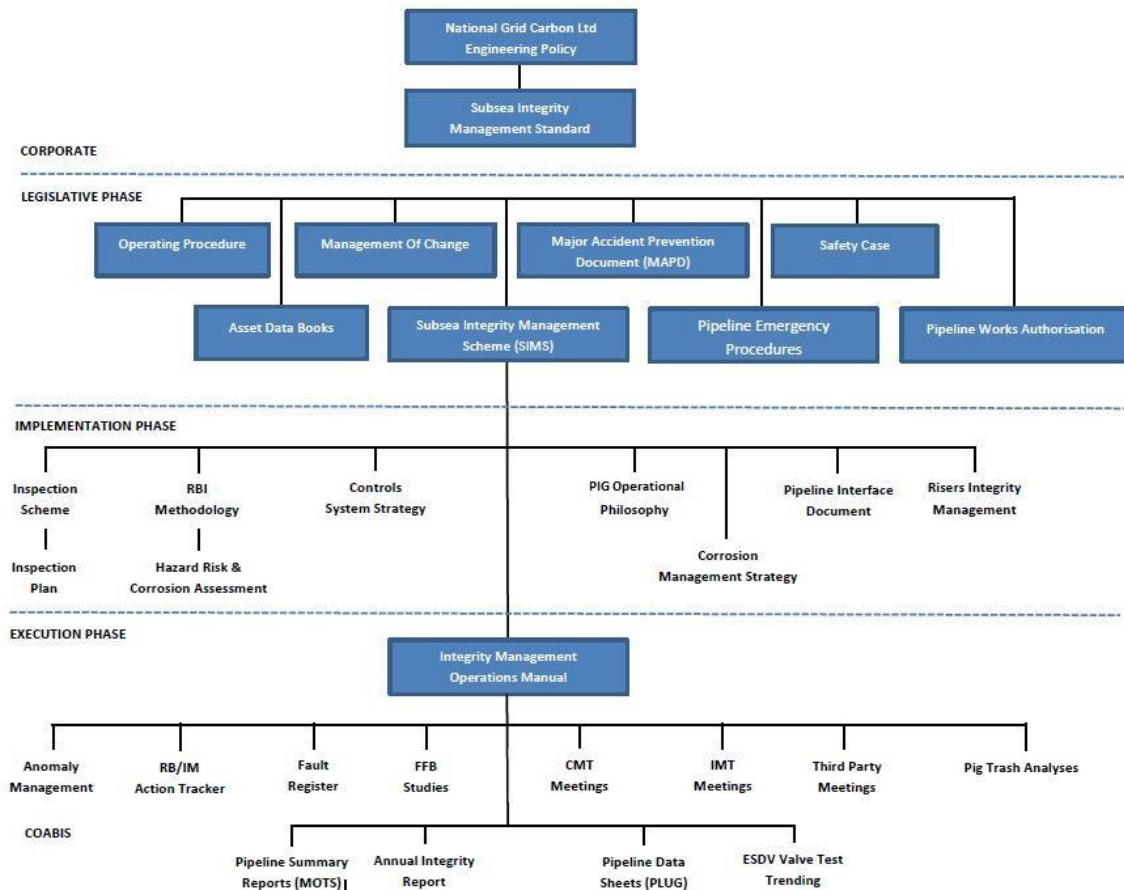
The design life of the CP system will be 40 years.

7 Operation Maintenance and Integrity Management

An integrated Inspection, Maintenance and Repair (IMR) regime is required which covers the entire pipeline system and manages IMR requirements across the following interface locations:

- PIG launcher / Receivers and by-pass facilities at Drax, Camblesforth and Barmston pumping station (onshore);
- the onshore pipeline (including Block Valves);
- the offshore pipeline including the riser; and
- PIG receiver and bypass facilities at the wellhead platform (offshore, above water).

Figure 7.1: Integrity Management Flowchart



7.1 Inspection

To ensure a high level of safety and reliability in operation of the transportation of CO₂, it would be essential that a system of inspection and maintenance exists for associated assets.

All the plant and equipment forming part of the T&S system would be either:

- duplicated or ranged equipment such as CO₂ pipeline pumps and injection wells;
- provided with bypasses; or
- or provided with facilities for on-line inspection (as with pipeline PIG operation).

The pipeline system will be designed to allow for inspection, maintenance and repair regimes typical for UK cross-country systems and North Sea pipeline systems as appropriate.

7.2 PIG Operations

The onshore and offshore pipelines will be inspected using intelligently PIGs.

The pipeline system provides bypasses to allow for on-line internal pipeline inspection facilitated by the PIG launching facilities at Drax, Camblesforth and Barmston pumping station and PIG receiving facilities also at Barmston pumping station and on the wellhead platform. The launching/receiving PIG trap arrangements include pipework and valves with local and remote control and monitoring systems to enable on-going operations and maintenance of the pipeline system.

The main focus of internal pipeline monitoring would be to determine the condition of the pipeline system trap-to-trap, onshore to offshore, and to provide an accurate description of all significant defects. Each discovered defect can then be considered, evaluated and, where necessary, repaired. The internal pipeline inspection would be carried out primarily to identify metal loss due to possible but will be capable of identifying other features and defects in the pipeline.

During detailed design of the pipeline system the geometric requirements for the deployment of intelligent PIGs, will be fully addressed.

7.3 Maintenance

The target for the pipeline system, both onshore and offshore, is to operate for the specified design life with minimal planned maintenance. However, it is understood some components located within the pipeline e.g. Block Valves, the PIG launching / receiving facilities at Drax, Camblesforth, Barmston and offshore will require maintenance during design life. These components would be maintained and tested, as a minimum, in accordance with supplier and manufacturers' recommended requirements.

Any planned maintenance of the pipeline system, which may interrupt the flow of CO₂ will ideally be performed during planned shutdown of the power station and/or the wellhead platform. An integrated maintenance programme for the full chain would be developed to ensure timing of planned maintenance of the pipeline system does not interrupt flow within the pipeline.

Maintenance will be undertaken by dedicated maintenance teams, who would retain the specialised knowledge and history of the equipment, augmented by long-term maintenance agreements with specialist maintenance contractors.

7.4 Repair

Repair to the pipeline system will only be necessary if there is an unexpected event that results in damage. It is recommended that:

- general, but high level, repair procedures are developed for all items of equipment; and
- specific repair procedures are developed as, and when, required.

A permit to work must be obtained prior to any repair and all local operating procedures must be followed. It is recommended that both HAZID and Hazard and Operability study (HAZOP) assessments are carried out for significant repair work.

Prior to any intervention a period of planning and procedural development will normally be required. Depending on the extent of damage incurred, the planning and lead time for repair requiring pipeline shutdown, depressurisation and possible internal conditioning, could be extensive.

7.5 Spares

A list of spares will be based on the repair philosophy. As a minimum, spares will be held according to supplier and manufacturer recommendations and the experience of NGCL with similar equipment. Key spares would be held at the NGCL onshore base.

It is recommended that a cost benefit analysis should be performed for major components to ascertain whether these items need to have sparing provision. In addition, outcomes from reliability analyses should be carried out to identify any additional requirements for sparing equipment.

8 Onshore Pumping Facility Design

A Barmston Pumping Station would be available to maintain the pressure of the dense phase Carbon Dioxide within the pipeline for transportation offshore and to enhance the volumes of Carbon Dioxide that could be transported by the pipeline for offshore storage should other emitters connect into the Onshore Scheme in the future.

8.1 Pump and drive design

8.1.1 Basic Design Scope for Pumps

The basic design of the pumps would be as follows:

- multi-stage centrifugal pumps as amended by section 7 of this specification. Each pump would include:
 - double mechanical seals;
 - Plan 53B pressurised barrier fluid seal system;
 - 2-pole, air cooled, 6.6kV electric motor matched to the Variable speed drive (VSD);
 - dedicated lubrication system; and
 - condition monitoring instrumentation for pump and motor;
- a single structural steel skid for mounting each pump and its drive motor;
- VSD matched to the electric motor;
- a stand-alone mechanical seal top-up skid to serve four pumps;
- inspection and factory acceptance testing at Supplier works;
- on-skid interconnecting piping, pipe fittings, pipe supports, isolation valves, vents and drains, all terminating at skid edge flanges;
- on skid instrumentation cables wired to skid edge terminal boxes; and
- skid earthing and bonding system.

8.1.2 CO₂ Service

The pumps would be specifically designed for dense phase CO₂ service. Appropriate calculated corrections would be made to the pump performance, efficiency and power curves to account for the CO₂ compressibility and other properties. Supplier would confirm pump CO₂ discharge temperature for the cases given on the data sheet. It is anticipated that the pumps will start-up at low flow against closed discharge check valve would not need to start up in recycle. Each pump will have a recycle connection from the discharge pipework to the suction manifold with air cooler and control valve. This recycle will be used only for pump testing / proving during commissioning and after major pump maintenance. Pumps will operate on suction pressure control by the plant Integrated Control and Safety System (ICSS).

Pump materials would be selected with due consideration, especially for flange bolting and seal chambers, of the low temperatures that would occur in the event of a CO₂ leak.

8.1.3 Mechanical Seals

The pumps are required to operate at varying speeds, varying suction pressures, varying discharge pressures, varying temperatures, varying CO₂ compositions and start / stop several times per day. Double mechanical seals, with pressurised barrier fluid systems, have been selected to give reliable service and long seal life. Barrier fluid would be low viscosity mineral oil which does not contain additives that are detrimental to seal faces.

Pumping station is unmanned, so high reliability and long maintenance intervals would be required.

Each seal would have its own dedicated seal system, mounted on the skid, including accumulator, air cooler and instrumentation. Accumulator would be sized for at least 5 days of operation at normal leakage rates. Each system 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. Each system would include appropriate instrumentation to permit remote, monitoring and trending of barrier fluid consumption as an indication of seal condition. Transmitters would be used, not switches, and pump would trip on low seal system pressure.

The seal top-up skid would be compressed air and / or electrically powered. The skid would be sized to serve four of the CO₂ booster pumps to be installed at Barmston. Reservoir would be sized for at least 2 months at normal leakage rates. Filters and pumps would have 100% installed spares which can be isolated and maintained without interrupting the supply of barrier fluid to the CO₂ booster pumps. Reservoir would be fitted with an electric heater if required. Heater would be removable without having to drain any liquid from the reservoir. Skid would be fully instrumented with transmitters for remote operation / monitoring. Skid would include suitable connections, isolations and valving to allow connection and barrier fluid supply from / to the other seal top-up skid to be installed at Barmston. These would only be used in the event of one of the skids being out of service for a prolonged period.

8.1.4 Pump Turndown

Pumps would be selected to provide the required high turndown stated on the data sheets. In order to achieve this, it is anticipated that; the pumps would be direct driven by 2-pole electric motors, rated point would be to the right of Best Efficiency Point (BEP); VSD would be used to increase as well as decrease frequency relative to 50 Hertz supply.

8.1.5 Lubrication

The bearing lubrication would ensure long bearing life and at least 6 months between oil changes. Bearing/lube oil temperatures would be monitored by transmitters. Vibration would also be monitored for bearing condition monitoring.

Standby CO₂ booster pumps would be available for instant starting, so requirement for pre-lubrication is not acceptable. Oil heaters would be provided as required. Lube-oil cooling would be by air only; there is no cooling water supply at the pumping station.

All lube-oil cooling pipework would be stainless steel. If a pressurised lube oil system is required, this 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 pressure control valve (with block and bypass valves). System would have two positive displacement pumps, the main one shaft driven and the standby one motor driven. The shaft driven pump would be designed to provide sufficient lubrication at all pump operating speeds and during pump rundown in the event of a power failure.

8.1.6 Pump Type

The CO₂ booster pumps may be a “between bearings” type or “surface” (horizontally mounted electro-submersible derived) type multi-stage centrifugal pumps or vertical type canned pumps. Reliability, efficiency across the required wide operating envelope, ease of maintenance, operating expenditure and capital expenditure would be important considerations.

8.1.7 Monitoring

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

8.1.8 Pump Skids

Each pump and the associated driver, pressurised lube oil system (if required) and seal systems (excluding seal top-up skid) would be mounted on a single structural steel skid. Skid dimensions would be minimised (without impacting ease of operation and maintenance) such as to allow road transportation. The only item that may overhang the edge of the skid is the main motor junction box.

Each pump skid will be installed in its own dedicated unheated, ventilated pump house. The only equipment within the pump houses will be that associated with that pump. Noise emissions from the pumping station are restricted, so pump skids would be designed to be low noise without requiring acoustic enclosures.

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

8.2 Control and instrumentation design

8.2.1 Control

The Barmston Pumping Facility is provided with dedicated manual and actuated isolation valves, which are fully defined in KKD K31 (Transport and Storage Piping and Instrumentation Diagrams).

The onshore transport system battery limits are provided with motor operated valve isolation on the inlet and the outlet of the facility; the operation of the outlet valve is subject to the operation and control system while the inlet is locally controlled. The actuators are electrical motorised powered from the 400V 3phase 50Hz supply. A High Integrity Pressure Protection System (HIPPS) is employed on the common discharge to protect the offshore pipeline from overpressure in a blocked in scenario.

ESDVs which can be used as part of the valve isolation are also available; actuators are pneumatically operated and are tripped from the ESD system set to close in the event of power failure.

Pumps are installed in parallel with independent positive isolation of the inlet and outlet of each pump being provided by hand operated lock open valves, to allow maintenance of one pump whilst another remains operational. ESDVs which can be used as part of the valve isolation are also available, actuators are pneumatic operated and are tripped from the ESD system to fail close.

Manual isolation valves on the inlet and outlet lines are provided for depressurisation/drainage provision to enable cleaning or maintenance of the filter body and element.

Locally controlled motor operated isolation valves on the inlet lines are provided on all the filters that are spared to permit maintenance of the blocked filter while the system is online. The process logic will include a soft interlock to ensure stand-by filter inlet valve is opened before duty valve filter inlet is closed. The safety of their manual operation would be via the permit to work system.

A filter By-pass line is available for venting onshore pipeline via the Barmston vent stack.

Pressure transmitter internal materials in contact with the process fluid would be suitable for the process fluid and conditions specified on instrument data sheets, supplied with 2 or 5 valve manifolds to suit static or differential pressure measurement. Electronics would be mounted in a sealed section of the transmitter housing.

8.2.1.1 Process Control System

The Process Control System (PCS) would be accessible through the Human Machine Interfaces (HMIs) in the Local Control Room (LCR) and at the NGCL Control Centre. The PCS facility will include the ability to:

- adjust controller set points, and to set in manual or auto control;
- monitor and control utilities;
- monitor and control the status of all sequence and shutdown valves;
- start / stop and sequence electrical drives and perform duty/standby changeover;
- monitor the power distribution system, UPS and storage batteries;
- accept and reset (process system) alarms;
- monitor the status of the ESD system and effect manual shutdown;
- monitor the status of the F&G sensors;
- monitor and control the HVAC system;
- display diagnostic functions from field devices;
- interface with third party controllers to provide a common operator interface; and
- switch control between remote NGCL control centre and local control at the facility and provide data hand off of information related to the facilities.

8.2.2 Monitoring

Non-invasive temperature measurement is preferred; thermowells would be used by exception.

Surface mounted Resistance Temperature Detector (RTD) type measurement temperature transmitters would be utilised with a clamp mounted or welded thermowell sensor.

Where pipeline intrusion is possible, head mounted RTD type measurement transmitters in flanged thermowells may be utilised.

All process applications have duplex sensors, spare element terminated in the sensor head, of platinum wire wound, mineral insulated and suitable for 3-wire or 4-wire connection.

The primary method of flow measurement utilised is that of differential pressure measurement principle by the use of orifice plates complying with *BS EN ISO 5167 UK Standard - Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*. Materials in contact with the process fluid would be suitable for the process fluid and conditions. The orifice carrier will be 'Senior' type to allow for the removal of orifice plates without the need to vent parts of the system.

8.2.3 Control

The ICSS will be configured to operate in both manned and unmanned modes. When in unmanned mode, the Barmston Pumping Facility will be remotely operated and controlled via the SCADA system. The Barmston Pumping Facility ICSS will control and safely initiate shutdown of all plant systems without intervention from the NGCL Control Centre.

When manned, the Barmston Pumping Facility would be available to allow a local operator to control the facility via its ICSS HMI. The personnel at Barmston would also be able to manually shut the facility down via the emergency pushbuttons located at the Emergency Shut Down (ESD) matrix panel located in the Barmston LCR.

For ICSS maintenance and configuration purposes, engineering functions (with restricted access) will be provided on the HMI console located in the Barmston LCR.

8.2.4 Measurement and Protection

Protection relays in both the MV and LV systems would be of the electronic, microprocessor-based, multi-functional type that is commonly referred to as being Intelligent Electronic Devices (IEDs).

Liquid filled MV transformers would incorporate thermal protection relays and where equipped with a conservator, a Buchholz relay would provide alarm and trip signal for gas accumulation and liquid surges.

Cast resin LV transformers would have winding temperature alarm and high temperature trip protection.

Additionally, the circuit breaker supplying a transformer would have a multi-functional transformer protection relay to provide:

- Restricted Earth Fault;

- Unrestricted Earth Fault;
- Phase Differential Protection; and
- Overcurrent and High-set Overcurrent.

Each LV motor would have a motor management device, an intelligent electronic device (IED), with integral LCD display located at the motor starter.

Motors supplied from a circuit breaker would have a multi-functional, motor protection relay. The protection functions would vary according to the size and supply voltage of the motor.

Motors supplied from a MCCB / contactor would include earth fault protection (30kW or lower) and thermal (overload) protection / short-circuit protection to suit the rating of the motor.

Differential protection would be provided on all motors rated in excess of 1000kW.

Each outgoing feeder would be provided with a feeder management device, an IED, with integral LCD display.

Cables (including feeders to VSD units) that are protected by a circuit breaker would have a multi-functional protection relay with overcurrent and earth fault protection.

Where differential relays are used the Current Transformers (CTs) would be matched.

Where applicable, bus-transfer schemes would have appropriate logic to provide momentary paralleling facilities and isolate a faulty section (due to a bus-bar short-circuit).

All protective relays would be microprocessor type and be suitable for the following electrical supply characteristics:

- rated frequency: 50Hz;
- CT rated AC current: 1A;
- VT rated AC voltage (3-phase): 110V; and
- rated DC voltage: 110V.

8.2.5 Control and Communication

Each motor would be controllable from a Local Control Unit (LCU) or Unit Control Panel (UCP provided as part of a package) that incorporates a 'Hand-Off-Auto' selector switch as a minimum.

Motor control and status to and from LCUs / UCPs would be hardwired with ESD trips also hardwired through relays located within an Interface Relay Panel (IRP).

Remote control and status signals to and from the ICSS would be transferred over a dual-redundant serial data link.

The remote control mode will be automatic from the PCS at Barmston with data forwarded to the NGCL Supervisory Control and Data Acquisition (SCADA), to facilitate control and monitoring during un-manned operation.

Control circuits would accept an Emergency Shut Down (ESD) trip (de-energised to trip) from the ICSS using 24V DC interface relays within an Interposing Relay Panel (IRP) with the ESD being capable of tripping either an individual drive or a group of drives / feeders (as determined using the shut-down system's cause & effect diagrams).

Status signals (RUNNING, STOPPED, TRIPPED, LOAD, AVAILABLE) would be available at the UCP by hardwired signals and at the ICSS using the dual redundant serial data links.

A manual trip facility would be provided at the switchgear for every circuit and remain operable under all circumstances.

A test facility to permit testing of each motor control circuit (motor isolated) would be provided.

Monitoring and metering information from each Intelligent Electronic Device (IED) would include at least the following and be transferrable to the ICSS:

- Amps;
- Volts;
- kW;
- kVAr;
- VA;
- Power Factor; and
- Events Log.

8.3 Electrical design (high and low voltage)

8.3.1 General Design Requirements

8.3.1.1 General

The electrical system design requirements would be governed by the following principles:

- personnel safety;
- plant and equipment integrity;
- environmental conditions of the site;
- reliability of supply depending on the importance of service;
- reduction of space and cost;
- ease of management and maintenance / operation;
- commonality of electrical equipment for operator familiarity;
- adequate flexibility for future installations and inter-changeability;
- standardisation and availability of components;
- reduced risk of fire or explosion;
- fail safe features for safety related controls;
- maximising project value;
- simplicity of operation; and

- automatic protection of all electrical equipment through a selective relaying scheme.

The design of all electrical installations would provide a safe and reliable supply of electrical power at all times with an availability target in excess of 99.8%. Where an equipment failure would result in loss of the production facility duplicated units on a duty / standby basis would be provided. Safe conditions should be ensured under all operating conditions, including those associated with start-up and shut-down of the plant and throughout any plant shut-down period.

The design of the electrical system and selection of equipment would ensure that all operating and maintenance activities can be performed safely and conveniently with a minimum undisturbed operating period of 1 year. Maintenance would always be achievable without any need to shut-down the plant.

The insulating and dielectric materials used in all electrical equipment would be non-toxic and not contain any compounds that will persist and/or may be hazardous to the environment.

8.3.1.2 *Design Life*

Electrical equipment would have a minimum design life of 40 years under the specified service conditions. However, batteries would be either valve-regulated, partial recombination nickel-cadmium cells (IEC 62259, 20 year expected life) or valve-regulated, recombination lead-acid (VRLA) (IEC 60896, 10 year expected life). All equipment would be brand new and of recent manufacture.

8.3.1.3 *Electromagnetic Compatibility*

As mandated under EC laws the electrical equipment provided would have limited EMC emissions and be suitable for operation on an electrical power distribution system.

8.3.1.4 *Site Service Conditions*

Below is a summary of the site service condition which would be used for design of the electrical system and selection of the equipment used.

Temperatures:

Maximum outdoor ambient air temperature	28°C (Onshore)
Minimum outdoor ambient air temperature	-7°C (Onshore)
Maximum sub-station ambient air temperature	45°C
Minimum sub-station ambient air temperature	5°C
Sub-station HVAC design temperature	25°C
Maximum battery room ambient air temperature	40°C
Minimum battery room ambient air temperature	5°C

Altitude:

The height above sea level less than 50m (above MSL)

Humidity:

Maximum outdoor relative humidity (at 28°C) 95%

Maximum sub-station relative humidity 50%

Soil:

Maximum soil temperature (at pipeline burial depth) 15°C

Minimum soil temperature (at pipeline burial depth) 4°C

8.3.1.5 Design Temperatures

The design temperatures for selection of electrical equipment are as follows:

Indoor Equipment with redundant HVAC components	25°C
Transformers	40°C
Motors	40°C
Cables laid in ground (at pipeline burial depth)	15°C
Cables laid on cable trays (above ground)	28°C
Cables laid inside ducts	15°C.

8.3.2 General Engineering and Design Criteria

8.3.2.1 Electrical System

Power for the Barmston Pumping Station will be provided by Northern Powergrid with a single 66kV Grid supply brought to the site and terminated on to a 66kV disconnector provided as part of this project.

The power distribution system at Barmston Pumping Station will comprise of 6.6kV and 400V secondary selective switchgear with radial distribution feeders.

The medium voltage (6.6kV) distribution system will comprise of 3-phase, 50Hz supplies to the eight CO₂ pumps that are driven by suitably rated Variable Speed Drive (VSD) units and the two 6.6/0.42kV transformers that supply the 400V distribution system.

The Low Voltage (400V) system will comprise of three-phase and neutral (TPN) and single-phase (SPN), 50Hz supplies to the connected equipment (motors, heaters, HVAC, process packages, lighting and power sockets).

Supply to items of equipment designated 'critical' (instrumentation and telecoms) will be provided from an Uninterruptable Power Supply (UPS) at 230V AC. Each UPS system would be of a non-redundant design with a by-pass and a battery that's sized to support the load for 8 hours.

Supply to items of electrical protection equipment (and other items located within the sub-station) will be provided from a suitably rated Uninterruptable Power Supply (UPS) at 110V DC. The system would have dual-redundant rectifiers and two half-time rated batteries that are sized to support the load for 8 hours for switchgear tripping and protection supplies.

8.3.2.2 Voltage Levels, Frequency and Neutrals

All AC systems would operate at a frequency of 50Hz and unless stated otherwise, be designed for voltage variations of $\pm 10\%$ (as per IEC 60038 Series I) and frequency variations of $\pm 5\%$ of nominal.

Every item of electrical equipment would operate satisfactorily at both the steady-state and transient voltages / frequencies shown in Section 7.7.2.3 (System Variations).

System voltages at Barmston and AGIs would be as follows:

Table 8.1: Electrical Power System

Service	Voltage		Phase	Frequency
	DC	AC		
MV Electrical Supply	-	6.6kV	Three	50Hz
VSDs for motors of 1200kW and greater	-	6.6kV	Three	50Hz
Motors above 132kW and up to 1200kW (DOL)	-	6.6kV	Three	50Hz
Motors above 0.37kW and up to 132kW (DOL)	-	400V	Three	50Hz
Motors of fractional horse power (up to 0.37kW)	-	230V	Single	50Hz
Trace Heating and Lighting / Small Power	-	230V	Single	50Hz
Anti-condensation heaters	-	230V	Single	50Hz
Protection	110V	-	-	-
Circuit breaker control	110V	-	-	-
Contactors control (LV Control)	-	110V	Single	50Hz
Instrumentation (UPS)	-	230V	Single	50Hz

Note: Distribution systems would operate at the voltages shown above or as specified elsewhere within the project documentation. The supply voltage selected for each item of equipment would be determined by its loading.

The following methods of system earthing would be provided:

- a) MV System: Star-point low resistance earthed using a Neutral Earthing Resistor (NER).
- b) LV System: Neutral solidly earthed.

- c) AC UPS: Neutral solidly earthed.
- d) DC UPS: Both positive and negative poles are connected to a high resistance divider creating a mid-point for the DC voltage. The fault detection circuit (earth fault monitoring / alarm unit) is located between this mid-point and earth.
Telecommunications equipment may require to be earthed differently to suit manufacturer's recommendations.

8.3.2.3 System Variations

The following variations for voltage and frequency apply:

- steady state voltage variations at equipment terminals would not exceed $\pm 10\%$;
- steady state voltage and frequency variations at UPS output terminals would not exceed $\pm 1\%$;
- transient state voltage variations at switchgear would not exceed $+20\%$ and -10% ; and
- transient state frequency variations at switchgear would not exceed $\pm 5\%$ (recovery time would not exceed 5 seconds).

8.3.2.4 Voltage Drop

The voltage drop (at the full load current) on feeder cables would not exceed:

Transformer to switchboard:	1%
LV feeders to distribution boards:	2%
Lighting final circuits:	2%
Socket outlet final circuits:	2%
Battery to distribution board:	1%
UPS / VSD feeder:	2%
Motor feeder (running):	4%
Motor feeder (starting):	14%

The maximum voltage drop at the terminals of a running induction motor (at Full Load Current) would be 5% and whilst starting not more than 15%.

8.3.2.5 Hazardous Area Classification

It has been determined by HSE that a pinhole leak in the CO₂ booster pump seals or piping may create a flammable mist and each pump package enclosure within the Pump House and the Seal Oil Skid building have therefore, been classified as Zone 2 areas (subject to the ventilation arrangements provided).

Electrical equipment located within one of these potentially hazardous areas would be classified in accordance with IEC 60079 and, unless specified otherwise, would be suitable for use in Gas Group IIB with a Temperature Class of T3.

Within a battery room, electrical equipment would be non-certified as mechanical ventilation will ensure sufficient air changes are made to dilute any hydrogen gas produced during cell recharge to a concentration below that which may result in a potentially explosive mixture.

Electrical apparatus for use in hazardous areas would be compliant with the requirements of the ATEX Directive (EU directives to protect employees from explosion risk in areas with an explosive atmosphere).

The Area Classification Code for Installations handling flammable fluids would be as follows:

- Zone 0: That part of a designated hazardous area in which a flammable atmosphere is continuously present or present for prolonged periods;
- Zone 1: That part of a designated hazardous area in which a flammable atmosphere is likely to occur during normal operation;
- Zone 2: That part of a designated hazardous area in which a flammable atmosphere is not likely to occur in normal operation or, if it does occur it will exist only for a short period.

Non-classified (standard) items of electrical equipment (switchgear, distribution boards, DC control / converters, AC UPS and DC systems, motor starters, voltage regulation, power factor correction and batteries) would all be located within non-hazardous areas.

Electrical equipment which is installed within a potentially hazardous area would be of the correct type for the Zone and type of hazard present and would be selected in accordance with BS EN 60079 (IEC 60079).

The following would be used in the selection process:

Zone 0 Hazardous Areas

Electrical equipment would not be installed within a Zone 0 area.

Zone 1 Hazardous Areas

Motors installed in a Zone 1 area would be:

- LV Motors: Ex de; and
- MV Motors: Ex de.

All inherently non-sparking equipment such as junction boxes and terminal boxes would be Ex e (as a minimum). However, inherently sparking equipment (distribution boards, local control stations, luminaires and socket outlets would be Ex d or utilise a combination of the protection methods mentioned above).

Zone 2 Hazardous Areas

Motors installed in a Zone 2 area would be:

- LV Motors: Ex de / Ex nA; and
- MV Motors: Ex de.

All inherently non-sparking equipment such as junction boxes and terminal boxes would be Ex e (as a minimum). However, all inherently sparking equipment would be Ex d or Ex de (as required for Zone 1 areas).

Non-Hazardous Areas

Electrical equipment installed indoors and/or within designated non-hazardous areas may be standard industrial, weatherproof equipment.

However, for commonality of spares and to cater for the possibility that areas will be re-classified at a later date, consideration would be given to installing equipment suitable for Zone 2 areas in the outdoor areas of the plant. This requirement applies especially to motors, local control stations, lighting fittings and power outlets.

Junction boxes would not contain both Ex i and Ex e circuits.

Electrical equipment such as a distribution boards, DC control systems, converters and regulation equipment would, wherever practicable and economic be located within non-hazardous areas.

Where electrical equipment is to be installed within a designated hazardous area its protection would be suitable for the relevant Zone in accordance with IEC 60079 or an equivalent International standard.

8.3.2.6 Ingress Protection

The assessment of Ingress Protection (IP) rating required for equipment subject to an onshore plant environment would be based on the operational layout and the planned maintenance routine. An operational minimum for all electrical equipment located outdoors would be IP56 (motors IP55).

Equipment located indoors (switchboards, MCCs, control and indication panels) would be at least IP42 and with the doors open the protection afforded would remain IP2X, or better.

Battery cells placed on open type stands or within enclosures would be located in a dedicated battery room with battery cell terminals, inter-cell and inter-tier connector cables double-insulated to provide a fault-free zone to protect against short circuits. Ingress protection would be IP20 or better.

8.3.3 Design Calculations and Studies

8.3.3.1 General

The design intent is for energy consumption to be minimised by specification and selection of highly efficient electrical equipment. During Detail Design and prior to Equipment Procurement a cost / benefit analysis would be carried out to evaluate the use of high efficiency / power factor motors and low-loss power transformers with VSD drives used to control speed, flow and power.

As a minimum, the studies required would include:

- Electrical Load Studies (for equipment requirements);
- Load Flow Calculations;

- Voltage Profile Studies;
- Power Factor Correction Calculations (for equipment requirements);
- Short-circuit Calculations;
- Motor Starting Studies (including motor acceleration);
- Dynamic / Transient Stability Calculations:
 - Largest induction motor stability (after starting);
 - Motor re-acceleration and/or re-starting schemes;
 - Fault disturbance severity and fault clearance times (to include establishing the Critical Clearing Time (CCT)): and
 - Load changes (loads to be connected and disconnected);
- Harmonic current and voltage distortion calculations (to include sizing of harmonic filters);
- Protection Relay Co-ordination Studies; and
- Earthing Calculations.

The above studies would be used to consider the technical implications of including Automatic Changeover Schemes (ATS) and the suitability of the proposed electrical protection and control equipment.

The Power System Study Specialist would detail all of the above in a fully detailed Electrical Power System Study report which would include any further studies considered necessary during the Detail Design stage.

8.3.4 Electrical Equipment

8.3.4.1 General

All the equipment that forms part of the electrical system would be capable of withstanding the dynamic, thermal and electrical stresses caused by a short circuit and comply with the Utility Supply Company requirements in respect to voltage tolerances, fault level, power factor and harmonics at the point of common coupling.

The selection of electrical equipment for the Project would be governed by the criteria detailed above in Section 6 - General Design Requirements.

The design of electrical equipment and systems would ensure that all operating and maintenance activities can be performed safely and conveniently with the potential need for inter-changeability of spare parts considered when selecting materials and equipment.

Where appropriate, the system's design would ensure that under fault conditions the hazardous area rating of the installed equipment will not be compromised.

Provision may be required for alternative supply sources and/or cable routes and spare / stand-by system capacity. However, simultaneous failure of two items of equipment would not be catered for in the system design.

Wherever possible, the electrical installation's design would ensure that sufficient access / space is available for operational and maintenance activities without the need for ladders or scaffolding.

8.3.4.2 Battery Rooms & Cabinets

At the Barmston Pumping Station a dedicated battery room will be provided in the Switchhouse.

Batteries would be disconnected automatically due to low voltage, as specified by the manufacturer. Electrical equipment within the battery rooms will not be hazardous area certified because any hydrogen vented by the batteries will be diluted by the ventilation system.

Each battery bank would use only non-sparking devices with connections double insulated to create a fault-free zone within the room. A certified battery enclosure is not required.

An override switch would be provided on each battery's isolation device to inhibit the ESD contact from tripping the breaker.

The temperature within the battery room would be maintained between 20°C and 25°C.

The battery room would be designed to contain all necessary battery banks and be adequate to allow safe access maintenance and replacement activities. All battery rooms would be provided with at least one equipment access door.

8.3.4.3 Motors

Squirrel cage induction motors would have a fan directly mounted on the motor shaft. Motors would be IP55/56 as noted on the Motor Data sheets.

Unless stated otherwise on the Data Sheet all motors would be suitable for direct-on-line starting.

MV motors would have built-in thermal protection (PT 100, three wire temperature probes), but unless stated otherwise on the Data Sheets, LV motors would not have built-in thermal protection unless they are:

- supplied from a VSD; or
- rated in excess of 75kW.

Differential Protection would be provided on all motors rated 1000kW and above.

Only the CO₂ Booster Pump packages are currently installed in a hazardous area. This will be reviewed during Detail Design and documents reviewed to reflect final classification.

All motors would accelerate their load successfully under the following conditions:

- applied terminal voltage is 80% of nominal; and
- Combined variation of +/-2% rated frequency and +/-5% rated voltage while the motor continues to supply nominal torque.

MV and LV motors would be Class 'F' insulated with their temperature rise limited to Class 'B' (80°C over 40°C) and would have a starting current of no greater than 600% Full Load Current.

The suitability of any motor having a higher starting current than that listed above would be verified during Detailed Design.

MV motors would have provision to fit all equipment necessary for connection of an on-line Condition Monitoring System (CMS).

All auxiliary drives would be connected to the same section of the switchboard and ultimately fed from the same source as the main motor (to ensure optimum availability).

Each motor would have an Emergency Stop (stay-put button) located within 1m. However, where required by the P&ID the motor would also have a Local Control Unit (LCU) with Start and Stop buttons and selector switch for 'Local-Off-Remote'.

Motors that will be driven by a VSD would be de-rated appropriately for use with the VSD. Where appropriate, the motor and VSD would be certified as a 'system' for use in the potentially hazardous area in which the motor is located.

Motors would be air cooled squirrel cage induction type with an Ingress Protection rating of IP56 or better.

Stator windings would have Class F insulation with the operating temperature limited to 120°C (at maximum output and the site's highest ambient temperature).

8.3.4.4 Variable Speed Drive Systems

VSDs would be utilised where the system dictates the need for variable speed motor operation.

The input transformer of a VSD, where part of Supplier standard design, is to be incorporated into the line-up of equipment cubicles. The transformer(s) would be designed and built in accordance with IEC 60076 and IEC 60270.

Each VSD will be located within one of the two CO₂ Pump houses. A dedicated VSD room will be provided in each pump room with ventilation and heating and classed as a non-hazardous area.

VSD selection would reduce the extent of harmonic current that will be provided by the power system to reduce harmonic voltage distortion to an acceptable level. Therefore, twenty four pulse (or higher) VSDs would be considered for all large drives. For smaller (especially LV) drives the use of twelve pulse units should be acceptable.

Each VSD / motor combination would be designed to accommodate all operating characteristics of the motor to allow the motor to operate without overheating.

Where applicable, the VSD and motor 'system' would be jointly certified for use in the potentially hazardous area in which the motor is located (the motor itself would be Ex de certified in all cases). The protection functions within the VSD drive would be utilised to protect the motor. However, a separate thermal protection device (and the ESD system) will directly trip the contactor at the switchgear / MCC.

VSDs would be suitable for control using the built-in control panel or Operator Control Panel (OCP) located nearby and via the ICSS.

8.3.4.5 Standardisation of Equipment and Materials

Equipment of a similar nature and with similar components would be provided by the same manufacturer. This requirement would apply to all LV sub-distribution equipment, cables and accessories.

Standardisation of materials and equipment would always be compatible with a rational design and ensure that spare parts will be available for the design life of the plant.

8.4 Civil design

8.4.1 Site

8.4.1.1 Site Layout and Topography

The area that surrounds the Barmston Pumping Facility comprises relatively flat agricultural land. The Barmston Pumping Facility itself will be bordered on all sides by landscape mounds (5m height) to minimise visual impact of process equipment and above ground piping.

8.4.2 General Design

The application for the Development Consent Order includes an outline design for the Barmston Pumping Station. The level of design detail for this AGI is set out below:

8.4.2.1 Layout

A design has been developed (Document 2.10) which identifies the locations of the two pump buildings, administration building, workshop, switch package building, substation enclosure, VSD units, above ground pipework and internal vehicular and pedestrian access routes. The site is also enclosed on all sides by landscape mounds.

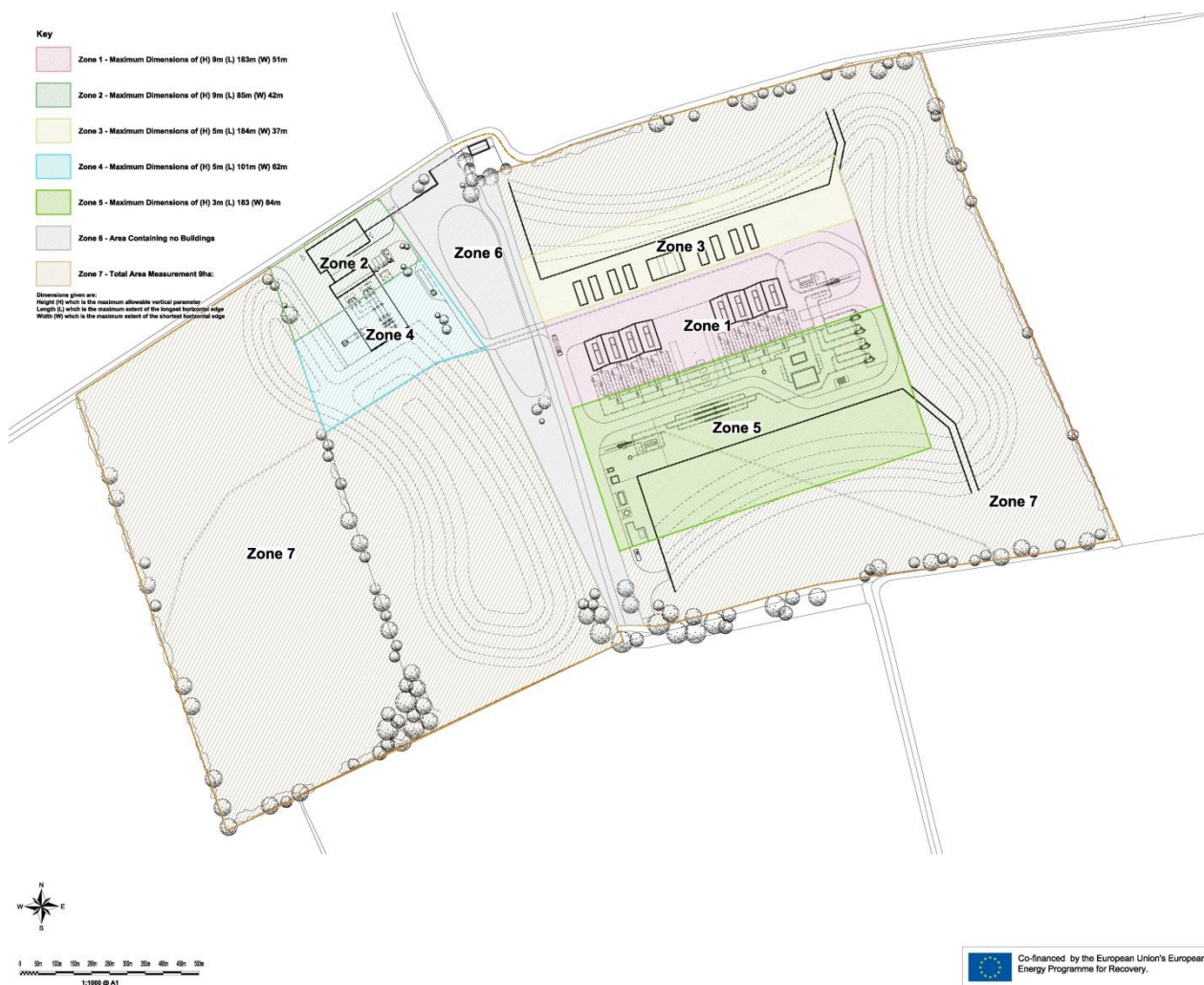
8.4.2.2 Appearance

The mounded landscape will enclose the site into the wider landscape setting but also acts as a strong visual feature. The administration building, workshop and switch buildings have been positioned to act as a modern farmstead, taking inspiration from the surrounding farm building. A materials palette has been developed for the buildings and surface and boundary treatments.

8.4.2.3 Scale

A parameter plan has been developed within which the component parts of the Pumping Station site will be developed. Figure 8.1 details the parameters for each of the component parts.

Figure 8.1: Barmston Pumping Station Parameter Plan



8.4.2.4 Access

Temporary and permanent vehicular access in and out of the Pumping Station has been identified.

8.4.3 Layout and Landscaping

The Barmston Pumping Station has been designed to integrate into the existing landscape setting. An outline onsite landscaping strategy around Barmston Pumping Station has been developed. The landscape treatment will be designed for the benefit of biodiversity through considered choice of grassland and wildflower species.

Figure 8.2: Pumping Facility Layout



The following provides a description of the concept design.

The site is enclosed by a mounded landscape in response to views of the site from the A165 and Fraisthorpe.

The two Pump Buildings are the tallest buildings on site at 9m above ground level and are located in the centre of the site. The buildings are formed in a way which can be constructed in phases as and when they are required.

The package building is located adjacent to the Pump Buildings. The height of this building is 7m above ground level, rectangular in shape and contains compressors, condensers and dryers to process air via the receivers into nitrogen and instrument air for purging and instrumentation purposes.

Eight VSDs will be located within the Pump Buildings.

The administration building is adjacent to the northern boundary of the site. The height of this building is 9m above ground level and contains office and welfare facilities for staff and visitors and a control room for maintenance personnel. The building is connected to the site workshop and switch house and have been positioned to appear as a modern farmstead.

The substation enclosure is located to the south of the administration building. The substation includes transformers and switch gear up to 5m above ground level.

A vent stack, which will be 8m high, is located in the centre of the site.

Internal access routes provide access to the main buildings. The ancillary buildings and above ground pipework is accessed via pedestrian access routes which link to the internal vehicular access routes.

Landscaping is proposed around the installation between the security fence and boundary fence and comprises a mix of native woodland, scrub and grass mixes. An outline planting strategy has been prepared which accompanies the DCO application.

8.4.4 Appearance

A materials palette has been developed to reduce the amount of hard-standing within the site, to minimise the hard appearance of the site.

A range of natural materials including timber, stone cobbles and brick and green roofs will be used to construct / clad structures. The administration building, workshop and switch house are designed to appear as a cluster of buildings in a farmstead type arrangement. The Pump and package buildings will be constructed from timber battens to reflect the local Yorkshire board style cladding used in agricultural buildings. The roofs of the Pump and package buildings are intended to use green roof technology. All ancillary buildings will be clad in either timber or metal.

Alternative paving solutions including grass reinforced paving will be used where possible within the site to reduce the amount and appearance of hard standing. The exception to this will be around the Pipeline infrastructure and around the administration building where more standard paving solutions are proposed to ease pedestrian movement.

The area around and under the above ground pipework will be gravel of a similar tone and colour to the stone used within the gabian walls.

The perimeter fencing will be a 3m high. The perimeter fence will be integrated through a range of boundary treatments including colour, tree and hedgerow planting.

Lighting will be mounted onto the external walls of buildings. The lighting will be zoned to provide light only where required. Lighting will only be required for and limited to occasional maintenance.

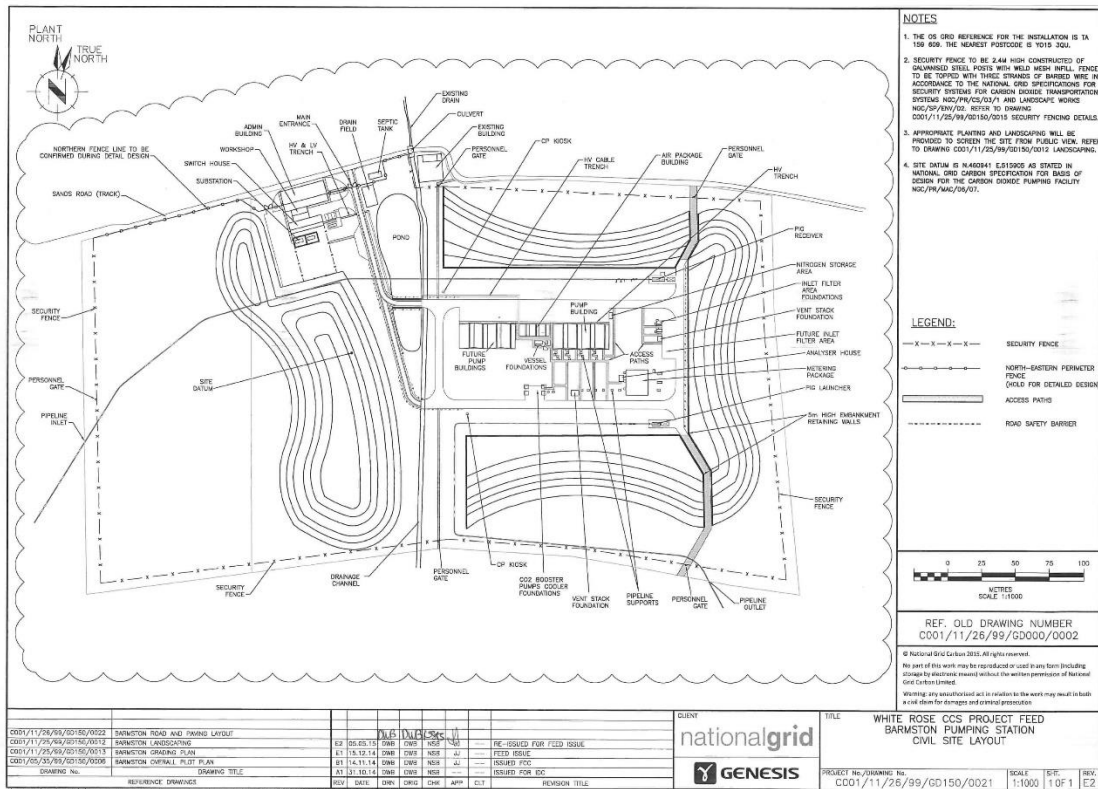
8.4.5 Pump Houses

Each pump skid will be installed in its own dedicated unheated, ventilated pump house. The only equipment within the pump houses will be that associated with that pump. The seal top-up skid will 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 from a pin-hole leak in the high pressure seal system. Equipment would be suitably rated for the area classification. Purged motors would not be acceptable. The buildings would have a structural steel frame and wide access doors for maintenance. The pump houses will 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 will have a separate non-hazardous rated room, accessed by a separate door to outside, to house the VSD for that pump. Entry to the buildings will be controlled due to the danger of CO₂ leaks.

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

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

Figure 8.3: Barmston Plot Plan



8.5 Formal Process Safety Assessment

8.5.1 Formal Workshops

8.5.1.1 Pumping Station HAZID Workshop

A Hazard Identification (HAZID) workshop for the Onshore Transport system was held to review the full Onshore Transport system scope of design, including the Barmston Pumping Facility. The workshop was conducted on a system / sub-system basis to ensure that all the hazards were adequately identified. The workshop procedure was as follows:

- identify hazards – guideword prompt;
- identify failure mode / cause;
- identify direct / Indirect consequences;
- identify safeguards in place;

- assess mitigating effect of safeguards;
- if required then recommend additional safeguards / risk reduction measures;
- where a requirement for additional safeguards is identified, determine if safeguard / action should be implemented;
- assign Actionee; then
- manage actions until close-out or handover at the end of FEED.

13 actions relating to the Barmston Pumping Facility were raised and transferred to the Safety Action Management System (SAMS) Register.

8.5.1.2 Pumping Facility HAZOP Workshop

A Hazard and Operability Study (HAZOP) workshop was held to review the full Onshore Transport system scope of design, including the Barmston Pumping Facility.

The HAZOP study was initially performed on the basis that the transport system was in full operation, with input only from the Drax OPP and no other emitters. Initially, when the reservoir pressure is sufficiently low, the booster pumps would not be in operation. However, for this base case review the booster pumps were assumed to be in operation.

The HAZOP workshop was conducted on a nodal level, with the Barmston Pumping Facility assessed as a single node. The HAZOP procedure was as follows:

- define the design intent;
- confirm operating conditions e.g. pressure, temperature;
- confirm mode of operation e.g. normal, start-up;
- identify credible deviations (using guideword prompts);
- consider the existing safeguards against the impact of a credible deviation and whether the existing safeguards are adequate;
- propose actions (recommendations) as appropriate;
- determine if any additional safeguard / action should be implemented;
- assign Actionee; and
- manage actions until close-out or handover at the end of FEED.

46 actions relating to the Barmston Pumping Facility were raised from the HAZOP workshop and transferred to the SAMS Register.

8.5.1.3 SIL Workshop

A Safety Integrity Level (SIL) workshop for the Barmston Pumping Facility was conducted to review all instrumented control loops identified as having a potential protective function (Safety Instrumented Functions, (SIFs)). The SIFs requiring assessment were identified prior to the SIL workshop, based on a review of Piping and Instrumentation Diagrams (P&IDs), with confirmation during the Barmston Pumping Facility HAZOP workshop. The objective of the SIL workshop was SIL target determination.

The SIL workshop procedure was based on a Risk Graph approach, which uses a number of parameters to describe the nature of the hazardous situation, which could arise when SIFs fail or are not available. These parameters allow a graded assessment of the risks to be made and represent key risk assessment factors.

The basic approach was as follows:

- identify SIF control loops within the project scope and record the tag and P&ID number(s) – identified during HAZOP;
- determine the functionality of the loop and the potential safety hazard(s) against which the loop is protecting;
- identify possible causes for demand on the loop being evaluated;
- evaluate the consequences if the loop fails on demand (at this point ignoring any independent risk reduction measures such as mechanical protective systems);
- determine the SIL target for each function;
- agree the environmental loss parameter (E) and use the environmental risk graph to determine the Environmental Integrity Level required on environmental risk considerations;
- agree the financial loss parameter (F) and use the asset risk graph to determine the Asset Integrity Level required on financial loss risk considerations;
- determine the overall SIL requirement (i.e. the greater of the three integrity level numbers: SIL, E or F);
- where independent risk reduction measures existed, such as pressure safety valves, credit was then taken for those measures and a reduction in the integrity level was applied; then
- record the results and any associated assumptions or actions.

9 actions relating to the Barmston Pumping Facility SIFs were raised and transferred to the SAMS Register.

8.5.1.4 ENVID Workshop

An Environmental Impact Identification (ENVID) workshop for the Onshore Transport system was conducted to assess of the Barmston Pumping Facility including process design, civil design, pumps and associated equipment. The workshop procedure was as follows:

- Pre-populate the assessment worksheets with available information on the activity, its aspect and associated environmental impacts related to the activity;
- During the workshop, complete the worksheets including information on all environmental impacts;
- Risk rank impacts (using a likelihood x severity score) into Low, Medium and High significance / risk score;
- Identify controls and actions;
- Risk rank impacts with consideration of controls and mitigation.

9 actions applicable to the Barmston Pumping Facility were raised and transferred to the SAMS Register.

8.5.1.5 Safety Action Management System Register

All actions, including those required to mitigate identified risks, were transferred to the FEED SAMS Register, which provides a record of all Actions logged from formal workshops, audits and reviews, ensuring that:

- all design safety actions were recorded and notified to lead discipline engineers;
- all actions could be tracked;
- the method of resolving actions was recorded so that there was a clear and auditable trail; and
- all action responses could be reviewed and reference documentation checked, before formal sign off by the Engineering Manager as part of the acceptance and closure procedure;

Any actions not closed at the end of FEED could be taken forward to Detailed Design.

8.5.1.6 3D Model Review

A formal review of the Barmston Pumping Facility layout was conducted on to review of the Barmston Pumping Facility layout included assessment of access and escape; maintenance and operability; foundations; utilities; mechanical handling, review against P&IDs and venting.

The following safety actions relating to the Barmston Pumping Facility were identified:

- access platforms (where required) should incorporate fixed stairs rather than ladders;
- a wind sock should be provided;
- review building safety in relation to fire risk due to building materials and equipment within the Pump Buildings; and
- review arrangement of bunds and requirement for ventilation analysis.

The FEED layout design is now frozen, with the overall layout as shown in Figure 8.2.

Escape route layouts drawings have been developed, including internal and external escape route diagrams. A ventilation analysis of the Barmston Pumping Facility has been conducted

8.5.1.7 Additional HAZOP Workshop (Onshore Transport)

A second HAZOP workshop for the Onshore Transport system was conducted to review operation of the system in year 10, with import of carbon dioxide from other, as yet unspecified, emitters in addition to the Drax OPP, and operation at the design capacity of the system. The scope of the Additional HAZOP workshop included the additional fine filters and booster pumps at the Barmston Pumping Facility.

3 new actions relating to the Barmston Pumping Facility were raised and transferred to the SAMS Register.

9 Glossary

Abbreviations	Meaning
40D	40 x Diameter
1000D	1000 x Diameter
AGI	Above Ground Installations
ACSE	American Society of Civil Engineers
ALA	American Lifelines Alliance
ASTM	American Society for Testing and Materials
bara	bar absolute
barg	bar gauge
C	Celsius (unit of temperature)
CCP	Carbon Capture Plant
CCS	Carbon Capture and Storage
CO ₂	Carbon Dioxide
CP	Cathodic Protection
CPL	Capture Power Limited
CT	Current transformer
DCO	Development Consent Order
DECC	UK Government's Department of Energy and Climate Change
DSV	Diving Support Vessel
EBD	NGCL's European Business Development group.
EEPR	European Energy Programme for Recovery
EIA	Environmental Impact Assessment
ENVID	Environmental Impact Identification
EOR	Enhanced Oil Recovery
EPRS	Emergency Pipeline Repair Systems
ESD	Emergency Shut Down
ESDV	Emergency Shut Down Valve
EPRS	Emergency Pipeline Repair Systems
Ex e	Increased safety (BS EN 60079 -17; IEC 60079-7)
Ex d	Flameproof (see BS EN 60079 -17; IEC 60079-1)
Ex de	Flameproof; increased safety (see BS EN 60079 -17; IEC 60079-1/7)
Ex nA	Increased safety (see BS EN 60079 -17; IEC 60079-2)
Ex i	Intrinsic safety (see BS EN 60079 -17; IEC 60079-11)
FEED	Front End Engineering Design
FBE	Fusion Bonded Epoxy
HAZID	Hazard Identification
HAZOP	Hazard and Operability study
HDD	Horizontal Directional Drill
HIPPS	High Integrity Pressure Protection System
HSE	Health and Safety Executive

HVDC	High Voltage Direct Current
HYSYS	Oil and gas process simulation software that enables optimization of conceptual design and operations
IED	intelligent electronic device
IGEM	Institute of Gas Engineers and Managers
IID	Intelligent pipeline Inspection Device
IMR	Inspection, Maintenance and Repair
IRP	Interface relay panel
kg/m ³	Kilograms per cubic metre
KKD	Key Knowledge Deliverable
km	Kilometre
KPs	Kilometre Points
KSC	Key Sub-Contract
LAT	Lowest Astronomical Tide
LCU	Local control unit
LV	Low Voltage (1000V or lower)
mm	Millimetres
m	Metres
MAOP	Maximum Allowable Operating Pressure
MCCB	Moulded Case Circuit Breaker
MIP	Maximum Incidental Pressure
MTPA	Million Tons Per Annum
MV	Medium voltage (between 1000V and 36000V)
NGCL	National Grid Carbon Limited
OPP	Oxy Power Plant
O ₂	Oxygen
PD	Pressure Directive
PIG	Pipeline Inspection Gauge
PTFE	Polytetrafluoroethylene
QRA	Quantitative Risk Assessment
SAMS	Safety Action Management System
SAWL	Longitudinal Submerged Arc Welding
SIF	Safety Instrumented Function
SIL	Safety Integrity Level, the relative level of risk-reduction provided by a safety function
SMYS	Specified Minimum Yield Strength
UCP	Unit Control Panel
V	Volt (unit of electrical charge)
VAP	Virtual Anchor Points
VIV	Vortex Induced Vibration
WR	White Rose

10 Nomenclature and Jargon

Term	Meaning or Explanation
Anchor block	Reinforced concrete block cast around a straight piece of pipe, designed to restrain the pipe against longitudinal movement
Auger bore	A well proven technique that can be utilised for short and medium length crossings of up to 100m. Depending on the ground conditions and length of crossing the Auger bore crossing technique is used for non-major highway crossings, ditch crossings, minor river and canal crossings. Ground conditions dictate where this technique can be best utilised
Bathymetry	The study of underwater depth of lake or ocean floors. Bathymetric maps may also use a Digital Terrain Model and artificial illumination techniques to illustrate the depths being portrayed
Cofferdam	A temporary enclosure built within, or across, a body of water and constructed to allow the enclosed area to be pumped out, creating a dry work environment for the major work to proceed
CP	Cathodic protection is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell
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
Design factor	Factor applied to hoop stress when calculating the wall thickness or pressure
Elastic bending	A means of bending pipes using the natural elastic property of pipe to achieve the change in direction of the pipeline route
Environmental loading	Disturbance in ecological systems caused by humans, resulting in deviations from normal behaviour
FEED contract	Contract made between DECC and CPL pursuant to which WR Project FEED (as defined) will be performed
Field cold bending	A means of bending pipes, along the pipeline route, by special pipe bending machines to a relatively gentle radius of 40D
Free spanning	A length of the pipeline where the seabed sediments have been eroded, this mainly occurs as a consequence of an uneven seabed and local scouring due to flow turbulence and instability
Geohazard	A geological state that may lead to widespread damage or risk
HAZID	A systematic assessment to identify hazards and problem areas associated with plant, system, operation, design and maintenance
HAZOP	A structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment, or prevent efficient operation
Hoop stress	The stress in a pipe wall, acting circumferentially in a plane perpendicular to the longitudinal axis of the pipe and produced by the pressure of the fluid in the pipe
Horizontal directional drill	A tunnelling technique that involves drilling a pilot hole along a shallow arc from a launch pit to a receptor pit, both of which are typically at or close to ground level. The hole is then enlarged by a back reamer and swabbed in both directions to ensure no protruding objects are present that the pipe could snag on. Finally the pipe is pulled through. For large diameter pipelines the technique is only capable of drilling shallow arcs and is therefore best suited to long distances. A large area of land either side of the proposed crossing is required when using the HDD crossing technique for the storage of pipe and equipment
Hydrotest	Process by which the pipeline is pressure tested to a predefined pressure above the operating design pressure of the pipeline
Induction bending	A controlled means of bending pipes through the application of local heating using high frequency induced electrical power
Longshore current	An ocean current that moves parallel to shore caused by large swells sweeping into the shoreline at an angle and pushing water down the length of the beach in one direction

Term	Meaning or Explanation
Maximum allowable operating pressure	Maximum pressure at which a pipeline system is allowed to operate. Must not be exceeded in steady state conditions
Maximum incidental pressure	The maximum pressure which a gas system can experience during a short time, limited by safety devices
Microtunnelling	A tunnelling technique that involves jacking the pipe forward while spoil is removed via a cased auger. A thrust wall is constructed to provide a reaction from which to jack. As the tunnel progresses, new segments of pipe are attached at the launch pit and the process repeats until the microtunnel reaches the receptor pit, where the drill bit is detached from the tunnel and removed. The jacked pipe can be the final pipe itself or a sleeve through which a smaller pipe is then threaded. Shafts are often required in place of pits when the pipe is situated at depth
PIG Operations	An essential maintenance activity that optimises the smooth operation of the pipeline using a Pipeline Inspection Gauge (PIG) to traverse the pipeline to inspect and/or 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
PIG trap	A facility to allow PIGs to be inserted into and removed from the pipeline
Primary design code	PD 8010 Parts 1 and 2
Specified minimum yield strength	An indication of the minimum stress a pipe may experience that will cause plastic (permanent) deformation
Tie-in	A connection between an existing and new pipeline. During pipeline construction 'tie-in' points are left at regular intervals and at crossings
Von Mises Criterion	According to this criterion, named after German-American applied mathematician Richard von Mises (1883-1953), a given structural material is safe as long as the maximum value of the distortion energy per unit volume in that material remains smaller than the distortion energy per unit volume required to cause yield in a tensile-test specified of the same material
Vortex-induced vibrations	Motions induced on bodies interacting with an external fluid flow, produced by – or the motion producing – periodical irregularities on this flow
WR Assets	All those assets that would be developed pursuant to the WR Project
WR Development Project	A project to develop, operate and decommission the WR Assets which may transpire following the completion of the WR FEED 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
Variable speed drive (VSD)	Variable speed drive